Validation of the Haptic Cow:

A Simulator for Training Veterinary Students

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Submitted for degree of Doctor of Philosophy

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June 2007

Abstract

A virtual reality simulator, the Haptic Cow, has been developed using touch feedback technology for training veterinary students to perform bovine rectal palpation of the reproductive tract. The simulator was designed to supplement existing training and address some of the difficulties associated with teaching palpation-based skills. Students need to achieve a certain level of proficiency by graduation but this has become increasingly difficult because of problems with current training methods and a reduction in the number of opportunities to practice. A simulator-based teaching tool was developed as a potential solution. The first step involved designing a simulator on the basis of requirements established through consultation with both veterinary surgeons, as teachers, and students, as learners. Research was then undertaken to validate the simulator by following a set of established criteria described for the evaluation of new technologies used in medical education. The virtual models were assessed by experts as realistic enough representations of the same structures in the cow. An experiment to assess the effect of simulator training compared the performance of one group of students, whose training was supplemented with a simulator session, with another group of traditionally trained students. The subsequent performance for finding and identifying the uterus when examining cows for the first time, was significantly better for the simulator trained group, indicating that skills learned in the simulator environment transferred to the real task. A project was also undertaken to integrate the simulator into a curriculum, with training included as part of the farm animal course at the University of Glasgow Veterinary School. The training was well received by students, useful feedback was gathered and the simulator continues to be used as part of the course.

Further developments were undertaken with the aim of creating a more versatile teaching tool and addressing some of the questions and issues raised. An automated version of the Haptic Cow was designed for students to use on their own, with computer guidance replacing the instructor's role. An evaluation found that the new version of the teaching tool was both usable and an effective way of equipping students with the skills required to find and identify the uterus. The potential to use haptic technology to investigate various aspects of performance was also explored in relation to the question of hand choice for certain palpation-based skills: differentiating between objects on the basis of softness and size. Ongoing research and development options are discussed, with the aim of building on the current work by expanding the role of haptic technology in veterinary education in the future.

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Acknowledgements

Many people have been involved in the Haptic Cow project over the years and I am very grateful for the help and encouragement I have received. I regret that I cannot thank everyone individually but I would like to acknowledge several groups in particular. First and foremost, I would like to thank the students at the University of Glasgow Veterinary School. I am grateful for the time they have given up to take part in the experiments and for their enthusiasm about the project. I have also received encouragement, help and feedback from colleagues in the veterinary profession, particularly at Clyde Veterinary Group, Lanark, and the University of Glasgow Veterinary School, and I would like to extend my thanks to them. I would also like to thank researchers and staff in the Department of Computing Science at the University of Glasgow. The working environment has an atmosphere that has enabled me to ask for and receive help, as well as having the opportunity to discuss ideas in a stimulating and informative setting.

There are certain individuals I would particularly like to thank:

Steve Brewster, my supervisor in computing science, for having a style of supervision that has proved both easy to work with and productive, and has allowing me to undertake a PhD in such an efficient and enjoyable way.

Dominic Mellor, my supervisor at the vet school, for patiently explaining various aspects of research including experimental designs, statistical analysis and some of the idiosyncrasies of the English language! The learning curve has been steep and is ongoing…

Also thanks to both my supervisors for some great discussions and chats over the years.

I would also like to thank Vicki Dale, Willy Lawson, Peter Chambers, Christos Giachritsis and Hong Tan for their various contributions to the project. And John Baillie for help and support along the way, and for tolerating the demands this project has placed upon my time.

And finally I owe a huge debt of thanks to Andy Crossan for his excellent teaching, encouragement, support and patience throughout this project.

The PhD has been supported by a scholarship from the Institute of Comparative Medicine, University of Glasgow. The work investigating the feasibility of integrating the simulator into the curriculum was supported by a mini-project grant from the Learning and Teaching Support Network for Medicine, Dentistry and Veterinary Medicine (LTSN-01 2003).

Declaration of Originality

The material presented in this thesis is the result of my own work carried out in the Department of Computing Science and Faculty of Veterinary Medicine, University of Glasgow, UK, under the supervision of Professor Stephen Brewster and Dr Dominic Mellor. All other referenced material has been given full acknowledgement in the text. Work from Chapters 4 and 5 has been published (Baillie, Crossan *et al.* 2005; Baillie, Mellor *et al.* 2005).

Chapter 1: Introduction

1.1 Background and Motivation

1.1.1 Overview of Veterinary Education in the United Kingdom

There are six veterinary schools in the United Kingdom and nearly six hundred graduates enter the profession annually (RCVS 2005; Hill 2006) with numbers predicted to increase in the near future and a seventh school opening in the autumn of 2006. The traditional undergraduate course spans five years, with basic sciences taught in the preclinical years followed by progressive development of clinical skills in the third, fourth and final years. The majority of the course material is delivered through a combination of lectures, laboratory practicals and small group teaching. The clinical training involves practical experience with patients, which is gained both at university and during placement training, extramural studies (EMS), in practices with veterinary surgeons.

The veterinary schools are required to provide training for work with all the major domestic species, broadly categorised as small animal, equine and farm animal. The standard is monitored by the Royal College of Veterinary Surgeons (RCVS) and Quality Assurance Agency for Higher Education (QAA) and students must be able to demonstrate the required level of clinical competence and scientific knowledge by graduation. There are guidelines that outline the procedures a new graduate should be able to undertake, the 'Day One Skills' (RCVS 2001; QAA 2002). These include practical competence performing a thorough clinical examination of all major body systems in each species.

The future of veterinary education and the profession has been the subject of a RCVS review 'Veterinary Education: 2010 and beyond' (RCVS 2001). There is increasing difficulty providing all students with the opportunities to develop the required clinical skills within the five year course. Veterinary schools have an increasing role providing referral services to the profession and consequently the proportion of first opinion cases that students encounter at university is tending to reduce. This means that ensuring students acquire the basic clinical and surgical skills and a working knowledge of common cases is becoming more difficult. A recent survey of new graduates indicated that in many cases they worked under minimal supervision and with limited access to assistance (Mellanby and Herrtage 2004). A high proportion reported making mistakes and in many cases this had a negative emotional impact on the individual. As one potential solution to the challenges facing veterinary education, a move towards an equivalent to the pre-registration year in medicine has been considered. This would involve continued training, supervision and evaluation in the immediate postgraduate period. The scheme has been piloted over the last three years and from 2007, a one year professional development phase (PDP) will be compulsory for all new graduates. Another way of addressing some of the limitations in veterinary training would be to allow students to specialise prior to graduation, which would mean that those most interested in a particular area would have priority access to the available resources. However, the RCVS review indicated that the profession considered the veterinary schools should continue to provide a broad science-based education and cover all species, with specialisation being a matter for the post-graduate period. A recent survey of final year students indicated that nearly 70% expected that their first job would be in mixed practice (Ward 2003), which requires skills for all the main species. Therefore, in line with students' post-graduate aspirations and the expectations of the profession, it is likely that veterinary undergraduate courses will continue to need to provide all students with multi-species training.

1.1.2 Bovine Rectal Palpation: Traditional Training and Current Problems

Students need to learn a wide range of clinical skills in preparation for their work as veterinary surgeons. One of the key procedures performed by farm animal practitioners is bovine rectal palpation, which is used as part of a clinical examination and to diagnose pregnancy and fertility related problems. The procedure is a routine part of farm animal work and one that new graduates would be expected to perform with a basic level of competence. At the University of Glasgow Veterinary School students are taught the anatomy and physiology of the reproductive tract in preclinical years in lectures and have the opportunity to examine *in vitro* specimens in the laboratory. In third and fourth year, this is followed by the pharmacology of fertility drugs, pathology of reproductive disease and reproductive management techniques appropriate to modern farming systems. The integration of these disciplines and their application in farm animal practice depends on skilled performance of rectal palpation, manual examination of the reproductive tract, uterus and ovaries in the pelvic and caudal abdominal areas of the cow. These skills are developed while examining cows and considerable practice is required to identify structures accurately. However, in the undergraduate curriculum there are difficulties associated with teaching farm animal clinical skills, including bovine rectal palpation because access to cows is limited (Penny 2002). This is due, in part, to the increasing number of students per year together with animal welfare guidelines that restrict the number and frequency of examinations allowed per cow (Parkins and Harvey 2001). Therefore, students perform the majority of examinations while undertaking EMS with veterinary surgeons on farms and may perform their first examination of a cow with only minimal preparatory training in this invasive procedure. The current economic climate facing British agriculture places both farmers and veterinary surgeons under considerable time and financial pressure, which may further limit the students' access to clinical cases.

Providing students with sufficient training for work in farm animal practice immediately after graduation is difficult. Inadequate skill levels may result in failure to make the correct diagnosis when performing bovine rectal palpation, which could have serious consequences. For example, if certain drugs are administered inappropriately after pregnancy examinations, abortion may be induced. Associated negligence claims are lodged more frequently against recent graduates than more experienced practitioners (VDS 2004). Clinical training in both human and veterinary medicine traditionally follows an apprenticeship model with novices learning under the guidance of experts, observing, assisting and then performing the task with increasing level of participation and responsibility (Meier *et al.* 2001). In the case of bovine rectal palpation, the teacher, the veterinary surgeon, is unable to observe the student's technique inside the cow and cannot confirm the identification of structures palpated or easily direct the exploration. Therefore, providing guidance or giving accurate feedback on performance is difficult. Additionally, the student cannot learn by watching and copying the veterinary surgeon's actions, which means that the procedure is, at least in part, self-taught. These problems would also apply to other internal examinations in cattle and other species. There are also animal welfare issues to consider as there are concerns about using real animals for training purposes as inexperienced operators may cause damage. The current trend is to reduce, refine and replace the use of animals as educational resources (Martinsen and Jukes 2005). Overall, there is a need to investigate new teaching techniques for certain procedures, including bovine rectal palpation, if the universities are to continue to provide a multi-species education for the increasing numbers of students.

1.1.3 Simulators: A Potential Solution

A palpation skills simulator represents one possible way of supplementing existing training methods for bovine rectal palpation. The training would be provided within the university curriculum and could be standardised for all students. Currently there is considerable variation between EMS placements and this area of veterinary education is not subject to quality assurance. An additional advantage would be that students could be equipped with skills prior to the first live animal examination, with benefits for animal welfare. The training environment would need to be realistic, enable the teacher to have a more effective input into the learning process, and equip the student with relevant transferable skills.

Simulators have been used in medical training for many years. The modern mannequins are highly sophisticated and can provide a wide variety of clinical cases, feedback on performance and react to the trainee's actions. There is an increasing range of physical models of animals, or the relevant parts, available in veterinary clinical skills laboratories, particularly for teaching minor procedures, psychomotor skills and basic surgical techniques (Hart *et al.* 2005). For teaching rectal palpation, in both cows and horses, several options are available. *In vitro* tracts are used routinely to illustrate the anatomy and for students to practice palpation. Whole bovine cadavers have been used to teach rectal palpation and abdominal surgery (Van Camp *et al.* 1988), although the specimens only lasted for a short period before deteriorating. A fibreglass horse with preserved intestines has been developed at the University of Veterinary Medicine, Vienna specifically for teaching rectal examination of colic cases (Von Künzel and Dier 1993) and is in use at a number of veterinary schools around the world.

A relatively new and rapidly expanding area of simulator development involves using computer-generated virtual reality. This can provide sophisticated 3D training environments with representations of the patient or organ, and the surgical or other instruments. In medicine these have proved particularly applicable for minimally invasive surgery (MIS) and procedures (Liu *et al.* 2003). A core skills simulator, MIST-VR (Mentice 2004), provides training for the component skills used to perform minimally invasive or 'keyhole' surgery. Other simulators have been developed specifically for laparoscopic and endoscopic procedures (AccuTouch, Immersion Corporation), and for minor procedures including epidural injections (Dang *et al.* 2001), suturing (Webster *et al.* 2001), and intravenous catheter placement (CathSim, Immersion Corporation).

Some of the virtual reality simulators provide only a graphical representation of the patient but an increasing number now incorporate some form of haptic (touch) feedback as well. The word 'haptic' is derived from the Greek *haptein* and means relating to the sense of touch. In computing terms, this means interacting with a computer through the sense of touch rather than the more traditional visual or audio cues, and a range of devices have emerged over the last decade or so that support touch related interaction. Haptic technology has been used in computer aided design where, for example, a user can feel while sculpting virtual clay. Haptic feedback also provides support for visually impaired users and has been included in interfaces developed to enhance a range of activities including browsing graphical data (Wall and Brewster 2003). Many of the medical virtual reality simulations now also include haptic feedback where the interactions of an instrument or the physician's hand with an organ can be felt and the tissue reaction visualised. Providing high quality haptic interaction is particularly important for palpation-based procedures where the clinician is in direct contact with the patient rather than indirectly through an instrument. A few virtual reality simulators have been developed for medical procedures that rely on palpation, including training tools for the detection of subsurface tumours (Langrana *et al.* 1997), for the diagnosis of prostate cancer (Burdea *et al.* 1999), and a simulation for the palpatory techniques used in osteopathic medicine and physical therapy: The Virtual Haptic Back project (Williams *et al.* 2004). The first virtual reality veterinary simulator, the Horse Ovary Palpation Simulator (HOPS) was designed by Crossan (Crossan *et al.* 2000; Crossan 2004) using a PHANToM haptic device (Massie and Salisbury 1994; SensAble 2005). This was followed by the development of a prototype bovine rectal palpation simulator using the same technology during a Master's in Information Technology at the University of Glasgow by Baillie (Baillie 2003).

1.1.4 A Virtual Reality Simulator for Teaching Bovine Rectal Palpation

The work undertaken to develop a bovine simulator by Baillie (Baillie 2003) demonstrated that the PHANToM haptic device could be used to create a range of virtual anatomical models, some of which were rated by experts as realistic representations (Baillie *et al.* 2003). One of the key advantages over traditional training was that the teacher could follow the student's movements inside the virtual cow on the computer monitor, compared with the situation of standing beside a cow, and therefore, could potentially provide more effective guidance. Students who took part in an evaluation of the simulator-based teaching tool considered that training was useful and that their performance examining cows had improved. However, these results depended on student assessment of their own performance, which may not be accurate. Additionally, some of the improvement could have been attributed to reasons other than the haptic training. For example, performance would improve over time as the student examines more cows and would also depend on the on-farm experience, which is very variable.

Baillie (Baillie 2003) demonstrated that a bovine rectal palpation simulator developed using haptic technology has potential to address some of the issues facing training using traditional methods. A decision was made to build on this promising start by continuing the project as a PhD. There is no doubt that there is a need to find ways of supplementing existing training if students are to make the most of the limited learning opportunities and to reach the required level of competence by graduation. The initial aim of the research work was to take a structured approach to the design and development of the simulator-based teaching tool and to address some of the issues that had been raised by Baillie (Baillie 2003). For example, the student feedback had indicated that the simulator would be most beneficial if used to train students before examining cows. Therefore, the specific learning needs of complete novices needed to be identified. A range of methods are available for conducting requirements analyses to gather information from the relevant stakeholders, in this case with veterinary surgeons, as experts and teachers, and students, as learners. The information would provide the basis for the design of the simulator, which was to be developed using an acknowledged framework for teaching packages (Laurillard 1993). The computing challenges that needed to be addressed included developing the required range of virtual anatomical models. These needed to feel sufficiently lifelike when palpated. Additionally, the learner would need to be able to perform all the stages of the procedure in the simulated environment and the teacher would need to be provided with an interface that could be used to direct the training.

The next major issue, and the main research work of the thesis, was to address the need to conduct a thorough validation, without which the benefits of training could not be guaranteed. If the simulator does not provide the skills, at best, the operator remains untrained and at worst, the skills may be inappropriate and the animal or patient may be put at risk. A set of criteria have been identified by Neufeld and Norman as a systematic way of assessing, or validating, simulators used in medicine (Neufeld and Norman 1985). First, the design of the teaching tool needs to be evaluated and in the case of the bovine simulator, the anatomical structures in the virtual environment would need to be realistic enough and the training protocol structured in a way that would deliver the required skills. There is also a need to demonstrate that skills acquired during simulator training transfer to the real task. There have been studies that describe undertaking one or more of the stages of validation for both surgical and other clinical procedure virtual reality simulators used in medicine, but only a limited number have demonstrated that training has resulted in improved performance during the real task (Seymour *et al.* 2002; Schijven *et al.* 2005). For palpation-based procedures, learning effects have been demonstrated on certain simulators and for specific aspects of the tasks (Langrana *et al.* 1997; Crossan *et al.* 2002; Williams *et al.* 2004). However, performance was measured either in the virtual environment or using *in vitro* specimens, which are only approximations for the real task. The evaluation of the bovine simulator developed by Baillie (Baillie 2003), although undertaken during the real task, relied on students' assessment of their own performance during EMS and therefore, lacked independent verification and standardisation. In the PhD, if the design meets the requirements for realism and training needs, the next stage will involve assessing the simulator's worth as a teaching tool by conducting a controlled trial and measuring trainees' subsequent performance during the real task in an objective way. Another aspect of validation relates to practical considerations, including demonstrating that the new teaching technology can provide effective training in a real world situation. Therefore, a trial will be undertaken to investigate the feasibility of including the simulator as part of a veterinary curriculum. Another practical consideration relates to the cost and effort of one-to-one teaching. An alternative approach is proposed with the development of an automated version to address the teacher-related issues. Such a version will present particular design challenges as the teacher's role will need to be replaced by computer guidance. Work will also need to be undertaken to assess the validity of this version of the simulator for skill development.

The simulator has the potential to provide an accessible and effective teaching tool as a supplement to existing training. Additionally, computer simulators provide tools with which to measure and assess human performance. If the bovine simulator were used in this way, information could be gathered about how the procedures are performed, which would have benefits for teaching and learning. For students, the opportunities to gain hands-on experience are increasingly limited and therefore, finding ways of providing skills efficiently in alternative environments is necessary. If given more effective training and preparation for examining cows, students would be able to make better use of this valuable, but increasingly limited, learning resource. There would also be benefits for the university, as the simulator would help to standardise training and ensure all students have the opportunity to develop at least a basic set of skills in a controlled environment. However, all of these perceived benefits depend on the simulator being proven as an effective training tool and therefore, the need to conduct research to validate the simulator, using a structured approach and following an accepted set of criteria, cannot be underestimated.

1.2 Thesis Statement

A virtual reality simulator, the Haptic Cow, developed to provide training for bovine rectal palpation can be validated as a teaching tool. The simulator can be used to equip students with useful skills that are transferable to the real task. The simulated environment can also have a role in investigating veterinary palpation-based skills.

The following research questions will be addressed to defend this statement:

a) In validating a haptic simulator designed to teach bovine rectal palpation the following questions need to be addressed:

   - Are the representations of the bovine reproductive tract realistic enough?

   - Will students trained with the simulator be equipped with skills that transfer to the real task resulting in improved performance?

- Is it feasible to integrate the simulator into a curriculum?

b) Does the simulator provide a means of investigating various aspects of palpation-based skills?

The chapters presented in this thesis, and summarised in the next section, will be structured to address these questions.

1.3 Thesis Overview

Chapter 2 is a review of the literature and begins by introducing the term 'haptic' in relation to human perception and exploration. The field of computer haptics is described and the devices that support touch-related interaction are compared. A review of simulators in medical and veterinary training has been conducted with particular reference to those used for palpation-based procedures. The methods for creating realistic tissue models and the challenges facing designers of virtual reality training environments are discussed. Other roles for haptic technology are described including enhancing other areas of human computer interaction and measuring various aspects of performance. The final section covers the important issue of validation, without which the benefits of new teaching methods and technologies cannot be guaranteed. A systematic approach for validating simulators is described and other work, which has been conducted to validate simulators used in medical training, is reviewed.

Chapter 3 describes the design and development of the simulator. First, a requirements analysis was conducted with veterinary surgeons and students to determine the current problems and the simulator's role as a teaching tool for learning bovine rectal palpation. The approach to the design of the simulator is described, which involved using an established method for developing computer aided learning tools. The series of required virtual anatomical models and the design of the teaching protocol, together with the resulting simulator-based teaching tool, the Haptic Cow, are described. The final part of this chapter presents an evaluation undertaken with veterinary surgeons to assess the simulator with regard to the degree of realism of the virtual models and the structure of the teaching protocol.

In Chapter 4, an experiment to determine whether training with the simulator equips students with useful skills is described. The performance of two groups of students was compared, one group received simulator training with a teacher and the other group, the control, had traditional training only. The students were then set the task of finding the uterus when examining cows for the first time. The effects of training on skill development are discussed. Some of the benefits of using a simulator and the limitations of the work are also considered.

Chapter 5 describes a project undertaken to integrate the simulator into a curriculum. The project involved providing students with two simulator-based training sessions and gathering feedback using questionnaires, a focus group and during farm visits. The chapter finishes with a discussion of the practical considerations and issues relating to providing training with the Haptic Cow as part of a curriculum.

Chapter 6 describes the development and evaluation of an automated version of the simulator. This work addresses one of the limitations of the simulator: the requirement for one-to-one teaching. The ways of replacing the role of a human instructor with computer guidance are discussed and the design of the automated version is described. An experiment is then presented to validate the automated version in a similar way to the teacher-led version by comparing the performance of simulator-trained students with a control group. The results of this experiment are discussed as well as making a comparison with the teacher-led training. The chapter concludes with a discussion about the work undertaken to validate the Haptic Cow and conclusions are drawn.

In Chapter 7, a different role for the simulator is explored, which involved measuring certain aspects of human performance for palpation-based tasks. The motivation for the work is presented. This related to a question often asked by students: 'Which hand should I use (*to perform rectal palpation of a cow or horse*)?' The question is first addressed by gathering information through a survey of veterinary surgeons about hand use and reasons for the choice. The relative perceptual abilities of each hand are compared after reference to evidence from the literature. An experiment is then described where the abilities of the left and right hands were compared when participants performed some of the component tasks of bovine pregnancy diagnosis in the simulated environment. The results are discussed in relation to the students' question about the choice of hand. Other findings to emerge from the investigation about learning palpation-based tasks are presented and discussed.

Chapter 8 brings the thesis to a conclusion. The work undertaken to design and validate the simulator, the Haptic Cow, is summarised. The contributions of the thesis to veterinary training and simulator research are presented. The limitations of the simulator-based teaching tool and the research work are discussed. Options for future work are presented and finally, conclusions are drawn.

Chapter 2: Literature Review

2.1 Haptic Perception

The word haptic is derived from the Greek 'haptein' and is defined (Oxford English Dictionary, 2004):

"*haptic, a. (and n.): Of, pertaining to, or relating to the sense of touch or tactile sensations.*"

Touch is a very important and complex sense, which is highly developed in neonates and, although in constant use, thereafter is often eclipsed by more obvious senses including sight and hearing. We rely on our sense of touch to process information gathered during interaction with objects in our environment from a range of different types of sensory receptor in the skin and the musculoskeletal system. Each receptor type has a distinct function and the processing of the combined input provides an interpretation of the wide range of haptic information humans receive while interacting with their environment. There are thirteen sensory afferents collecting information and responding to stimuli, which are divided into four groups (Johnson 2002). Three types are located in the skin, the cutaneous system: pain or nociceptive; thermoreceptive, which are sensitive to local and ambient temperature; and mechanoreceptive, which respond to tactile information associated with deformation of the skin by pressure or vibration. These receptors are positioned in one of the layers of the skin, the epidermis, dermis or subcutaneous tissue. The fourth type of receptor, proprioceptive sensors, provides information relating to kinaesthetic perception, which involves feedback detected during movement. These receptors are associated with the musculoskeletal system and are located in muscles, tendons and joints, relaying information about position in the environment and interactive loads or forces. The distinction between the cutaneous and kinaesthetic systems of perception becomes important when defining the types of haptic device and the interactions supported.

The central or cognitive processing of haptic information results in perception of the body's position and interaction with the environment and where appropriate, leads to a motor response such as moving away from a painful stimulus. With regard to interaction with an object, the sensory inputs are combined to provide information about a range of properties including shape, weight, temperature, texture, position and softness (Johnson 2002). The sensory receptors are distributed throughout the body with particularly high concentrations of skin receptors in the fingertips. Therefore, the hands are a major instrument for the sense of touch with common interactions involving most, if not all, receptor types. However, in reality, object recognition often involves other senses, particularly vision, to guide and augment touch.

2.2 Haptic Exploration

Touch is a fully duplex channel, enabling the sending and receiving of information at the same time. Therefore, active exploration through the sense of touch combines with the processing of passively acquired sensations from objects in contact with the body. Recognition of an object through haptic exploration involves a combination of hand movements capturing information about that object. These movements have been classified into eight units called exploratory procedures (Figure 2.1) by Lederman and Klatzky (1987). Each exploratory procedure provides information about specific properties of an object:

- 'Lateral Motion' involves sideways movement with continuous contact between the object and the skin to appreciate texture, rough or smooth and the degrees in between.
- 'Pressure' involves applying a force to part of an object that is fixed or stabilised by an opposing force from a digit or the other hand. The surface is depressed with a poking action to perceive the firmness or compliance, the degree of object hardness or softness.
- 'Static Contact' when the hand rests on a fixed object supported externally on the other hand or another object. The temperature of the surface is perceived in this way.
- 'Unsupported Holding' the object is lifted and rests on the hand which provides appreciation of weight.
- 'Enclosure' the hand is moulded around the object, enveloping the surface, which provides assessment of global shape and volume.
- 'Contour Following' the hand moves over an object while maintaining contact combining a series of smooth non-repetitive actions to assess exact shape and volume.
- 'Part Motion Test' this involves the act of making a part move in relation to another part of the same object and therefore, enables identification of moving parts.
- 'Function Test' executes a movement that performs an action relating to the object's specific function such as closing a pair of forceps while grasping tissue.

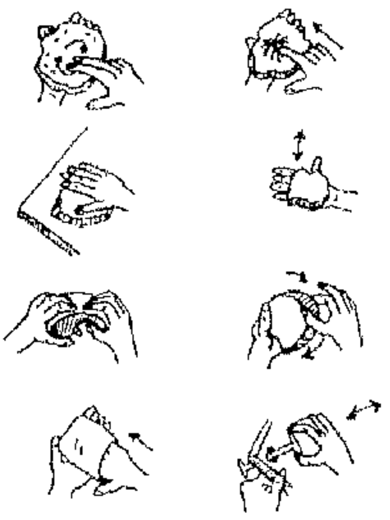

Figure 2.1. The exploratory procedures described by Lederman and Klatzky (1987) for determining object properties using touch.

Properties of an object are categorised as substance-related properties (texture, hardness, temperature and weight), structure-related properties (weight, volume, global shape and exact shape) and functional properties (part motion and specific function). This information about an object is established using the movement patterns that are associated with each of the eight exploratory procedures, used either individually or in combination.

Palpation is defined as *"examination by feeling"* (Oxford English Dictionary, 2004) and in medical examinations the clinician will use a combination of exploratory procedures to gain information about anatomical structures including the feel of normal and pathological tissue. When a veterinary surgeon palpates the bovine reproductive tract the properties assessed for each structure include firmness, volume, global shape and exact shape. Texture is less important because all the surfaces are covered with moist membranes. The firmness of an object is assessed using the exploratory procedure of 'pressure'; a force is applied to the object surface, which depresses to a certain degree. Therefore, the bony pelvis is perceived as hard because the surface does not deform when pressed whereas the pregnant uterus, with a fluid-filled lumen, feels soft as the surface yields under pressure. The assessment of volume and shape are important for identification of parts of the reproductive tract as well as other pelvic and abdominal structures and for the diagnosis of pregnancy. The hand and digits perform 'object enclosure' and 'contour following' to build up a picture of the object's shape and size. The volume provides additional information about the physiological state, for example a large follicle is close to ovulation and the cow is in, or about to enter, oestrus. During an examination, the information gathered from exploratory procedures will be combined with anatomical knowledge of the relative positions of structures to determine an object's identity. For example, the uterus is in front of and attached to the cervix, lying on the pelvic floor or extending cranially into the abdomen.

The ability to process information gained from the sense of touch increases as skills develop, and experts are able to feel and distinguish a great deal more than novices. This was considered, even in the early 19th century, to be because people learn to make better use of the touch organs, focussing on touch and learning to move the hands more appropriately (Weber 1834: translation 1978). Training in haptic exploration will therefore, have an important role in the development of touch dependant skills. A training environment for a particular procedure will need to incorporate the exploratory procedures identified for the task in the real patient or animal. If objects can be created that are recognisable using the sense of touch while performing the correct exploratory procedures, this should provide the trainee with skills that would transfer to the real task.

2.3 Computer Haptics

2.3.1 Overview of Computer Haptics

The term computer haptics refers to the generation of virtual objects that a user can interact with through the sense of touch (Srinivasan and Basdogan 1997). A range of devices have emerged over the last ten years or so that support touch-related interaction with a computer generated environment. These haptic devices allow users to experience a sensation of touch and appreciate physical form while exploring and manipulating simulated objects. Haptic feedback improves certain types of computer simulation, making a case for the inclusion of this type of interaction. If the real task includes a haptic component, providing haptic feedback in a simulated environment should improve the realism and the user's immersion in the task. For example, designing a three-dimensional object with a conventional mouse provides a less natural interaction than using a three-dimensional haptic device, which allows the user to navigate round and feel the object. Haptic feedback can also be used to help the visually impaired use computers and has been included in interfaces developed to enhance a range of activities including browsing graphical data (Wall and Brewster 2003). The addition of haptic feedback has been shown to be beneficial for a range of training environments and was built into the early flight simulators in the 1960s (Stewart 1965). Adams *et al.* (2001) demonstrated that providing force feedback during a manual assembly task, building a Lego™ bi-plane, improved participants' performance. Whereas, a simulation that did not include haptic feedback, the knee arthroscopy simulator VE-KATS (Sherman *et al.* 2001), demonstrated only a weak correlation between performance and experience. This was considered to be because surgeons use haptic as well as visual cues during navigation within the joint and therefore, haptic feedback should be an integral part of such a simulation. A study that looked at performance during a suturing task found haptic feedback was beneficial (Moody *et al.* 2003). Participants who received haptic feedback while using the simulator were faster and more accurate than those who worked in the same virtual environment but without haptic information.

There are a variety of factors that make computer haptics both challenging and viable, including the increasing processing power of computers. The haptic presentation must be of high enough fidelity to allow the user to interact with the virtual environment with imperceptible resistance or impediments to movement. The human haptic system can sense vibration at in excess of 500Hz (Minsky *et al.* 1990) and therefore, a system that provides update rates in excess of this will be required for smooth interaction (whereas graphic update rates need only be around 30Hz). The haptic device, as an additional component for human computer interaction, presents design challenges for engineers and the development will need to operate within the cost constraints that would provide commercially available versions as well as research tools.

Haptic devices can be classified broadly into two groups according to the way in which information is relayed to the user, either through tactile feedback, providing stimulation to the cutaneous system, or through force feedback, processed by kinaesthetic perception. The devices provide feedback (output) to the user with forces, torques and sensations on the skin as well as sensing and recording human movement (input). The tactile devices stimulate sensors in the skin through temperature, pressure or vibration. This can be delivered as a pneumatic stimulus where jets of air are fired onto the skin, alternatively an array of pins vibrate against the skin. The tactile devices provide awareness of a point of contact and, in some cases, the surface texture but have limited support for the exploratory procedures identified by Lederman and Klatzky (1987) used in object recognition.

2.3.2 Force Feedback Computer Haptics

The force feedback haptic devices apply resistance at the user's point of contact, restricting movement and generating the illusion of contact with an object. The devices use motors, or actuators, to generate the forces and the user's point of interaction is supported in most cases via a mechanical arm or glove. By adjusting forces and other parameters, including three-dimensional coordinates, an environment can be created where the user can appreciate differences in the size, shape and feel of a range of objects. For example, as a user touches a virtual wall the force applied by the motors of the device stop the user's motion, preventing penetration of the surface, and the wall is perceived to be solid.

There are a range of factors by which force feedback devices are classified both with regard to the specifications provided and the quality or fidelity of the interaction. The forces generated by the motors vary from a few Newtons to several hundred (Laycock and Day 2003) and a device's suitability for a given task relates to the forces a human would use or experience while executing the real procedure. The user explores the virtual environment in a number of dimensions, the degrees of freedom. These include translational movements in the x, y, and z planes, which are important for the performance of the exploratory procedures used for object recognition and during a palpation-based procedure. A single degree of freedom would only allow one-dimensional movement, which would support for example, pressing of a button but no further exploration of the object surface. Some devices also provide rotational interaction, classified as pitch (around the x axis), roll (y axis) and yaw (z axis), and these could be used to simulate, for example, an instrument being twisted during certain surgical procedures. The workspace size varies between devices from a few centimetres to over a meter (Laycock and Day 2003) and the degree of physical intrusion from the hardware should also be considered when modelling a given task. The user's interaction with the environment will involve body movements at different joints, commonly with articulation at the wrist or elbow although some devices provide interaction for the torso (Checcacci *et al.* 2003). The other factors to consider are the number and application of the points of contact. The user may have a single point of contact, via one finger (the PHANToM device: SensAble) or multiple points on several digits (the Rutgers Master II: Bouzit *et al.* 2002) or the whole hand (CyberGrasp: Immersion Corporation). The number of points of contact affects the user's interaction with the virtual environment from just feeling a surface to manipulating and grasping objects. The user's interaction may be supported by suspension from the device, which will therefore, be grounded on a desktop or the floor or via an exoskeleton over a glove or the hand. In the latter case, the weight of the device is an important consideration unless the actuators can be positioned remotely.

There are a variety of different types of force feedback haptic device providing the user with a range of levels of interaction with a virtual environment. A mouse or joystick can relay tactile or force feedback and provides added aspects to computer gaming and personal computing (TouchSense: Immersion Corporation). In computer-aided design, haptic devices augment traditional graphic displays, allowing more intuitive hand-eye coordination while modelling products, and this has been used to enhance the design of toys and footwear (SensAble).

Automobile engineers have used a large haptic device to test the design of a vehicle in the virtual environment before entering the construction phase, when modifications become more expensive to implement (SensAble). One of the largest areas for haptic applications is in the medical world where the devices are used to provide training environments for a variety of procedures including minimally invasive surgery and palpation-based examinations, and for certain patient treatment regimes. A range of force feedback haptic devices used in medical and other fields will be considered in the next section.

In the main, computer haptics have been used to increase the realism experienced when users interact with objects in virtual environments, providing feedback via the sense of touch. However, the force feedback can also be used to guide or assist users during tasks, providing haptic guidance. For example, gravity wells acting like magnets have been shown to be helpful when visually impaired users were trying to find targets in a virtual environment (Wall *et al.* 2002). The forces can be used to control unwanted movement either for motion-impaired users (Hwang *et al.* 2003) or during delicate operations: the da Vinci surgical robot (Intuitive Surgical 2005) removes tremor while translating a surgeon's actions. The haptic device can provide assistance when users are learning movements, giving a kinaesthetic understanding of what is required. Feygin *et al.* (2002) found that when the user's hand was guided along a path the subsequent performance recalling the movement was better than after training with visual cues alone. Haptic devices have also been used in the treatment of stroke patients, where the device moves the arm along a pre-set path as part of the motor rehabilitation process (Loureiro *et al.* 2001; Broeren *et al.* 2002).

As the technology and research continue to advance, new developments and applications appear. These advances have included superimposition of the graphic and haptic interfaces (Reachin), which provides a more natural working environment for certain tasks. Also, with high speed Internet connections, virtual environments can be networked and haptic information shared between workstations. This new development has lead to a transatlantic handshake (Handshake Interactive), a surgeon performing an operation on a patient in a different hospital (Handshake VR Inc) and trainees practising virtual surgery together or with an instructor when in different geographical locations (Hutchins *et al.* 2006). Also as the field grows, the technology becomes cheaper and therefore, available to a wider audience.

2.4 Force Feedback Haptic Devices

2.4.1 The PHANToM

The PHANToM (Personal HAptic iNTerface Mechanism), marketed by SensAble Technologies, was developed by Massie and Salisbury (1994). The device is grounded on the desktop and the user interacts with a virtual environment via a single point of contact, a gimbal, at the end of a mechanical arm. There are a range of gimbal attachments including a standard pen-like fitting, a thimble and other application specific tools. The device can support interaction in up to six degrees of freedom, transitional and rotational movement in the x, y and z axes and provide three degrees of high fidelity force feedback to resist or drive motion. The graphic representation of the scene is presented in real time depicting the user's current position and in some cases the response of the object to actions. The graphic and haptic presentations run concurrently but are not synchronised with refresh rates of 30 and 1000 Hz respectively, in line with the sensitivity of human perception in each field. There are six PHANToM devices: the Omni, Desktop, and Premium 1.0, 1.5 (Figure 2.2), 1.5 High Force and 3.0, which provide a range of workspace dimensions and forces. The smaller versions support hand or lower arm movement, pivoting at the wrist or elbow, while the largest model, the Premium 3.0, allows whole arm movements from the shoulder.

Figure 2.2. The PHANToM 1.5 force feedback haptic device (SensAble). The user places a finger in a thimble at the end of the mechanical arm and palpates virtual objects, in this case the bovine reproductive tract depicted on the computer monitor.

The exploratory procedures supported by the PHANToM have been defined by Wall and Harwin (2001) as lateral motion, pressure, static contact, unsupported holding and contour following, although limitations are described with regard to the lack of temperature feedback during static contact and a limited perception of local features during contour following. This means the user is able to gather information about an object, determining the size, shape and surface texture while moving over the object, assessing the firmness by depressing the surface, and the weight when lifting.

The potential of the PHANToM hardware is realised either through the General Haptic Open Software Toolkit (GHOST) or using the recently released OpenHaptics toolkit. These allow developers to simulate virtual objects and to create the illusion of physical properties including weight, shape and firmness. A three-dimensional virtual environment is built using either the range of geometric objects provided in the standard libraries or the programmer can created original application specific objects. There are a group of functions that control object values including stiffness (firmness), surface friction and damping and adjusting the parameter values results in subtle variations in the feel of different objects.

The PHANToM is one of the most widely used haptic interfaces in research and industry. The newest model, the Omni, is relatively inexpensive and supports, for example, computer aided design where a tool can be used to sculpt in digital clay using for example, SensAble's Freeform program. The Omni has only one fixed gimbal, a stylus with buttons that allow the user to lock on to objects. The larger PHANToMs are more expensive but have found a diverse range of applications some examples of which are displayed in the Haptic Gallery (SensAble). In the aircraft industry, the PHANToM has been used to control the movements of a mannequin while practising safety procedures and during landing gear testing (Stone 2001). The inclusion of haptic feedback in this simulation was considered, on the basis of task analysis, to be beneficial. A military application has been developed by the French army for training personnel to sweep an area for mines using a special probe attached to the PHANToM mechanical arm (Stone 2001). The PHANToM has been included in a robotic system for teleoperative surgery, where the surgeon operates a master robot, which controls a slave robot at the operation site. The advantages of this system include scaling of the surgeon's movements and removing or damping tremor (Preusche *et al.* 2002). There are a wide range of applications of the PHANToM in medical training including simulations for suturing (Webster *et al.* 2001), palpation of tumours (Langrana *et al.* 1997; Burdea *et al.* 1999), patient rehabilitation (after a stroke: Broeren *et al.* 2002), training for osteopathic examinations (Williams *et al.* 2004) as well as in the Horse Ovary Palpation Simulator (Crossan *et al.* 2000; Crossan 2004) and a bovine rectal palpation simulator (Baillie 2003) in veterinary education.

2.4.2 Immersion Corporation Gloves

A range of commercial hand-based haptic devices are produced by Immersion Corporation. The user's hand is enclosed within a glove, which together with a variety of additional appliances, supports a range of movements and interactions with virtual environments. The CyberGlove is an elastic tethered glove that has a range of sensors positioned to capture hand movements. CyberTouch is a modification of CyberGlove and provides vibro-tactile feedback to each finger and the palm of the hand. The user perceives a buzzing sensation when in contact with an object. An additional development is represented by the CyberGrasp, a lightweight exoskeleton fitting over CyberGlove, which applies resistive force feedback perpendicular to each finger and the palm via tendons driven by remotely positioned actuators (Figure 2.3). The user can hold and manipulate virtual objects appreciating their weight and size. The latest development, CyberForce, is a desktop-based force feedback system which can be attached to the back of the CyberGrasp exoskeleton to provide a whole hand force feedback system. There are three degrees of translational force feedback to the hand, but only one to each finger, and six degrees of tracking for translational and rotational movements.

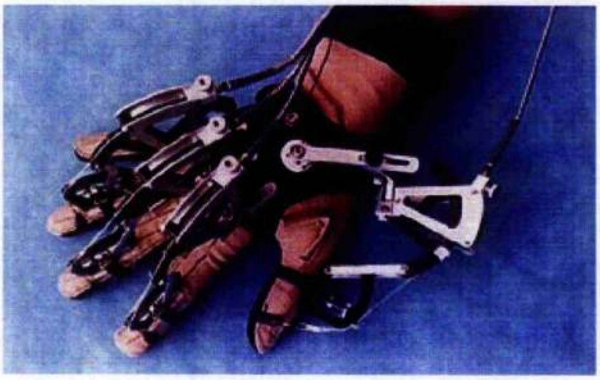

Figure 2.3. CyberGrasp: one of the haptic devices from Immersion Corporation. An exoskeleton fits over a glove (CyberGlove) allowing a user to lift and manipulate virtual objects.

With regard to the exploratory procedures, CyberForce combined with CyberGrasp supports pressure, static contact and unsupported holding as well as enclosure through multiple contact points. However, with only one degree of freedom for each finger lateral motion and contour following are not possible. This range of hand-based products is used in a wide variety of applications including computer aided design, prototype evaluation, gesture recognition, assembly tasks and in the entertainment industry.

In addition, Immersion produces a range of instrument-based simulators for medical training (Section 2.5.1). There are devices for minor procedures including catheterisation (CathSim) and minimally invasive surgery: the AccuTouch range for laparoscopic and endoscopic procedures.

2.4.3 Rutgers Master II

Another glove-type haptic device has been developed for research applications at Rutgers University (Gomez *et al.* 1995). In the latest version, the Rutgers Master II-ND (Bouzit *et al.* 2002), the glove component has been reduced, which means the device can be adjusted more easily to accommodate the natural variation in human hand sizes and the weight is a third of Immersion's CyberGrasp. Forces are delivered to the thumb, index, middle and ring fingers by pneumatic actuators and the sensing equipment is positioned on the palm. The device supports object enclosure through the four points of contact and static contact, pressure and unsupported holding but, as with the Immersion gloves, is limited to one degree of freedom for each finger. The glove was used in the liver tumour palpation simulator developed by the Rutgers research team (Langrana *et al.* 1997) but the group then used the PHANToM for a prostate tumour simulator (Burdea *et al.* 1999). The reasons for the use of different devices by the same group probably relates to the technique for assessing both prostatic changes and tumours in any tissue. This would involve both contour following and lateral motion, which are supported by the PHANToM but not the Rutgers Master device. The prostate examination is performed with a single digit and therefore, the multiple points of contact, which are one of the main advantages of glove devices, are not required.

2.4.4 Other Devices

Other devices that support haptic interaction include the Wingman series (Logitech) developed for the computer games industry, where the player experiences force feedback in two dimensions using a mouse or in three dimensions using a joystick. The mouse has been used to help the blind and visually impaired access information on a webpage, alerting them to the presence of images or hyperlinks (Yu *et al.* 2006). The HapticMASTER (HapticMASTER 2002) is a robotic arm which provides a large workspace, three degrees of freedom at a single point of contact and greater forces than the PHANToM. The device has applications in design, in assisting a stroke patient's movement during rehabilitation and in surgery, controlling tremor during delicate procedures. A different approach to haptic interaction has been developed with the SPIDAR (Kohno *et al.* 2001), which provides two-handed multiple finger interaction. There are three strings attached to each fingertip and haptic feedback is provided by controlling the tension on each string. The user manipulates objects with each hand but there have been problems delivering smooth interaction and preventing the strings interfering with each other. In a modification, the SPIDAR G&G, the user grasps solid spheres, one with each hand, and this was reported as providing an effective way of manipulating virtual objects (Murayama *et al.* 2004). Another device that provides multiple points of contact is the Haptic Interface Robot (HIRO) (Kawasaki *et al.* 2003). The haptic interface consists of a robotic arm with three fingers and the user's hand connects with the robot via three magnets on the thumb, index and middle fingers.

In spite of continuing advances and developments, currently there are no devices that provide a completely natural interaction for the whole hand to cover the wide range of human manual tasks including grasping, manipulating, palpating and other interactions with objects. Such a device needs to support all the movements (translational and rotational degrees of freedom) that are performed by the digits, hand and wrist (and other joints of the arm) while also providing a level of fidelity that is representative of the perceptual experiences of the human sensory system.

2.5 Medical Simulators

2.5.1 Overview

For many years, traditional medical training has been based on the apprenticeship model (Halsted 1904; Kerr and O'Leary 1999). The trainee learns from an expert during the course of patient care, watching and then practicing under an expert's direction, but this has certain limitations (Berg *et al.* 2001; Aucar *et al.* 2005). These include the need for access to enough patients to develop the required skills. The skill levels and confidence of junior doctors have been shown in certain surveys to be quite low, which has been attributed to the limited opportunities they have to perform procedures under existing training systems (Nakayama and Steiber 1990; Stolarek 2002). Additionally, there are ethical issues associated with trainees learning while practicing on real people who may be put at risk. One alternative to human patients, particularly for surgical training, has been the use of animals but again there are ethical considerations and the value of the training may be limited by the differences in the anatomy. There are also financial considerations relating to resources, including any materials used and the expert's time. Therefore, finding the most cost-effective and efficient methods for modern medical training is increasingly important.

Within the last couple of years, there have been two new rulings that have implications for the training of health professionals. In August 2004, the European Working Time Directive (EWTD 2004) was extended to include the medical profession and this reduced the number of hours worked and therefore, the opportunities to see and practice procedures. After these changes, a survey found that the majority (70%) of specialist registrars considered that training had deteriorated as a result (Royal College of Physicians 2004). There are also moves to make demonstrating that a surgeon is competent before performing a particular procedure on real patients mandatory, with the aim of reducing medical errors. In the USA, the Food and Drugs Administration (FDA) has ruled, for the first time, that surgeons must undertake simulator training before performing a certain procedure, carotid stenting (Gallagher and Cates 2004). Both these rulings further increase the need to research and develop new methods for training the health professionals of the future.

There are currently many initiatives in medical education to improve training and provide safer and more effective methods as adjuncts to traditional approaches. These include computer aided learning packages now widely available on CD, DVD or online. Trainees can use these resources to learn about a range of topics and watch videos of experts performing procedures. These packages often include some form of self-evaluation and feedback, which enhance the learning process and students can progress at their own pace. There is also a wide range of simulators, from whole and body part mannequins to those developed in the rapidly expanding and increasingly sophisticated area of computer-based virtual reality. Mannequins have in fact been used in medical training for centuries. There are reports in the literature of one used to teach midwifery in the 18th century (Gelbart 1998) and a mannequin used in Italy at about the same time forms part of the Henry Wellcome medical collection (Arnold and Olsen 2003).

Simulators are particularly useful for learning clinical skills and surgical procedures as a novice can gain hands-on experience in a standardised, safe environment without risk to the patient. An example of a relatively simple mannequin is the dummy used for 'First Aid' training that allows members of the public to practice simple life saving procedures. A cardiac simulator, 'Harvey' (Figure 2.4), is a life-sized computer-enhanced mannequin that presents the trainee with a range of cases and currently includes two normal cases and twenty-five examples of cardiac disease (University of Miami, 2005). The model has a simulated pulse, exhibits respiratory movements and can be auscultated for heart sounds, which change to represent different disease conditions. Some of the more sophisticated mannequins provide additional feedback including: responses to the trainee's actions, such as drug administration and minor procedures, and performance evaluation ('Stan' (Standard Man) The Human Patient Simulator™, from Medical Education Technologies Inc); and improved graphic representations of procedures (LapTrainer from Simulab Corporation). There is now widespread inclusion of simulators in the skills laboratories at many medical schools, indicative of their importance in modern medical training.

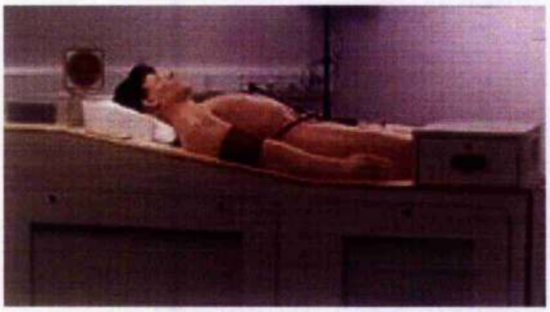

Figure 2.4. **'Harvey', the cardiology patient simulator (University of Miami, 2005). A computer enhanced mannequin that can be auscultated for heart sounds and palpated for pulses. Trainees have access to a wide range of cases: 2 normal and 25 examples of disease.**

In addition to physical or mannequin-type models, there are an increasing number of virtual reality simulators. These have proved particularly suitable as training tools for minor procedures including placement of intravenous catheters (CathSim from Immersion Corporation), epidural injections (Dang *et al.* 2001; Zhu 2005) and suturing (Webster *et al.* 2001). The commercially available CathSim provides a student with a range of simulations including the normal adult and the more challenging veins of paediatric and geriatric patients. This flexible environment presents an alternative to existing training methods, which include using rubber arm models or practising on other students (Barker 1999). A core skills trainer, MIST-VR from Mentice, provides an environment in which the trainee can practice a range of techniques that form the basis of minimally invasive surgical (MIS) procedures including knot tying, suturing and tool manipulation. There are also procedure-specific virtual reality simulators for practicing minimally invasive surgery and techniques. When performing MIS, the surgeon operates through a small incision, a keyhole, and views the instrument actions on a monitor. In the MIS virtual reality environment, the trainee interacts with modified instruments while viewing a graphic representation of the operating area in real time. A range of laparoscopy simulators have been developed including Immersion's AccuTouch series (Immersion Corporation), with which trainees can practice abdominal surgical procedures on the bile duct, anastomosis of blood vessels and certain gynaecological techniques. An arthroscopy simulator has been developed for the shoulder (Smith *et al.* 1999) and another for the knee (Sherman *et al.* 2001), where the surgeon practices using a modified arthroscope inserted into a physical model of the leg. Other minimally invasive techniques have been simulated including endoscopic procedures, with the Immersion Corporation producing bronchoscopy and colonoscopy simulators. A couple of other procedure-specific simulators have been developed by the Uniformed Services University at Bethesda, Maryland. One allows physicians to practice pulmonary artery catheterisation (Liu *et al.* 2006). Another has been developed for training medical personnel to perform crichothyroidotomy, which is considered an important skill for the practice of emergency medicine on the battlefield (Liu *et al.* 2005). The user feels for the crychothyroid membrane then picks up a scalpel, makes and enlarges an incision, and finally tries to insert a tracheostomy tube.

As well as providing risk-free and accessible learning environments for trainees, simulators can be used by experienced surgeons to practice new procedures or to learn how to use new equipment. Virtual reality is a useful tool for preoperative planning leading to improved decision making (McCloy and Stone 2001). The surgeon can rehearse a procedure in a simulated environment prior to the real operation using patient specific data (derived from Computed Tomography (CT) and Magnetic Resonance Imaging (MRI) scans) and view the postoperative effects. This approach has been used for facial reconstruction (Keeve *et al.* 1996) and for neurosurgical procedures (Welschehold *et al.* 2004). Another application for virtual reality is in the treatment of phobias where the patient is immersed in a simulated scene and learns to overcome the fears or trigger stimuli and an example would be an environment developed for practising public speaking (Jo *et al.* 2001).

Some virtual reality simulators provide graphic representations only, particularly the early surgical ones, but the inclusion of haptic feedback is increasingly common. This is important as many medical procedures involve touch-related interaction with patients, either directly or using instruments. Bholat *et al.* (1999) demonstrated that touch feedback is present during MIS and Sherman *et al.* (2001) considered that the lack of haptic feedback in their knee simulator, VE-KATS, was responsible for the poor performance of experts compared with novices. Therefore, simulators are now designed to include haptic feedback to allow the user to feel the effects of instruments interacting with virtual tissue. An area where haptic feedback is particularly important is during palpation-based examinations and procedures as touch is the primary, and sometimes only, sense available to the physician. Palpation skill training has particular relevance to this thesis and will be covered in detail in following sections (2.5.2 and 2.6.2). As well as adding realism to training environments, haptic technology has potential for use in certain areas of patient treatment. In one example designed for stroke patients, the user has a passive role and the device drives limb movements, providing physical training as part of the rehabilitation process (Loureiro *et al.* 2001; Amirabdollahian *et al.* 2002; Broeren *et al.* 2002).

2.5.2 Medical Palpation Simulators

Advances in medical technology, particularly imaging techniques, provide powerful diagnostic tools but many conditions are still diagnosed using palpation during a first opinion routine clinical examination when the physician feels for swellings, heat, guarding and abnormal structures using touch. Palpation is cheap, available to every clinician and effective, and is an important way of screening for certain types of cancer, including of the prostate (Burdea *et al.* 1999) and the breast (Miller *et al.* 2000). Early detection of these cancers is the key to survival and in a large survey conducted by Kuroishi *et al.* (2000), a reduction in breast cancer mortality rates were attributed mainly to the use of physical examinations. However, the level of proficiency among health professionals performing clinical breast examinations (CBEs) has been found to be variable, with many reporting low levels of confidence and requesting further training (Wiecha and Gann 1993). As well as being used as a diagnostic tool, palpation is also a fundamental component of certain medical procedures, particularly in obstetrics and paramedical disciplines including osteopathy and physiotherapy.

Training for all palpation related skills presents particular challenges for the teacher who is unable to feel and, in the case of internal examinations to see, the trainee's actions and therefore, can provide only limited guidance. During training, the student learns initially to appreciate the normal before progressing to recognising the changes associated with different physiological states or disease processes. In a conventional medical education system, knowledge about breast cancer has been shown to increase with each year of the course but this did not correlate with development of palpation-based skills (Lee *et al.* 1998), while specific palpation skill training for CBEs has been shown to improve examination sensitivity (Campbell *et al.* 1991). A further consideration for certain examinations is that patients may be unwilling to allow trainees to practice the procedure. However, without adequate training and skill development there may be risks to patients associated with poor performance of procedures as well as reluctance, on the part of the physician, to use palpation as a diagnostic tool.

Simulators provide a potential solution to the challenges of palpation-based procedure training and this was recognised by Madame du Coudray, who was commissioned by Louis XV to travel the length of France instructing midwives using her full-sized mannequin, which included a baby with flexible limbs to simulate a range of presentations (Gelbart 1998; Fissell 2000). These trainees had no formal medical knowledge and learned the skills of their trade through trial and error during real deliveries. The mannequin provided an alternative and safe training environment with which to gain hands-on experience. In modern medical training, there are a wide range of sophisticated whole patient mannequins and body-part models available for learning palpation-based skills. An example of one of these physical models is a silicon breast, used for CBE training, in which the lump size, firmness, position and degree of attachment to underlying structures could be varied and this was shown to be an effective training tool (Gerling *et al.* 2003). In a modification to the original model, the lumps were made to pulsate and, although not natural, this made small and deep lumps easier to detect. Training on the pulsating model was shown to increase detection rates, without increasing false positives, and the skills acquired also resulted in improved lump detection rates on the original static model (Gerling and Thomas 2005). Other simulations have been developed where computer controlled additional features enhance the training environment. The Stanford E-pelvis (Pugh *et al.* 2001) combines a mannequin with internal electronic sensors that provide feedback on the trainee's performance with regard to position and force. The performance of three groups, E-Pelvis simulator-trained, manikin-trained but without the internal sensors and controls, who used anatomical parts and drawings, was compared. The results indicated that the feedback available during the examination of the E-Pelvis had a beneficial effect on subsequent performance.

Haptic feedback is an integral part of any virtual reality environment designed for palpation skill training and a small number of simulations have been developed using force feedback devices. The first versions were developed at Rutgers University in the 1990's. Langrana *et al.* (1997) developed a simulation in which a trainee learns to detect liver tumours while feeling through the abdominal wall for masses of different firmness within the liver parenchyma. The trainee moves the hand over the liver surface receiving force feedback from the Rutgers Master II glove in response to pressing actions with one or more fingers. There is a simultaneous graphic display, which provides visual representation of the hand moving over the abdomen, with options to see through the abdominal wall to the underlying organs or to change the viewpoint. A prostate simulator has been developed for training urologists to diagnose malignancies using the PHANToM (Burdea *et al.* 1999). The trainee uses the index finger to palpate a series of simulations including the normal prostate and examples of hypertrophy and early and advanced malignancies. The tumour positions can be randomised to present twelve different patients. During training, initially the user is allowed to see the graphic representation of the examination and then practices with haptic feedback only, as in the real examination. There is an option to record and playback an examination to analyse a trainee's technique or present an example of an expert's technique for teaching purposes. More recently, a group in Japan, also using the PHANToM, have developed a model that attempts to include representation of the interaction between the rectal wall and the prostate gland (Kuroda *et al.* 2005). The prostate model, developed in collaboration with urologists, currently has two settings: soft and firm (cancerous).

A head and neck tumour simulation has been developed in Sweden (Stalfors *et al.* 2001). The patient is examined in a district hospital and then assessed remotely by a team of specialists in another hospital. The three-dimensional graphic representations are created from patient data gathered during MRI and CT scans. The haptic information is captured using a sensing device, such as a CyberGlove, during palpations performed by the examining physician. The ENT surgeons and oncologists then perform an examination using the PHANToM to palpate the virtual version of the patient while receiving monoscopic or stereoscopic visual representation. This simulator also has potential for training future specialists and medical students. Another simulation has been developed for tumour palpation using the Haptic Interface RObot (HIRO) (Daniulaitis *et al.* 2004). Using three points of contact (thumb, index and middle finger) a trainee can palpate subsurface tumours associated with breast cancer. The training environment was developed using a recording of a CBE performed by an expert on the virtual model (while wearing a combination of HIRO and CyberGlove).

A group at Ohio University are developing a training environment, the Virtual Haptic Back (VHB), for medical students, osteopaths and physiotherapists (Williams *et al.* 2003; Williams *et al.* 2004). The group, a multidisciplinary team, have identified their aim as "adding science to the art of palpatory diagnosis" and have conducted an iterative design process, progressively improving the simulation over four versions. The graphic model has been developed based on measurements from a human subject and is dynamic, responding to user actions in real time, with an option to reveal the underlying structures. There are simulations of structures in the cervical, thoracic and lumbar regions including the vertebrae, other bony landmarks, ligaments, muscles, subcutaneous tissues and the skin. The haptic representations are based on a spring damper system with varying stiffness values for different tissue types. Force feedback from a PHANToM haptic device is relayed to the user's thumb or finger in the thimble gimbal. The model's haptic properties have been set by the development team rather than from real patient measurements. The user depresses the skin, experiencing increasing force with penetration depth, and can appreciate the hard bony spinous and transverse processes of the vertebrae or the less firm interspinous ligaments. The vertebrae rotate in response to manipulation and can be set up in abnormal, as well as normal alignment. A toolbar provides menus to access much of the enhanced functionality provided by the training tool, including the type of graphic presentation and a range of cases of varying difficulty. During a test, the user indicates his or her answer using a foot pedal and then receives audio feedback. The authors describe a two phase training schedule (Williams *et al.* 2003). First, the trainee has a passive role and is pulled along by the PHANToM motors following the path of a pre-recorded expert examination. Then the trainee can explore on his or her own and can practice performing the examination and palpating structures. The system records the trainee's examination in both phases for comparison and assessment. A newer version (Williams *et al.* 2004) uses two large PHANToMs, 3.0s, for bimanual palpation of a full scale representation of the entire spinal region and future developments are planned to represent muscle spasm and to improve the realism of the interaction by giving digit dimensions to the points of contact.

2.6 Veterinary Simulators

2.6.1 Overview

There are increasing numbers of students training at the UK veterinary schools but the availability of clinical material for teaching purposes is declining. This means the universities have difficulty ensuring all students have the opportunities to gain enough hands-on experience to develop skills to the required standard by graduation, which ultimately puts patients at risk. In the USA, a survey of practitioners attempted to define the attributes required of new graduates (Walsh *et al.* 2001), similar to the 'Day One Skills' (RCVS 2001). The researchers found that practitioners were concerned that graduates lacked certain surgical and procedural skills (Walsh *et al.* 2002) and similar issues have been raised in the UK (Routly *et al.* 2002). There are also concerns about the use of live animals for teaching purposes and the associated ethical and welfare issues have been raised by students, teachers and the public (McBride 1989; Rollin 1990; Martinsen and Jukes 2005). As a result, there is a move to reduce, replace and refine the use of animals as educational resources: the pursuit of the '3Rs'. This not only applies to veterinary education, but also animal use in medical training and for teaching dissection in secondary and higher education (Hart *et al.* 2005).

These concerns and shortfalls have lead to attempts to develop alternative teaching environments as supplements to traditional methods and there is an increasing range available (Hart *et al.* 2005; Scalese and Issenberg 2005). The majority aim to provide training for surgery and minor procedures, although there are a few designed specifically for palpation-based skills (Section 2.6.2). One approach is to use cadavers, which are particularly useful for practicing certain basic surgical skills including incision making and wound closure as well as for specific surgical procedures. Another approach has been to develop physical models of whole animals or the relevant parts. For example, plastic bones have been used for practising orthopaedic surgical procedures for many years (Deyoung and Richardson 1987). Manikins of a dog and a cat have been developed by Rescue Critters, Critical Care Jerry and Fluffy, to allow students to practice intravenous access, bandaging and endotracheal intubation, and the most recent version includes heart and lung sounds for auscultation (Rescue Critters, 2004). Models of a canine forelimb and the head and neck have been developed by University of California Davis for practicing vascular access and blood sampling (CALF 2006). There are also several canine models of the head and neck that have been developed specifically for intubation (Mosing and Auer 2003; CALF 2006). Greenfield *et al.* (1993) developed an abdominal surgery simulation with physical models of the spleen, liver and kidney for students to practice taking biopsies and organ removal, such as splenectomy. Another model, the Dog Abdominal Surrogate for Instructional Exercises (DASIE), made from laminated fabric and foam rubber is available commercially for students to practice using surgical instruments, suturing and placing ligatures (Holmberg *et al.* 1993). A hollow organ simulator made from laminated polyurethane has been developed for students to practice gastrotomies and hollow organ closure (Smeak *et al.* 1994), as an alternative to developing the skills during real or terminal surgeries, and the model and accompanying auto-tutorial are available commercially. An ovariohysterectomy model was developed at the University of Edinburgh for students to practice basic skills and the procedure as a whole in preparation for performing the operation on live animals (Griffon *et al.* 2000). Recently, a simple cheap model has been developed for practicing castration of the guinea pig with emphasis on a closed technique (Wheler 2006). A human mannequin (The Human Patient Simulator™, Medical Education Technologies Inc) has been used for veterinary students to practice induction and maintenance of anaesthesia (Modell *et al.* 2002). As well as species or procedure specific models, veterinary clinical skills laboratories contain an increasing range of more generic models for learning psychomotor skills and practicing basic surgical procedures including suturing, knot tying, blood vessel ligation and instrument handling (Johnson and Farmer 1989; Smeak *et al.* 1991; Olsen *et al.* 1996).

Another developing area is that of computer aided learning (CAL) packages that are readily available online or as CDs and DVDs. The CLIVE project (Computer aided Learning In Veterinary Education), is a collaboration between all the UK veterinary schools and provides a wide range of educational and revision material to supplement lectures and practical sessions. These resources include videos of experts performing and explaining a range of procedures as well as computer generated animations. The University of Georgia have developed a sophisticated graphics package, 'The Glass Horse' (Moore *et al.* 2002b), which includes three-dimensional images of the equine gastrointestinal tract depicting the normal anatomical arrangement and then the intestines move to various positions when the horse develops colic. The latest version includes a graphic representation of the hand moving in the rectum, and a recent addition to the package provides detailed graphic representations of the distal limb and foot. Another online learning package was developed to allow students to be involved in current small animal cases and although well received by students, proved too demanding of faculty members time and was discontinued (Dhein 2005). These computer aided learning packages do not provide the students with practical experience, which has already been highlighted as an area for concern in the veterinary undergraduate curriculum. Therefore, further developments in this area need to provide computer-based models that enable a student to examine an animal or practice certain procedures in virtual environments. One such simulator developed for medical training, CathSim (Immersion Corporation), is being used and evaluated at the Royal Veterinary College for training students to perform intravenous catheterisation (Clarke *et al.* 2003). Additionally, several palpation simulators have also been developed recently (Section 2.6.2: Crossan *et al.* 2000; Baillie 2003).

There are several databases and websites that provide easy access to alternatives to the use of animals in education. The Norwegian School of Veterinary Science has a large database, NORINA, an inventory of more than 3500 audiovisual and other resources, including simulators that provide alternatives and supplements to animals as teaching materials (NORINA 2006). The Association of Veterinarians for Animal Rights (AVAR) also have an alternatives in education database (AVAR 2003) and the International Network for Humane Education (InterNICHE) provide links to manufacturers of alternatives and a lending library. The University of California, has a computer assisted learning facility (CALF 2006), which provides access to their learning resources as well as a website that allows people to perform and customise keyword searches for alternatives to animals as teaching or research resources (Wood *et al.* 2005).

Although an increasing number of alternatives are available, there may be certain limitations. The opportunity to practice will depend on availability and reusability as, for example, for certain surgical procedures, such as ovariohysterectomy, a cadaver can only be used once. Also cadavers, physical and virtual models, depending on the quality, may lack the correct tissue handling properties and physiological responses, including bleeding, bruising and developing shock. Ideally training would involve a combination of simple models to practice basic psychomotor skills and other minor procedures together with more sophisticated whole animal or whole procedure simulations followed by access to cadavers and then real animals.

2.6.2 Veterinary Palpation Simulators

There are only a limited number of models that have been developed for teaching palpation-based procedures. For large animal rectal palpation, options include using cadavers or models with preserved intestines. A bovine cadaver has been used as a teaching aid at the College of Veterinary Medicine, North Carolina State University (Van Camp *et al.* 1988). The carcases of adult female cows were prepared using mineral oil and anti-fermentative agents and then a window was cut in the left and right abdominal walls. First, the students would look at the organs inside the abdomen and then perform rectal palpation and surgical procedures. Students had a 15 minute session with an instructor and each cadaver lasted for about 12 hours before putrefaction. A fibreglass rear-half of a horse containing plasticized preserved intestines and plastic models of other organs has been developed by the University of Veterinary Medicine, Vienna (Von Künzel and Dier 1993). The model allows students to perform a rectal examination while a teacher positions the intestines to represent the normal anatomy or one of a number of colic scenarios (Figure 2.5). Parts of the intestine can be blown up with air using a stirrup pump to represent for example, dilate loops of small intestine, which might occur as a result of an obstruction or strangulation. This model is in use at a number of veterinary schools around the world.

Figure 2.5. The model horse used to teach colic examinations, which was developed at the University of Veterinary Medicine, Vienna. During a training session, the student palpates the intestines and examines a series of cases that represent both normal findings and examples of colic cases.

The first specifically veterinary computer simulated virtual reality training tool for a palpation task was developed at the University of Glasgow by Crossan (Crossan *et al.* 2000; Crossan 2004), the Horse Ovary Palpation Simulator (HOPS) (Figure 2.6). The aim was to provide a safe training environment in which students could develop the skills required to perform equine rectal palpation for fertility examinations. In the real horse there are risks of causing damage during the examination, a rectal tear is one consequence (Rossdale and Ricketts 1974) and this can be fatal. Clients may be reluctant to allow students to gain experience while examining their horses and additionally, the student may be in danger of being kicked. As a computer-based learning environment, the VR simulator also had the potential to provide a flexible and reusable learning resource. The HOPS project used the PHANToM force feedback device and a computer model has been developed that allows a student to interact with the ovaries with a finger in the thimble attachment to the mechanical arm. In equine stud medicine rectal palpation is used to diagnose fertility problems and as a management tool, to ensure mares are covered at the correct time. In the model the number, size and position of follicles on the virtual ovaries can be altered, simulating different stages of the mare's reproductive cycle.

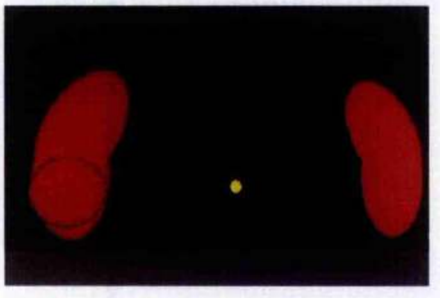

Figure 2.6. The Horse Ovary Palpation Simulator - HOPS (Crossan 2004). A follicle is present on the left ovary; the yellow dot represents the current hand position in the virtual environment. (Figure included by kind permission of Andrew Crossan).

The ovaries were created using geometric shapes and experienced veterinary surgeons provided input during the development of the models. Each ovary consisted of two stretched conjoined spheres with the follicles represented as exact spheres but of varying diameters and different levels of stiffness (softness or hardness). In an early version, a more anatomically correct representation was based on a clay model of an equine ovary, which was scanned to generate a three-dimensional image. However, the haptic representation, consisting of multiple polygons, was rejected by the veterinary surgeons because some of the polygon edges were palpable and the smooth geometric approximations were preferred. The ovaries were positioned opposite each other in virtual space but none of the other pelvic or abdominal landmarks were represented. The follicle had a fluid feel compared with the fibrous stroma of the ovary, which felt firmer. The haptic properties were established by five experienced veterinary surgeons. They worked in two groups and adjusted and selected the parameter values for the three standard haptic functions used in the GHOST SDK, stiffness, surface friction and damping (Crossan 2004). The two groups were in agreement with regard to the values selected for the follicles. However, there were discrepancies for all three haptic properties for the ovaries and input from a sixth veterinary surgeon was used to settle the differences and finalise the simulation. In the resulting virtual environment, the trainee palpates the ovary through a single point of contact with the index finger in the thimble gimbal and explores the surface of each ovary to locate the follicles and determine the size.

A series of experiments have been conducted to attempt to validate the simulator as a training tool (discussed in detail in Section 2.9). These included a comparison of the performance of experts and novices in a simulator test (Crossan *et al.* 2001), looking at the effects of regular training on student performance with the simulator (Crossan *et al.* 2002) and then comparing these students' skills examining *in vitro* specimens with a group trained in the traditional way (Crossan *et al.* 2002). The potential of the simulator as an assessment tool was also explored (Crossan 2004).

Another veterinary simulator has been developed by Baillie (Baillie 2003) for training students to perform bovine rectal palpation, also using the PHANToM force feedback haptic device. Ovary palpation, bovine or equine, is an important part of fertility assessment but during an examination in the real animal other anatomical structures would be palpated. The bovine model has been designed to include three-dimensional representations of the cervix, non-pregnant uterus, ovaries, ovarian cyclical structures and early pregnancies, all positioned within the bony pelvis (Figure 2.7).

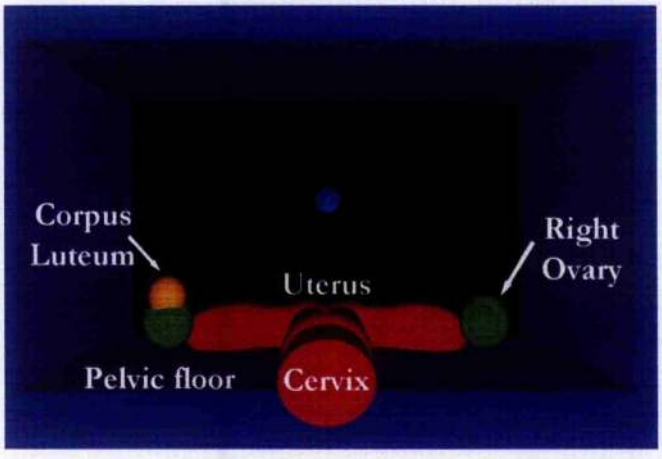

Figure 2.7. One of the simulations developed for the bovine rectal palpation simulator (Baillie 2003): A non-pregnant uterus in the pelvis. Students are trained to locate the uterus. The pelvis is in blue, cervix and uterus in red, ovaries in green and corpus luteum in orange.

During farm visits, the veterinary surgeon will examine a range of fertility cases and needs to assess the state of the entire reproductive tract and perform pregnancy diagnosis. Therefore, while learning bovine (and equine) rectal palpation the student will need to develop a systematic approach to locate the key anatomical structures. The technique is based on identification of certain landmarks and a systematic approach to navigating through the three-dimensional pelvic area. The simulator provides an environment in which students can develop a range of skills and enables the teacher to play an integral role during the training sessions. The teacher views the graphic representation of each simulation, follows the student's movements inside the virtual cow and can direct the student's exploration. The student learns to appreciate the haptic properties of anatomical structures, which can be identified by the teacher, as this will form the basis for recognition of the same structures when performing rectal palpation of real cows. A range of virtual environments support the progressive stages of skill development.

The creation of realistic anatomical models was the first important stage in the development of the teaching tool. The bovine simulations were designed by a veterinary surgeon and each model was assessed during a formal evaluation by nine other experienced practitioners (Baillie *et al.* 2003). The feedback indicated that certain models, including the pelvic brim and the ten week pregnancy, were considered to be a good likeness of the same structure in the cow. Information was gathered during the analysis with regard to the changes required for some models in order to create more realistic representations. The simulator underwent a preliminary evaluation as a teaching tool and student feedback indicated that training had had beneficial effects on their subsequent performance examining cows (Baillie *et al.* 2004).

The equine and bovine simulations represent new ways of teaching veterinary palpation procedures and providing students with skills in a risk-free and accessible environment. Additionally, providing effective training for novices prior to the first real examination would have benefits for animal welfare. The simulations demonstrate the potential to create veterinary virtual reality environments and as teaching tools, enable the teacher to have a more effective input into the learning process than when using more traditional methods. However, in both cases there were certain shortfalls (see Section 2.9 below). The virtual models in both simulators needed to be more realistic (on the basis of experts' feedback). Additionally, for HOPS, although learning effects have been demonstrated in the virtual environment, subsequent performance during the real task, when examining a horse, has not been investigated. The bovine simulator was well received by students, who considered that training had been useful for the real task. However, this assessment was based on the students' opinion and therefore, lacked independent verification. Therefore, in both cases, further research and development is needed if these simulators are to be used in veterinary training for equine and bovine palpation-based skills in the future.

2.7 Anatomical Models

2.7.1. Gathering anatomical data

One of the main challenges when developing medical, and other, virtual reality simulations is the creation of a realistic representation of the environment being modelled. This involves gathering information about the objects in that environment and the values that categorise each object's specific properties. The information is then used to develop a virtual organ that looks and feels realistic and responds to user interaction. A three-dimensional graphic representation of human anatomy can be built from MRI and CT scans, which are highly detailed and patient specific. The Visible Human Project (National Library of Medicine 2003) used these imaging methods to create a model of a whole human body from an executed prisoner, the first was male (1994) and this was followed by a female in 1995. The project created a highly detailed graphic representation of the human body, which is available for use in medical teaching packages and for the development of virtual reality models.

The inclusion of haptic feedback in a virtual environment aims to present the user with the same sensations as experienced during the task being modelled and therefore, will need to represent information about tissue biomechanical characteristics. There are various methods reported in the literature for gathering this information. One approach, manual estimation, involves creating an initial model as an approximation and then experts adjust the properties until the model is perceived to 'feel right'. Good quality models can be created provided a number of experts' opinions are elicited on a regular basis during the development phase. However, the reliability of this method has been called into question by Batteau *et al.* (2004) who found that experts' ability to recall accurately the haptic feedback associated with a needle entering a vein lacked consistency. Whereas others have found that the values selected by cardiovascular surgeons for a model of a normal and sclerotic aorta were within a narrow range (Nakao *et al.* 2003). Depending on the task, the visual sense may be as, if not more, important than haptics. For example, when performing needle insertion in a virtual environment high quality real time graphic feedback was found to have more of an effect on performance than haptics (Gerovich *et al.* 2004). During the experiment conducted by Batteau *et al.* (2004) participants were allowed to imagine they were performing whatever procedure they were familiar with, phlebotomy or catheter placement for intravenous drug administration. The lack of consistency of haptic recall could relate to the relative importance of visual over haptic cues during the real procedure, for example, the appearance of blood in the catheter confirms to the operator that a catheter is indeed in the vein. Another explanation could be that the haptic feedback provided in the simulated environment did not represent the situation when working with patients closely enough. Therefore, during the design process, determining the role of each mode of feedback, if not immediately obvious, will be important. This will help to ensure that the simulated environment provides the right level of feedback through the relevant channels. Internal palpation involves only the haptic sense and experts' knowledge was used as the means of setting object properties in both the veterinary palpation simulations (Baillie 2003; Crossan 2004). The resulting models varied in quality with only certain anatomical structures being considered to be realistic enough. In the bovine version, even this level of representation had required a large number of iterations within the implementation phase. This approach is time consuming and may not be feasible unless, as in the case of the bovine models, the programmer is also a clinician. The prostate simulation designed by Burdea *et al.* (1999) developed virtual models on the basis of the subjective evaluation of one urologist but were considered to lack realism by residents participating in experiments to diagnose malignancies. The Virtual Haptic Back model was also developed using subjective input, in this case from the design team and osteopathic doctors. The level of realism achieved is not discussed although further improvements are planned as the design process is ongoing (Williams *et al.* 2004).

Another approach is to capture tissue properties using a measuring device that probes the surface and records force responses. There are ethical considerations relating to gathering data from real patients and therefore, various alternatives have been used. Langrana *et al.* (1997) modelled subsurface tumours based on measurements from physical models where hard rubber balls, representing the tumours, were submerged within softer rubber. However, the realism of the resulting virtual models will depend on the quality of the physical models. Post mortem samples have been used to create force models for needle insertion using human skin and fat samples and porcine cadavers (Hiemenz Holton 2001). A special needle was used to record loads, which were correlated with MRI images to create displacement curves for the different tissue types encountered at different depths. Brouwer *et al.* (2001) took both *in vivo* and *in vitro* measurements from pigs. The *in vivo* tissue provided data from the natural state, perfused with blood and interacting with surrounding structures, the *in vitro* samples, though less realistic, allowed more precise modelling of certain aspects including shape. Another challenge is to engineer measuring devices that can be used within the body and return the information required to create virtual models. One approach is to develop special instruments that measure force responses while indenting or probing tissue while others have modified surgical instruments to measure tissue force deformation properties during surgical procedures. An example is the endoscopic grasper developed by Brown *et al.* (2002), which has been tested on physical models and porcine tissue, measuring both the grasping forces and the resulting tissue deformation. The majority of data have been collected from porcine samples, as pigs are considered to have the greatest similarities to human tissue. However, because of the anatomical differences, there is still a need to either develop an ethically acceptable means of measuring *in vivo* human tissue values or correlate accurately the animal derived findings with the human equivalent.

2.7.2 Computational Methods for Creating Models

The virtual environment will need to contain organ models created using the biomechanical values ascertained during the measurement phase from experts, physical models, animal or human tissue. The surgical simulators also need to include animated instruments and generate responses to interactions during the performance of procedures. The aim is to create realistic simulations that are believable to the user and this involves presenting high fidelity information, delivered with stable forces in real time. Fidelity has been divided into four components parts by Arthur *et al.* (1999), a group developing a knee arthroscopy simulator. In comparisons between the simulated and real environments the components are defined as: physical fidelity, which relates to the look and behaviour of objects; operational fidelity, the degree to which the simulator operates in the same way as the real object; functional fidelity, covers the similarities in the range of tasks; and motivational fidelity assesses the acceptability to the user. One of the problems in delivering these goals is the limitations of computational power, particularly in relation to haptic rendering for the physical fidelity, which requires higher update rates than for the graphic representation of the same structure. With modern processors this is increasingly achievable, more than one modality can be delivered simultaneously and an environment can be created in which the user feels immersed while performing a range of tasks. However, as the level of fidelity provided should correlate with the capabilities of human perception, if haptic recall of certain tasks is limited (Batteau *et al.* 2004) or other senses predominate, the need to provide incredibly realistic models may be unnecessary and computational power could be redirected.

The creation of virtual models that represent anatomical structures realistically has involved a great deal of research and a range of methods have been developed. Most organs deform, to a greater or lesser extent, when palpated or prodded directly by hand or indirectly via an instrument. The softer the tissue the greater the change in relation to the force applied and even bones, though not deformable through simple contact respond to the action of drilling instruments. Therefore, to convey the effects of interactions to the user, the virtual environment will need to include the change in tissue properties as the object is altered or deforms. Basdogan (1999) describes two broad categories for the techniques used by researchers to create deformable objects: geometrically-based or physically-based modelling. The geometric models are based on the shape of the object and the tissue properties are relayed to the user at contact points via a reaction force, which is calculated using a pre-determined formula. This method was used to create models of the prostate (Burdea *et al.* 1999), horse ovaries (Crossan 2004) and the bovine reproductive tract (Baillie 2003). Geometrically-based techniques have the advantages that the models are relatively fast and simple to create and require lower computational power than physically-based models. Although, the geometric models are perceived by the user to have different properties, for example, feeling soft or hard, the dynamic quality of these interactions are very limited and the variation in tissue properties throughout an organ are not represented.

The physically-based modelling techniques attempt to capture movement and tissue reactions, thereby simulating the dynamics of realistic interactions. A range of methods have evolved to capture the physical properties and responses of objects. A mass-spring model was developed where an organ is represented as a collection of springy tendons and this has been used in endoscopic and laparoscopic surgery simulators (Bro-Nielsen *et al.* 1999; Tendick *et al.* 2000), although the simulations are limited to relatively small deformations and softer tissues. A more sophisticated technique uses finite element models (FEM), where objects are composed of a large number of particles of finite size (Liu 2002). The models are created using the principle that when a load is applied to a surface, energy is transferred to the object, which results in a change of shape. The models are created from a series of discrete shape elements composed of interconnecting nodes. Physical properties, including elasticity, are conveyed using functions expressing strain energy and work done during displacement. The technique was used originally in mechanical engineering for static systems but has been developed further to include the aspects of dynamic medical simulations with instruments movements and human tissues responses. Additionally, in order to begin computing the deformation of an object and produce the topographical changes, the system needs to detect the interaction or collision between two objects or an instrument and an organ. The combination of all these factors has been demonstrated successfully in a microsurgery simulation (Brown *et al.* 2002) where the user repairs severed blood vessels using forceps to place a suture. Also the interactions between objects have been represented in a prostate simulation (Kuroda *et al.* 2005), where contact between the rectum and prostate models results in deformation relative to the elasticity or firmness of the two objects. The physically-based methods have the disadvantage of being computationally very expensive and therefore, slow. Algorithms are emerging to increase efficiency as well as the development of alternatives to the finite element models. These include using finite spheres (De *et al.* 2001), a boundary element method (Monserrat *et al.* 2001), although this assumes an object is homogenous, and a long element method, an efficient way of representing relatively simple shapes (Balaniuk 2002).

In recent years, there have been tremendous advances in the development of more efficient and effective software and hardware components for medical simulations. However, further research is required before a range of cost effective training tools, which incorporate haptic as well as graphic feedback, become widely available. Basdogan (1999) highlights some of the continuing needs facing developers and these include: continuing to improve the realism of simulations; the challenge of representing physiological responses, bleeding at a point of incision and whole organ changes, for example due to a fall in blood pressure; determining the degree of fidelity required, because the higher the quality the greater the computational cost although, in certain training environment lower quality may be acceptable; continuing human factors studies to understand the sensory cues used in real tasks and therefore, to be represented in the simulator; and selecting the procedures most suited to simulation with liaison between engineers and medical experts. The continuing efforts strive towards the ultimate goal, creating a haptic library of human organs similar to the graphic libraries of the Visible Human Project and eventually to deliver training over the Internet to a wide audience, the trainee health professionals of the future.

2.8 Other Uses of Haptic Technology

As well as providing touch feedback to increase the realism of virtual environments, haptic technology can provide assistance to the user and record information about human performance. When exploring a virtual environment the presence of an object within that space is conveyed to the user as a force in relation to the current position. Additionally, some devices support two-way flow of information and can record data about the user's actions, tracking the path taken as a series of x, y and z coordinates and the forces applied when interacting with an object. This functionality can be used in teaching tools as following an expert's path would be helpful when learning a procedure. The Virtual Haptic Back project includes a recording made when an expert palpated the spine and this was used in training, the learner's hand being moved along the expert's path by the PHANToM (Williams *et al.* 2003). When used in this way, directing a passive exploration, only positional information is available. A trainee can learn some of the kinaesthetic components of the procedure, the series of movements that are, for example, combined to perform an examination. In addition, the trainee will gain information about the shape and size of objects. However, when driving the user's hand movements, the PHANToM does not provide the variations in force that convey information about the relative firmness of different objects. In the Virtual Haptic Back project, the initial training was followed by a second phase when the trainee explored freely, performing an active exploration. During this phase, all object properties, including the feel (softness or firmness), would be conveyed to the trainee. Another medical training tool, an epidural injection simulator, includes haptic guidance in a slightly different way (Dang *et al.* 2001). The trainee tries to copy an expert's path and while practicing, if the needle deviates from the required trajectory, forces are applied to return the trainee to the correct position.

In medicine, as well as investigating new and more effective ways of providing training, there is an increasing drive towards continuing evaluation of competence and recertification of health professionals to maintain public confidence and increase patient safety. Medical competence covers a wide range of skills including: knowledge, clinical ability, decision making, communication and professionalism, for which there are a wide range of assessment methods combining objective and subjective elements (Accreditation Council for Graduate Medical Education (ACGME) 2000). Simulators can provide objective measurements and therefore, have a potential role in assessment. They have been used for many years in the aircraft industry to determine if pilots are ready to move from the training environment to the real plane. In medicine, simulators could be used to ensure that a trainee has acquired the necessary skill level to move into the operating theatre and that experienced surgeons maintain the level of competence required to continue to practice (Michell 2002). In surgery, dexterity and psychomotor skills are particularly important, and simulator designers have looked at developing devices that assess these skills in addition to providing training (Moorthy *et al.* 2003b). The MIST-VR simulator has been shown to be effective for assessment of psychomotor skills (Taffinder *et al.* 1998). Experienced surgeons were significantly faster and more efficient than trainee surgeons when performing skills that are used during laparoscopy. Using the da Vinci robot, the speed and direction of movements made by surgeons have been analysed using flight path calculations (Verner *et al.* 2003). Experts, when compared with novices, were faster and demonstrated superior movement patterns. This sort of work also helps to identify metrics of performance and establish benchmarks, which would then form the basis for assessment of competence to practice. A simple motion tracking device developed by Imperial College has been used in surgical skill assessment (Datta *et al.* 2001). When surgeons of different levels of experience performed a small bowel anastomosis, the dexterity (measured as the number of movements and time to complete) correlated with experience. Therefore, motion tracking, which could be included in virtual simulations, would be one way of assessing performance. Crossan (2004) investigated the potential of the Horse Ovary

Palpation Simulator (HOPS) as an assessment tool. Examinations were performed in the simulated environment by a veterinary surgeon who was instructed to represent a range of quality (experience, skill) including, for example, ones considered to be thorough or random. Recordings of the examinations, which included the path and a colour representation of the force applied, were then evaluated by ten experienced clinicians. The examinations were rated with regard to the search strategy, completeness of the examination and the forces used when palpating the ovaries and follicles. The experts watched each graphical playback and were able to evaluate the quality according to the stated criteria accurately. This indicates that the simulator could be used to assess performance and determine competence. As well as making use of a recording of an expert's examination, the trainee's path can be recorded and played back for subsequent analysis, which could be used to target areas in a student's technique that need improvement. Feedback on performance is an important component of the student's learning process and the detailed and retrospective analysis provided by the simulator would be a useful aspect of any teaching tool. Such a level of feedback is not necessarily available using other teaching methods including physical models or during real examinations, particularly for internal procedures.

Virtual environments can also be used to investigate certain aspects of a user's perceptual abilities. Various studies have looked at a subject's performance when using the sense of touch to determine object properties including: size, firmness, shape and texture. This work provides information that leads to a better understanding of human computer interaction in virtual environments that include haptic feedback and is helpful when designing simulations. This is particularly important where the sense of touch plays a major role in the interaction, including interfaces for visually impaired users and simulations for certain medical and veterinary procedures. If the measurements of perceptual ability in the virtual environment are similar to studies using real world objects, this supports the quality of the representations in the virtual environment. A study by O'Malley and Goldfarb (2002) found that subjects had comparable performances when assessing the size of both real and virtual objects for a range of values. Other studies in virtual environments have demonstrated that the assessment of one of an object's properties is affected by changes in one or more of the other properties. Detecting differences in height was affected by the stiffness of the surface, the firmer the surface the smaller the detectable difference (Walker and Tan 2004). Also subjects' abilities to judge the size of the curvature of a cylinder was affected by surface friction (Christou and Wing 2001), with the estimate of the curvature increasing as the surface friction decreased. However, Jansson and Pieraccioli (2004) found that the perception of a sphere's diameter was affected by surface texture but not by firmness or friction. Others have looked at perceptual abilities for compliance (firmness or softness) and smaller differences were detectable when using an instrument (DeGersem 2005) than a finger (Dhruv and Tendick 2000; Howell *et al.* 2006).

When designing procedure-specific virtual environments, including medical simulations, an understanding of both the task and human perception will contribute to the development of realistic training environments. For example, most anatomical structures have smooth surfaces and therefore, variations in surface texture would be minimal and may only have a minor role in haptic identification. However, changes in object dimensions (height, width, and diameter) and firmness would be important to the clinician when attempting to recognise the structure or diagnose an abnormality. Measurements of human perceptual abilities help when determining what level of fidelity may be required when designing virtual representations of objects. Investigations have found that quite small differences in virtual objects are perceptible, for example in the study by Walker and Tan (2004) a height difference between flat surfaces of as little as 0.17mm could be detected under certain circumstances. An example of an application of such findings was the use of the results of compliance evaluations to inform the subsequent design of robots for teleoperative surgery (Dhruv and Tendick 2000; DeGersem *et al.* 2005). Overall, the aim would be to match the virtual representation or computer generated haptic feedback to the level of human perceptual abilities, to provide a realistic environment and interaction, while not pursuing a level of fidelity that might be unnecessary.

2.9 Simulator Validation

All new teaching methods and technologies, including simulators, should be validated by demonstrating that they deliver effective training. This should be undertaken before any simulator is recommended for widespread use and is particularly important for those used in the fields of human and veterinary medicine. Part of the justification for development of simulators has been to reduce the risks to patients that occur either as a result of inadequately skilled operators performing a procedure or when real patients are used for training novices. In addition, there are ethical issues associated with training on live patients, human or animal, and there is growing concern from the public, teachers and students. There are increasing moves to utilise new technologies to provide alternatives and such changes are actively promoted by animal welfare organisations (AVAR 2003; InterNICHE 2005). There have been great advances in the field of medical simulators in recent years to address these issues but there is also recognition that validation is an important part of the development process (Magee 2003). Part of the acceptance of virtual reality training tools depends on the creation of realistic simulations and while practising a procedure the user should feel immersed in the environment in a similar way to during the real task. Additionally, there is a need to demonstrate that the learning outcomes are both desirable and verifiable (Scalese and Issenberg 2005). Greenfield *et al* (1994) consider that new training tools are acceptable as an alternative or complement to traditional teaching methods if students achieve at least the same level of proficiency. In the case of simulators, the student, clinician or health professional should have been equipped with skills that are useful subsequently for the real task. However, without validation the effects cannot be guaranteed, as the trainees could just be learning to use the simulator and not developing transferable skills. If the simulator does not provide the skills, at the least the operator is still untrained and at worst, the skills may be inappropriate and the patient may be at greater risk.

As noted above, validation should be an integral part of the process of developing a new simulator. The assessment should be based on an accepted method, thereby providing a standardisation with the ultimate aim of developing a means of certification for products. Higgins *et al.* (1997) have defined a series of stages that can be used during the design phase of a project. First, the simulator needs to model the procedure and to identify the component steps a task analysis can be used. Experts are asked to describe the motor skills used, how these are performed and the cognitive skills, why they make particular decisions and on the basis of what information (Schraagen *et al.* 2000). This approach has been used in medicine (Grunwald *et al.* 2004), dentistry (Clark *et al.* 2000) and other industries, including engineering (Clark and Estes 1996). The next stage is to assess the user's needs and information is gathered from experts during interviews or by observation while an expert is teaching or performing the task. Then, the established requirements need to be integrated into the simulated environment in a way that presents the trainee and teacher with a usable interface, free from distractions and providing immersion in the task. The involvement of experts within the design phase is important for the development of a successful training tool and also provides credibility within the peer group, who are likely to be the potential customers. The other stakeholders, the trainees, should also be involved to ensure that both their perspective on learning the task and their needs are supported in the design.

The simulator is developed with feedback from experts and learners as part of an iterative design process, and then evaluated. A set of criteria have been identified by Neufeld and Norman (Table 2.1) as a systematic way of assessing simulators used in medicine (Neufeld and Norman 1985). These have been discussed and defined in relation to virtual reality simulators used as teaching or assessment tools for surgical skills (Berg *et al.* 2001). When validating a simulator, the first step involves assessing the 'face validity' or credibility of the simulated environment, which needs to be realistic to be believable. This is particularly important if experts are to support the design and if, as in the case of palpation procedures, trainees are to develop skills that subsequently lead to recognition of the same structures in the real patient or animal. Then the simulator must be shown to include the component steps of the task being represented (content validity) and to perform in a reliable way in different situations, with a range of users and in different environments (reliability). Simulators are also used to provide objective assessment of skill in which case, validation involves establishing the credibility of the device as a measuring tool. This includes demonstrating that when different operators use the simulator their existing skill levels can be differentiated, experts performing better than novices (construct validity). Measurements should correspond to those made during the real task or using other established assessment methods (concurrent validity). Skills developed or measured on the simulator should predict subsequent performance; those who perform particularly well with the simulator should turn out to be more skilled at the real task (predictive validity). There are practical issues to address as well including demonstrating that simulator use would be feasible under real world conditions. Factors to consider include the resources required with regard to cost, accessibility for the trainees and provision of technical support (Cosman *et al.* 2002). Additionally, there is a need to demonstrate a shortening of the learning curve when compared with cheaper alternatives. All these factors contribute to the justification for the inclusion of a simulator in a medical or veterinary curriculum. Ultimately, the validity of such a teaching tool depends on the demonstration of skill transfer from the virtual environment to the real task and long term benefits for patients. This is stressed by Berg *et al.* (2001) who ask researchers working in the field of virtual reality medical simulators the key question: "Does proficiency in the simulator correlate with proficiency in reality?"

Evaluation category	Criteria specific to simulator-based training tools
Face Validity	How realistic are the simulations, how believable, credible?
Reliability	Does the simulator produce consistent results under different conditions?
Content Validity	How much of the task being modelled has been represented?
Concurrent Validity	Do measurements concur with those made using other methods?
Predictive Validity	Does the measurement of skill predict future performance?
Construct Validity	Do experts perform better in the simulated environment than novices?
Feasibility	Would using the simulator be practical? What resources are required?

Table 2.1. A list of the categories for the evaluation of educational tools used in medicine (after Neufeld and Norman, 1985). Each category has a short explanation of the criteria that would apply to simulator-based training tools.

There have been a number of attempts to validate both surgical and palpation-based simulators used in human medical training with variable levels of success both with regard to demonstrating any particular category of validity and the number of categories investigated. Experts are ideally positioned to determine the degree of the realism, or face validity, of virtual reality simulations and Gorman *et al.* (2000) used this approach to assess a suturing simulator. Eight surgeons performed tasks using the simulator and identified areas requiring improvement. These included a reduction in lag time, better 3D visualisation, increased realism in tissue properties and placing the tasks in surgical context. A bronchoscopy simulator, the AccuTouch Flexible Bronchoscopy Simulator (Immersion Corporation 2005), was assessed by Ost *et al.* (2001). They compared the performance across experience levels with nine experts, eight intermediates and eleven novices. During the experiment each individual had to carry out two tasks and the performance was recorded using the simulator. The skill level could be distinguished, which provides evidence of construct validity and a set of performance measures were defined including time to complete the task and wall collisions, which are undesirable and reduce as skill increases. The second part of the study compared the training effects of the simulator with a conventional method where the trainee observed and then assisted with bronchoscopy at a hospital. There were three novices in each group. The simulator trained group demonstrated improving performance over twenty training sessions and then performed better during the first actual bronchoscopies. These results indicate that the technology has potential for training and to provide an objective measure of skills, although as there were the small numbers in second part of the study further validation would be advisable. Similarly construct validity has been established for an upper gastro-intestinal tract simulator (Moorthy *et al.* 2003a) using a video-endoscopic method to assess performance and the skill scores in the simulator environment correlated with the three different levels of experience.

Kothari *et al.* (2002) compared performance using MIST-VR (Mentice 2004), a virtual reality simulator that promotes psychomotor skill development for instrument handling with a physical model skills trainer. The two groups were trained to tie a knot (for a laparoscopic procedure) and the change in performance as a result of the two training methods was equivalent, both improving. The MIST-VR system had the advantage of a playback, which would allow the trainee to review performance and the instructor to provide assessment and feedback. The MIST-VR simulator has been adopted in many training systems as it provides core skills applicable to minimal invasive techniques used in a range of disciplines including arthroscopy, laparoscopy and cardiovascular procedures. The construct validity of MIST-VR for laparoscopy has been demonstrated by differentiating between experience levels (Taffinder *et al.* 1998) and Gallagher *et al.* (1999) showed training benefits for a particular component of a task, the 'fulcrum effect', which represents the instrument interaction with the body wall at the point of entry, the key hole. However, another study that compared a range of training simulators, including several physical and one virtual, MIST-VR, (Paisley *et al.* 2001), found no difference across the experience levels for any of the variables tested on the MIST-VR system (construct validity was not established). Additionally, simulator performance did not correlate with experts' assessment of skill, based on competence undertaking the task, for any of the simulations, including MIST-VR, which means the concurrent validity, is not supported. Training over a period of time showed that participants became faster while performing on the simulator but they did not demonstrate improvements for other metrics defined for the task, which included: deviation for suture placement, force for knot tying and errors in technique. This study indicates that there is a need to consider carefully all aspects of validation and to define metrics that provide appropriate measures of skill during the real task.

The next stage is to demonstrate that the skills learned on a simulator transfer to a real task and with regard to MIST-VR, Ahlberg *et al.* (2002) posed the question 'Does training in a virtual reality simulator improve surgical performance?' They found no difference between two groups of medical students, one group having received training with the simulator, when performing an operation on a pig, with no demonstrable benefit of simulator training. The test used an animal, which highlights two important points; first there are ethical concerns when learning or testing skill development on real patients although animals may not represent a practical alternative for the same reasons and their use in medical procedure training is illegal in the United Kingdom. Additionally, the anatomy and physiology are different and surgical procedures cannot be represented exactly except for basic skills, including for example suturing or knot tying. However, there have been two studies using MIST-VR, alone or in combination with another simulator that demonstrated skill transfer for a specific procedure performed subsequently on human patients. In both cases, the evaluations were carried out with residents rather than medical students. Seymour *et al.* (2002) found that surgical residents undertaking training for diathermy using MIST-VR showed improved performance when dissecting the gallbladder (cholecystectomy) in the operating room, committing fewer errors than residents trained in a traditional way. Additionally, surgical residents undertaking a training course that included practice with MIST-VR and a laparoscopic simulator, LapChol (from Xitact), demonstrated a higher level of surgical skill compared with a control group when performing cholecystectomy (Schijven *et al.* 2005). In Schijven *et al.*'s study (Schijven *et al.* 2005), both groups were assessed for various criteria including 'fluency' and 'carefulness' using video footage of the operations reviewed by two experts, blinded to the residents training background. The Immersion product CathSim has received favourable customer feedback and provides an interactive visual, audio and haptic interface for training a specific task, intravenous catheter placement. CathSim is under trial at the Royal Veterinary College although preliminary feedback did not indicate how effective the simulator is as a training tool for the procedure in animals (Clarke *et al.* 2003). In a study by Prystowsky *et al.* (Prystowsky *et al.* 1999), who compared needle insertion by two groups of medical students, 1st and 3rd years, and a group of residents (into fellow trial participants) before and after training with an intravenous catheter placement VR simulator, there was no difference in performance, the simulator had not been effective as an instructional tool. Also the simulator failed to discriminate between the skill levels of the different groups and all groups showed similar success rates when performing simulator-based tasks. Therefore, these findings demonstrate that simulator training had not resulted in beneficial skill development and construct validity was not established. The authors concluded that on the basis of these findings, although students were enthusiastic to use the simulator, the results did not, at this point, support the widespread use of such VR simulations in surgical training.

The majority of simulators for human medicine have been developed in the areas of minimally invasive surgery and procedures. There are a limited number of palpation simulators and these present extra challenges to developers because the clinician interacts with organs and tissue manually, rather than indirectly through an instrument. Therefore, the representation needs to be of even greater fidelity and the credibility will depend on the creation of an environment that has a realistic feel when palpated. Langrana *et al.* (1997) presented a comparison for liver tumour palpation between two groups of non-medical participants, one palpating two physical spheres of different hardness set in a background representative of the liver and the other group using the VR liver tumour palpation simulator, developed with a Rutgers Master force feedback haptic device. The authors claim to have created a realistic training environment although the face validity, which usually depends on assessment by experts, is not detailed. However, both the groups of participants were very accurate at locating and differentiating between tumours of different firmness, with those using the VR simulator being more able to detect softness. The prostate tumour simulator developed by Burdea *et al.* (1999) was evaluated by comparing the performance of two groups, non-medical students and urology residents, when diagnosing abnormalities on the virtual version of the prostate. After a training session on the simulator, both groups were presented with twelve randomised cases and the non-medical students had a higher correct diagnosis rate. One explanation for the poorer performance of the urology residents could be that the simulations were not realistic enough. The means of achieving face validity is not described. The models were created based on input from one expert only and the urology residents comments indicated that the level of realism needed to be improved. The diagnosis rate of a third group, acting as the control, consisting of urology residents who were set a similar task when palpating physical models, was higher than both simulator groups, again suggesting the simulator lacked realism. The rectal and prostate simulation developed by Kuroda *et al.* (2005) was evaluated by fifteen medical students who could differentiate accurately between the two prostate models, soft and hard. Additionally, in a subjective evaluation, urologists commented that the simulator provided a realistic sensation of pressing against the prostate through the rectal wall but, rather than just varying firmness to represent cancerous change, the model would be more accurate if representations of the typical nodular lesions were included.

The Virtual Haptic Back simulation underwent a preliminary evaluation where participants were to identify abnormally stiff and abnormally rotated vertebrae (Williams *et al.* 2004). One group of thirty-six osteopathic medical students used the simulator four times at approximately three month intervals and another group of three performed six trials in one week. In both cases there was some evidence of a learning effect, between sessions one and two, for the high stiffness category, with a reduction in incorrect answers but no effect of training was found for either the lower stiffness values or rotation. A further study found an increase in skill after eight training sessions over a two week period when students were asked to try to detect areas on the virtual back that felt different (with regard to compliance or firmness) (Howell *et al.* 2006). Twenty-one students took part and their accuracy significantly improved over the training period. They were also quicker, although these results did not reach significance. The student feedback about the training tool was positive and most students considered that further practice with the simulator would be useful. The subsequent transfer of skills to the real task has not yet been demonstrated. The authors comment that assessing subsequent performance on real patients would be difficult to measure but work has been undertaken to investigate whether the simulator can discriminate between skill levels (construct validity). The performance of students, who had already received training in palpatory techniques, was compared with non-medical students (Howell *et al.* 2005). Two trials were conducted, one with the participants using a single point of contact (one PHANToM) and another using two PHANToMs. There was no difference in performance of the two groups in either trial, which was attributed either to a lack of realism of the simulator or to the test being too easy and therefore, not sensitive enough to discriminate skill levels (construct validity). However, subjective feedback from participants indicated that the two-point interaction was more realistic and easier to use. Further work is underway to increase the realism, to modify the tasks to correspond better to the skills needed and to evaluate the playback mode as an instructional tool.

Another palpation simulator, which uses the robotic arm HIRO for trainees to learn to detect cancerous lumps in the breast, has been subject to a limited evaluation (Alhalabi *et al.* 2005). The researchers compared the speed and accuracy of two individuals detecting virtual tumours, one participant was used to using the device while the other was new to the device. The limited trial found the two individuals had similar performance, which may again just indicate that the test was too easy but further evaluation with more participants should be undertaken.

There are fewer simulators, either physical or virtual, designed specifically for veterinary education. The validation studies that have been undertaken in many instances have compared a traditional teaching method with the simulator-based alternative. As already stated, the realistic appearance and feel of models is important and the abdominal organ models developed by Greenfield *et al.* (1993) when assessed by small animal surgeons were well rated with regard to feel and handling properties. A further study (Greenfield *et al.* 1995) compared two groups of students, one group trained on the models and the other operated on anaesthetised dogs that were later euthanased (the practice of terminal surgeries). Experts assessed students' performance for a range of abdominal surgical procedures while reviewing video footage and there was no difference between the two groups. Therefore, as the models were as effective a teaching method as the dogs, they could be considered as an alternative to using real animals. Also work by Olsen *et al.* (1996) showed that their haemostasis model was as effective as performing a splenectomy on a live animal for teaching the basic skills involved in blood vessel ligation. Another haemostasis model was found to equip students with better psychomotor skills than learning the technique from a video (Smeak *et al.* 1991). An ovariohysterectomy model was shown to be better than cadavers as a training environment for students to develop psychomotor and basic surgical skills (Griffon *et al.* 2000). Students trained on the model scored higher when assessed on their psychomotor skills, being quicker and making fewer errors. Also when subsequently performing spays, they received a higher rating from the supervising surgeon than those who had practiced on the cadavers. Johnson and Farmer (Johnson and Farmer 1989) found that inanimate models were superior to live animals as way for instructors to demonstrate basic tasks and for students to develop psychomotor skills. Whereas others (Smeak *et al.* 1994) found students whose training had been supplemented with practice using a hollow organ simulator were no better at performing a gastrotomy than those who had traditional training only. Certain deficiencies were identified in the plastic models with the material being stiffer and more friable than real tissue and suture pull-through occurred even when student technique was not at fault. Changes to the simulator material were planned to address the deficiencies in the handling properties of the model. The human mannequin used to train veterinary students in anaesthetic techniques was found to be effective, with students achieving higher clerkship scores during the subsequent anaesthesia rotation than a control group who prepared using self-study (Modell *et al.* 2002). A study conducted by Price *et al.* (2003) found that the equine colic simulator developed in Vienna (Von Künzel and Dier 1993) was an effective alternative to live horses as there was no difference between two groups, one simulator trained and the other live horse trained, when their performance was assessed subsequently on the simulator. However, students considered that live animals were still an important part of the training, indicating that simulators represent a supplement to, rather than a replacement for, traditional methods. The bovine cadaver used to teach rectal palpation and abdominal surgery (Van Camp *et al.* 1988) was reported to have beneficial effects on students' abilities to palpate the reproductive tract and allowed them to make better use of real animals, however the criteria used to draw these conclusions are not described.

The virtual reality based simulation created by Crossan (Crossan *et al.* 2000; Crossan 2004), the Horse Ovary Palpation Simulator (HOPS), was subject to a series of validations. An attempt was made to establish construct validity where experts, used to performing the tasks in the real animal, would be expected to outperform novices. Two groups, one of seven veterinary surgeons and one of ten veterinary students in the second year of the course were to identify the position and size of follicles on the ovaries (Crossan *et al.* 2001). Both groups received training on the standard blocks demonstration supplied with the PHANToM, becoming familiar with a virtual environment and then practiced palpating two spheres, having to discriminate size and softness correctly before starting the experiment. When the performance of the two groups in the simulated environment was compared, no significant differences were found for any of the tasks, positioning and sizing follicles or the time to complete the task, the novices performed as well as the experts. These results may relate to the different technique used by experts when performing the procedure in the real horse. The veterinary surgeon uses the hand, with several digits being used to grasp and manipulate the ovary. Another digit explores the surface and this is the only part of the examination represented by the single point of contact provided in the HOPS environment. Additionally, part of the examination involves locating the ovaries within the horse while making reference to other landmarks, none of which were represented in the virtual environment. Therefore, as the virtual environment presents the user with a less realistic way of performing the examination than in the real animal and as only part of the task was represented this may explain the failure of the simulator to discriminate between the different levels of skill and suggests that the simulation lacks face validity or credibility. The experts may have been distracted by the differences between the simulation and the real task and therefore, they may not have been totally immersed in the virtual environment and the task. However, as the novices were able to perform the experimental task, a component of the real examination, as well as the experts the simulator may have benefits as a training tool.

Another experiment was conducted to evaluate the effect of regular training sessions (Crossan *et al.* 2002). Eight veterinary students were presented with eight different ovary simulations weekly for four sessions with a final session conducted a month later. There were significant improvements in the trainees' abilities to size and position follicles correctly and a decrease in the time taken to complete the task over the four sessions, with no decrease in performance after the one month break. The students' performance after multi-session HOPS training indicated that the ability to recognise ovarian structures in a virtual environment had improved, demonstrating a learning effect. The skills acquired did not diminish after a short break, which would be an important factor if simulator training were to be included in the curriculum when practicalities would dictate that, for some students, a gap between a simulator session and real horse examinations would be likely.

The learning effect already demonstrated may only apply to performing the simulated task in the computer generated virtual environment. Therefore, an experiment was conducted to assess how closely the improvements translated from simulator training to a bench task: palpating post mortem specimens (Crossan *et al.* 2003). The performance of two groups of students was compared; one group had undergone the multi-session training with the simulator and the other received traditional training in the anatomy laboratory. The students were set the task of locating and sizing follicles while palpating tracts on trays, which were obscured from sight by a screen. There were no significant differences in the performance of the two groups, simulator trained students performing as well as traditionally trained students. The experiment used bovine material because of the limited availability of equine tracts. There are considerable anatomical differences particularly with regard to follicle size; all normal bovine follicles are smaller than the simulated models, which may have handicapped the simulator trained students. Greenfield *et al.* (1994) consider that new training tools are acceptable if at least the same level of proficiency is achieved as with traditional methods and therefore, these results indicate that the simulator could be considered as an effective alternative to the traditional method used in this comparison.

The bovine simulator developed by Baillie (Baillie 2003) was assessed for face validity by nine experts and certain structures were considered to be sufficiently realistic although others needed improvement. A limited evaluation of the simulator as a teaching tool was also conducted (Baillie *et al.* 2003). Fourteen veterinary students, all with some prior experience performing bovine rectal palpation, undertook a training session with the simulator. The students then examined cows during extramural studies and completed questionnaires to assess the effect of simulator training on their subsequent performance. Ten of the students reported a great improvement and four a slight improvement, none reported that their performance had deteriorated as a result of the training. All students considered that training prior to the first real cow examination (i.e. for complete novices) would definitely be beneficial.

When developing a simulator for an internal palpation-based procedure, which is unsighted, the creation of realistic models is particularly important. After using the simulator, trainees should be able to recognise the same structures when subsequently examining a real patient or animal. With both of the veterinary virtual reality palpation simulators, the potential to create virtual animal models has been demonstrated although improvements are needed with regard to the level of realism and the range of simulations presented. The bovine teaching tool requires further work to increase the quality of the models and to provide scenarios that support the learning needs of novice students specifically. The equine version would also need additional models if the simulator was to be used to teach a complete fertility examination, with the ovaries positioned relative to the pelvic and abdominal landmarks. Ideally, the simulator would provide more than one point of interaction, using two or more PHANToMs or a glove-based device, as this would better support the normal range of movements and manipulations used during equine and bovine fertility examinations.

There is a risk that a simulator could be providing skills that are only useful for performing the task in the simulated environment and these may not be relevant for, or transferable to, the real task. Therefore, the effect of simulator training should be tested on the real task, rather than for example, using the simulated environment as the test environment (Burdea *et al.* 1999; Howell *et al.* 2006) or using a bench test, with post mortem specimens (Crossan *et al.* 2001) or a physical model (Price *et al.* 2003). For the veterinary haptic simulators, there is still a need to do further evaluations to demonstrate that the skills learned during training result in improved performance for rectal examination of the live animal. The ovary simulations were tested by assessing performance on the simulator or when palpating post mortem tracts, which may not be representative of the real task. The evaluation of the bovine teaching tool, although conducted during examinations of real cows, depended on students assessing their own performance, which may not be reliable. Therefore, before these tools could be recommended as compliments to existing teaching methods, work should be undertaken to measure skill transfer to the real task, rectal palpation of the horse and cow, with independent verification of performance.

2.10 Conclusions

In conclusion, when developing VR simulators for teaching medical or veterinary palpation-based techniques including haptic feedback is important and increasingly feasible with advances in computer technology. However, all new teaching tools, developed in virtual reality or using other methods, should be validated before being recommended for widespread use. Although a large number of VR simulators have been developed for medical training, particularly in the fields of minimally invasive procedures and surgery, very few have been validated thoroughly. When conducting validation, there will be benefits in following a structured approach. Ideally, a simulator should demonstrate validity for each of the criteria identified by Neufeld and Norman (1985) that are relevant to the simulator's application for example, teaching or assessment. The creation of a realistic experience for the user, face validity, is one of the primary steps and is particularly pertinent for palpation-based procedures, where the fingers are in direct contact with the patient. This has proved difficult and has undermined some attempts to demonstrate other aspects of validity for palpation-based procedure simulators and therefore, continues to present a challenge to developers in this field. Once a realistic environment has been created with simulations that support performance of the task, then training needs to be shown to have benefits with the development of skills that transfer to the real task. This stage in the validation process involves demonstrating at least equivalent or preferably improved performance when compared with traditional training methods. The next step, provided that the simulator has been validated thus far, should be to demonstrate that the simulator can be used in a real world situation. This will involve addressing any practical issues associated with using the new technology under the constraints of a curriculum.

The importance of validation for simulators used in medicine and, more recently, in veterinary training has been stressed repeatedly (Berg *et al.* 2001; Magee 2003; Issenberg *et al.* 2005; Scalese and Issenberg 2005), with a structured approach being encouraged. The work presented in the following chapters will address the challenges of developing, validating and using a VR simulator for teaching veterinary students to perform bovine rectal palpation, with particular emphasis on supporting the learning needs of novices.

Chapter 3: Simulator Design

3.1 Background and Motivation

The aim was to design a simulator-based teaching tool specifically to train novice veterinary students to perform bovine rectal palpation, which is used by veterinary surgeons to diagnose pregnancy and fertility related problems. The simulator developed previously by Baillie (Baillie 2003) allowed a teacher to train students in a range of skills but the needs of novices were not elicited or supported specifically. As part of the project, a group of eighteen veterinary students took part in an evaluation of the simulator as a teaching tool. The students considered that the training had beneficial effects on their subsequent performance examining cows. They also indicated that the simulator's primary role should be to teach novice students, providing training in preparation for the first few examinations of cows. The simulator included a range of virtual anatomical models some of which veterinary surgeons rated as a reasonable enough likeness, indicating that haptic technology could be used to create realistic virtual representations of the bovine reproductive tract. However, there were areas that needed improvement and the information gathered provided the basis for further developments.

During and shortly after the Master's project by Baillie (Baillie 2003), the simulator was used to train fourth and final year students. As well as giving feedback on the training, students were asked to answer questions about their experiences prior to the simulator session. Twenty-six students provided information (18 during the Master's project (Baillie 2003) and 8 shortly afterwards) and this showed that experience levels, based on the number of cows examined, were quite variable, ranging from one to over fifty. The students were also asked to estimate how often they had found certain anatomical structures in these cows. The responses indicated that most students were able to find the pelvic landmarks but many were having difficulty finding the uterus and the ovaries. The graph in Figure 3.1 shows the number of students reporting finding the uterus in *less than one in three* of the cows examined across the experience levels. Finding the uterus is a basic skill and until mastered, students will not be able to progress on to learning to perform a thorough fertility examination, diagnose pregnancy or use an ultrasound scanner.

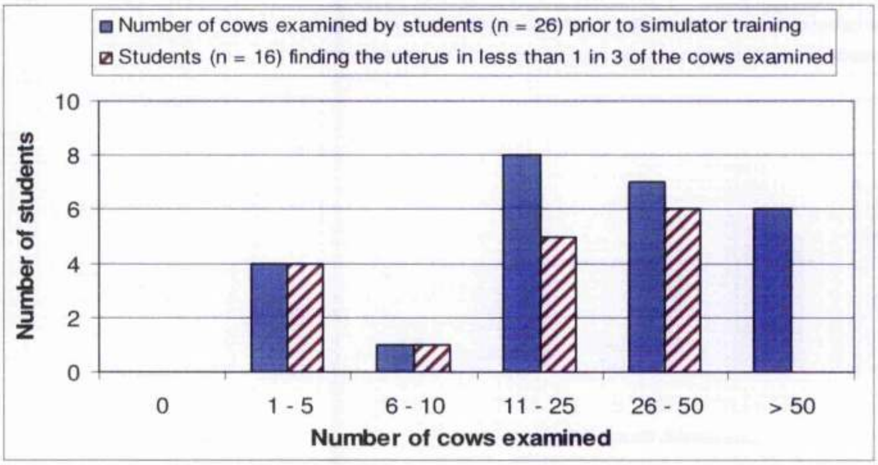

Figure 3.1. Student experience (based on number of cows examined) prior to simulator training (solid blue bars) combined with those indicating they had found the uterus in *less than 1 in 3* of the cows examined (hashed crimson bars).

The poor performance the students reported suggests that traditional training is not very effective and that students will need to examine a large number of cows to develop skills adequately. However, the number of cows available for undergraduate training is increasingly limited (Penny 2002) due to the large number of students per year and the welfare guidelines restricting the number of examinations allowed per cow (Parkins and Harvey 2001). The students taught with the simulator had all volunteered and therefore, may have represented those having particular problems. However, a previous survey had indicated that veterinary surgeons do consider that the procedure is difficult to learn (Baillie *et al.* 2003) and the students were reporting considerable problems finding some of the key anatomical structures. Therefore, there is a need to investigate ways of supplementing existing teaching methods, particularly for novices, and to ensure the training equips students with the basic skills: finding pelvic landmarks, the cervix and the uterus. Additionally, as bovine rectal palpation is an invasive procedure, providing effective training prior to examining the first live animals would be likely to have benefits for animal welfare.

A simulator represents a possible solution. The project by Baillie (Baillie 2003) demonstrated that a teaching tool developed using haptic technology has potential to provide training for bovine rectal palpation. However, the simulations were limited and the level of realism needed to be improved. Additionally, the student feedback indicated that the simulator's primary role should be as a teaching tool for novices. Therefore, this thesis will initially attempt to address the issues raised by Baillie (Baillie 2003) with the aim of developing a simulator to equip veterinary students with the palpation skills required to perform the first few rectal examinations of cows.

In this chapter, work is presented that aimed to address the specific issues relating to the design of a teaching tool for novices. A requirements capture was conducted with veterinary surgeons from practice and university and with veterinary students (Section 3.2). The aim was to identify the learning needs of novices and then, using the information gathered, to design a teaching protocol to be used with the simulator (Section 3.3). A teaching tool was then developed that included a range of anatomical models to support the novice's learning process (Section 3.4).

An important part of the development process of any new teaching method or technology is validation, which should be undertaken before considering widespread use. Therefore, the current thesis will focus on validation and research will be undertaken to address the key criteria identified by Neufeld and Norman (1985) for a simulator used as a teaching tool. The first part of the validation process for simulator-based teaching tools is to demonstrate that the virtual environment is realistic enough: face validity. The next step is to establish that the task being modelled is represented in the teaching environment: content validity. As part of the development process, veterinary surgeons assessed the quality of the virtual models and discussed the format of the teaching protocol (Section 3.5). Once a sound design has been established, the next key step in validation is to demonstrate that teaching with the simulator equips trainees with useful skills. In Chapter 4 an experiment is described that involved teaching students with the simulator and then determining whether skills developed during training transferred to the real task.

3.2 Requirements Capture

3.2.1 Introduction

Students training at the University of Glasgow Veterinary School perform the first bovine rectal palpation during farm animal clinical EMS placements undertaken from third year onwards. The preparation provided in the curriculum includes bovine anatomy lectures and practical sessions and students also have access to computer aided learning material (e.g. Bovine Pregnancy (Holmes and Summerlee 1995)) and standard text books (Fertility and Obstetrics in Cattle (Noakes 1997); Veterinary Reproduction and Obstetrics (Noakes *et al.* 2001)) in the library. The anatomical structures and diagnostic characteristics of pregnancy and fertility related conditions are described and illustrated. However, these resources do not include information by which a student could deduce exactly how to perform the palpation-based procedures and, as indicated in Figure 3.1 above, students reported having difficulty finding the uterus when examining cows. Clinical skills, which include bovine rectal palpation, are best learned by gaining practical experience of the real task (Bernado 2003), and this does not take place in the pre-clinical curriculum at Glasgow. The majority of teaching takes place during EMS but in the current economic climate, opportunities to practice may be limited due to time and financial constraints placed on farmers and veterinary surgeons. Additionally, the teacher is unable to see the student's technique inside the cow, which makes providing useful guidance, particularly to novices, difficult.

The resources available currently have had limited success in providing students with the required skills and therefore, there is a need to develop a more effective teaching method. Bernado (2003) suggests that after 'doing the real thing', simulating the experience is the next most helpful way to learn a task. The haptic simulator provides a potential solution but prior to starting the design process investigations were undertaken to identify the problems that need to be overcome, to determine the skills required to perform bovine rectal palpation and to develop a teaching protocol to support the students' learning needs as complete novices.

A list of bovine palpation skills has been described by Sprecher *et al.* (1994) and this has been used by the authors as a way of measuring students' competence (Sprecher *et al* 1994). A series of skills are defined: the student progresses from being able to describe the position of the reproductive tract, to describing the cervix, the uterus, the ovaries and cyclical structures during an examination, and then to retracting and uncoiling the uterus. The assessment framework could be considered as equating to the steps required for learning the procedure and form the basis for a teaching protocol. However, the index did not include a description of exactly how each skill is performed or the criteria used by the student while making the identifications. Additionally, the index was based on one instructor's technique and the skills for pregnancy diagnosis were not included, although Sheldon and Noakes (2002) have recently reviewed available techniques.

The aim of the requirements capture undertaken in the current study was to gather detailed information from experts, veterinary surgeons, and relative novices, veterinary students. Using a series of steps is recommended to ensure that the simulator models the procedure and the component steps have been identified (Higgins *et al.* 1997). The participants were to describe the current approaches to teaching and learning with regard to the shortcomings and then discuss ways of improving the situation. The simulator would provide the new training environment and contain a range of virtual bovine anatomical models. The student would palpate the virtual reproductive tracts while the teacher, following the student's progress on the computer monitor, would be able to give instruction. In order to elicit a teaching protocol for the simulator, veterinary surgeons and students described the procedures of bovine rectal palpation with specific reference to preparing novices for the first examination of a cow. The details of the technique were determined by conducting a task analysis with experts who were asked to describe in detail their actions and decision making process while examining cows. The information gathered formed the basis for the design of the simulator-based teaching tool. During the design process the researcher, an experienced bovine practitioner, reflected on the requirements on an ongoing basis. Three methods were used to elicit the requirements: interviews with four veterinary surgeons; a focus group with six veterinary students; and a task analysis with two veterinary surgeons.

3.2.2 Interviews with Veterinary Surgeons

A series of semi-structured interviews were conducted with four veterinary surgeons. The interviewer followed a list of pre-determined questions (Appendix 3.1) while allowing discussion, a format outlined by Coolican (1999). The list of questions enabled the interviewer to ensure that all the topics had been covered and that the interview remained within context. The discussions provided opportunities to exchange ideas and to enrich the information gathering. The participants were all farm animal veterinary surgeons experienced at performing the procedure of bovine rectal palpation and were involved in teaching students in practice or at university or both. All were familiar with the original version of the bovine rectal palpation simulator (Baillie 2003). Each interview began with a brief explanation of the purpose of the interview and stated that the contributions would remain anonymous. Each interview was recorded and later transcribed for analysis.

The interviews were analysed using the method described by Coolican (1999), which involves identifying facts in each interview and then classifying them according to one of a number of categories. The researcher, familiar with the subject area, created the categories. The analysis was performed by the researcher and an independent analyser who was not a veterinary surgeon. The two reviewers then discussed their classifications and resolved any discrepancies. The information gathered from the interviews has been detailed in Appendix 3.1. The categories are represented as the headings of the following subsections, with the facts summarised below.

Current Training

The interviewees described the training available to students at university in preparation for the first EMS placement in third year as well as the teaching of novice students on farm, with particular reference to the conditions encountered during EMS. All recognised that there are problems with the current training system with no easy alternatives and considered that, unless changes are made, producing graduates capable of performing the task will be increasingly difficult to achieve.

Training at University of Glasgow Veterinary School

The main pre-clinical teaching consists of anatomy and physiology lectures and practical sessions including access to *in vitro* tracts. Examining cows is not part of the pre-clinical curriculum and students do not perform bovine rectal palpation at the university until final year.

Training during Extramural Studies (EMS)

The veterinary surgeons would first discuss the procedure with students in the car as well as on the farm. This would allow the student to revise the anatomy, the veterinary surgeon to describe the techniques and to raise awareness of the potential to damage the cow. While on farms the student usually followed the veterinary surgeon and the interviewees tried to ensure students were allowed enough time and access to as many cows as possible. Using the information gained about the cow, either from an examination or from the history provided by the farmer, the veterinary surgeon tried to direct the student's actions. While examining cows, students were encouraged to think about what they 'see' with their hands and to describe their current position and the structures palpated.

Problems and Deficiencies

The veterinary surgeons recognised that bovine rectal palpation is difficult to teach and to learn. The students have not been prepared prior to the first EMS and do not know how to perform the procedure, to identify structures, to search and to describe their actions. Initially, some may be unsure about approaching the cow, how to start the examination, have forgotten the anatomy and lack confidence. With regard to teaching, the basic training was considered to be the university's responsibility although the interviewees felt that currently this obligation was not fulfilled. On farm, a major problem is that the veterinary surgeon is unable to see the student's hand movements inside the cow, which makes giving the correct instructions difficult. Ideally, the veterinary surgeon needs to take time to stand beside the student, particularly novices, but during EMS as veterinary surgeons are paid on time and have other work to complete this was not always possible. Therefore, the students may receive only limited guidance, have to watch rather than practice and learning opportunities are reduced. Farmers are also under time pressure with other work to attend to and some may be reluctant to let students examine their animals, further limiting the learning opportunities. There are also concerns for the cows' welfare as students may be rough, could cause damage and the number and duration of examinations allowed per cow has to be limited.

In summary, the current training at university provides inadequate preparation for performing bovine rectal palpation during EMS and the difficulties and pressures encountered during EMS may in some cases result in limited skill development. However, all students are still required to perform bovine rectal palpation to a level which supports the 'Day1' skills (RCVS 2001) and therefore, alternative approaches need to be sought. At university there are difficulties providing more training using conventional methods due to the large number of students and limited resources including access to cows, staff time and costs. Providing incentives for veterinary surgeons to spend more time teaching on farms may present a solution but could be costly and unless subject to some form of quality control the training received could still be variable. The simulator could provide a potential solution as a compliment to existing training at university with the aim of equipping students with basic skills prior to the first EMS placement.

Simulator Design

The computer-based virtual reality simulator was presented to the interviewees as a potential solution and the interviewer posed questions to elicit the design requirements for a teaching tool that would prepare novice students for the first opportunities to perform bovine rectal palpation.

Anatomical Models

The veterinary surgeons considered that a simulator had potential as a way of providing training particularly as hands on experience was an important part of learning palpation-based skills. They identified the following as key anatomical structures that should be included in the simulated environment: the pelvis with particular reference to the floor and brim; the cervix; the uterus including the characteristic 'dip' or 'groove' between the two joined parts of the uterine horns; a range of simulations representing some of the different positions and orientations of the uterus (in the pelvis or abdomen and stretched out or curled up); ovaries with a corpus luteum (CL) or follicle; pregnancies early and late; diagnostic features of late pregnancy (cotyledons, fremitus, part of the calf). This provides a checklist of models for inclusion during the design of the virtual environment.

Teaching Protocol for Novice Students

The steps used to perform the procedure were identified, with particular reference to novice students' skill development, and these would form the basis for the teaching protocol to be used with the simulator. First the student is trained to find the pelvic floor, going down and not too far in, and then sweep from side to side to find the cervix. The pelvic brim is a useful landmark and should be identified by moving forward along the pelvic floor towards the abdomen. The next step is to find the uterus, which should be the focus of teaching for novice students, and several techniques were described for different situations. The first approach involved locating the cervix on the pelvic floor and moving forward along the cervix to find the uterus. Alternatively, the hand is swept from side to side along the pelvic brim while feeling for structures extending into the abdomen. Finding the cervix would indicate the uterus was in the abdomen and could be located by following the cervix forward and down; finding nothing would indicate that the uterus had been missed in the pelvis and could be located by sweeping back over the pelvic floor. The uterus is recognised as two 'bumps', the conjoined horns, with a dip in the middle. The hand is advanced forward to the bifurcation and then round each horn to the tip. The next step is to find the ovaries, which three of the interviewees considered to be part of novice training, by advancing along one of the uterine horns and searching close to the tip. The difference in the feel of cyclical structures, including a corpus luteum and a follicle, should be appreciated. Pregnancy diagnosis was considered to be a skill that builds on the above techniques and should be taught with the simulator as students are likely to examine pregnant cows during the first EMS. In early pregnancy, diagnosis depends on appreciating the difference in size, tone and consistency (softness or fluid content) of the uterine horns. Later pregnancies include additional features and diagnosis depends on finding and recognising cotyledons, feeling fremitus and balloting (appreciating the rebound of structures when bouncing the hand up and down) on the uterus to feel part of the calf on the uterus.

While learning these steps the students should develop skills that enable them to orientate in three dimensions, build a 3D picture of the anatomical layout and develop a search strategy to find structures in a range of locations. The students need to develop the skills to recognise structures based on palpation alone, combining an understanding of the relative positions and an appreciation of the characteristic feel or haptic properties. The teacher should direct the students in the first instance while encouraging them to describe their actions, the structures identified and emphasising the need to stay in contact with objects. This should be followed by a phase when the students practice on their own, with guidance available rather than under test conditions, to increase confidence. Repetitions within one session and the opportunity for a further training immediately prior to examining cows would promote the retention of skills and represent the ideal situation. The students also need to be instructed in the approach to the first cow; how to insert the hand and deal with the challenges of the environment. Ideally this should be covered before the first examination to ensure all students are taught a safe and effective approach.

A simulator-based teaching tool was considered to have a number of benefits for students, with increased confidence and having received at least some training at university, cited repeatedly. This would be helpful during EMS because the student might then be allowed to examine more cows, would perform faster, learn more, and there would be less risk of untrained students causing damage. There were several concerns raised: there would be time constraints during the university curriculum in relation to integrating an additional teaching resource, and the simulated model would be different, in some respects, from a cow. Overall, simulator trained students were expected to make better use of the resources available during EMS.

3.2.3 Focus Group with Veterinary Students

A focus group was conducted with six final year veterinary students from the University of Glasgow Veterinary School to discuss their experiences and perceived needs for learning bovine rectal palpation. This was used as a supplement to the interviews as the expert and the novice are at different stages of the learning curve and may have a different perspective on the problems and task. The discussion followed the format described by Moore *et al.* (2002a) for identifying the learner's needs in veterinary medical education. A series of topic headings, based on the categories used to classify the facts in the experts' interviews, were used to provide direction for the discussion. The session has been summarised below and the information was used to establish areas of conformity with or omissions in the requirements as defined by the experts.

Experience Learning Bovine Rectal Palpation in the Current System

The students reported a range of skill levels and experiences. They considered that they had received no training prior to their first EMS placement and when first examining cows the students all reported having difficulty feeling anything and often felt lost. This was followed by a phase when they could feel structures but were often unsure as to the identity, even though they had learned bovine anatomy in lectures and practical laboratory sessions. The students then reported a range of rates of progress and this depended, in part, on the variation between EMS placements with regard to the opportunity for instruction and the time available per examination. Most of the veterinary surgeons who had supervised the students during EMS had expected that the basic technique would have been taught at university prior to the first EMS placement in third year. Students reported that veterinary surgeons' expectations of student performance as complete novices were realistic, especially if the veterinary surgeon was a recent graduate. However, after a few cows the expectations exceeded the student's rate of progress. Some students were worried that they would not have sufficient opportunities examining cows to develop skills adequately by graduation. Students considered that although most veterinary surgeons wanted to help, their contribution was often limited and self-teaching was therefore, a major component. Concern was expressed regarding the safety of the cows examined in the current system.

Anatomical Models

The students identified the anatomical structures that should be represented in the simulated environment and the criteria used during palpation for identification in the cow. For example, the cervix was described as a relatively easy landmark to find as it was always located on the floor of the pelvis in the midline and felt fairly firm. However, there was variation in shape (cylindrical, oval or flattened) and size between cows. Some described the cervix as a lump rather than a tubular structure. The uterus was considered to be the most important structure to identify but the size varied considerably in relation to the age, time post-calving and lumen content, all of which affect the feel. The conjoined part of the horns, felt as a double bump or groove, was used as the distinctive feature that uniquely identifies the uterus. The ovaries were described as relatively small (compared to other structures palpated), firm and oval or flattened in shape. Some students had not managed to find the ovaries, while those who had reported that the ovarian cyclical structures were difficult to distinguish and describe. The simulated environment should include a range of pregnancies, representing both early and more advanced stages. The students repeatedly mentioned the difficulties of recognising anatomical structures using only the sense of touch, which emphasises the need for good quality models in any simulator-based teaching environment.

Teaching Protocol for Novice Students

The students described the stages of bovine rectal palpation that they considered a novice would need to be taught in the simulated environment. The most important initial goal was to learn to find the uterus and then progress, in the same or subsequent training sessions, to palpate the ovaries and perform pregnancy diagnosis. Teaching should begin with the basic exploratory techniques required to orientate inside the cow and to find the cervix and pelvic landmarks. The next stage was to locate the uterus, the position of which varied between cows and therefore, students would need to learn search strategies to cover the variations. The students considered that finding the ovaries was difficult because they were small, mobile and in variable positions relative to other landmarks. They considered that including ovary palpation as part of the novice's training would be helpful and would allow students to make full use of cows examined during EMS. With regard to pregnancy diagnosis, some students had not been allowed to examine early pregnancies in case they caused damage and therefore, the students were keen for this to be incorporated into the simulator teaching. The students had been allowed to palpate more advanced pregnancies and had found identifying diagnostic features and following the veterinary surgeon's instructions comparatively easy. The students were aware that some veterinary surgeons used palpation of the chorioallantois, 'membrane slip', to determine pregnancy. The students expressed reluctance to perform the procedure, even if taught, because of the risk of causing embryonic death.

The input from a teacher during simulator-based training was considered to be very important and useful for a novice, who would be unsure how to proceed, and initially all hand movements should be directed. The student would need to be trained to develop a systematic search strategy to locate each anatomical structure and while palpating an object would need to be taught the distinguishing properties including shape, relative position and the feel of the tissue. After learning under the teacher's instruction, the student should have an opportunity to repeat each procedure as repetition would aid skill development. During this phase, the teacher should provide feedback on performance and further instruction, if required.

Summary and Comparison with the Veterinary Surgeons' Interviews

When compared with the experts' views, the students expressed similar concerns about the inadequacy of the present system at university and the training during EMS. The descriptions provided a similar list of anatomical structures and skills. The initial stage was to learn to locate the uterus, which involved mastering basic orientation and developing a search strategy, with the students placing more emphasis on the distinctive features used for identification. The students had found ovary palpation difficult and therefore, providing training in the simulator environment would be helpful, this had also been considered useful preparation for EMS by the veterinary surgeons. The simulator should be used to learn pregnancy diagnosis, although the students prioritised the early rather than the later stages based on their experiences during EMS. Both groups identified the need for the teacher to provide instruction initially and then for the student to reinforce the skills by repeating the procedure with guidance as required.

3.2.4 Cognitive Task Analysis with Veterinary Surgeons

The information gathered during the interviews and focus group provided an overview of the current training and the procedure. However, the details of exactly how bovine rectal palpation is performed were not elicited and are not currently available in the teaching material for students either in the literature or the curriculum. As novices will need to learn each step, the next stage in the requirements capture was to determine a detailed description of the procedure from bovine practitioners. Asking experts to describe what they do or how they do it is unreliable because they may fail to articulate some of the steps as certain parts of their knowledge will be tacit (Eraut 1993). Cognitive Task Analysis (CTA) has been recommended as a method by which a detailed description of a task can be established from an expert's knowledge (Schraagen *et al.* 2000). This has been used in industry to develop training protocols (Clark and Estes 1996) and in medical simulator design (Clark *et al.* 2000; Grunwald *et al.* 2004). The steps can be defined by observing the expert during the task but in the case of an internal procedure such as bovine rectal palpation this is not possible. Therefore, the veterinary experts were asked to describe each step verbally while examining cows and to mimic the action with the other hand if there was difficulty explaining a particular action or a description was ambiguous.

Two experts took part in the CTA and examined cows that represented each of the tasks identified as important for novice students to learn including: finding the uterus in different positions, ovary examination and pregnancy diagnosis. The experts described the processes that they used to perform each part of the procedure, including the manual skills, the knowledge base, and the factors that lead them to decide on a particular course of action while executing the task. The students had highlighted having difficulties finding structures often getting lost and therefore, the experts were asked to consider this problem and describe how they would deal with the situation. The researcher made notes during the examinations and the expert's verbal descriptions were recorded using a Dictaphone. The results were compiled and written in a pseudocode format for each procedure, which was discussed and edited with the two experts. The final version is detailed in Appendix 3.2 and provided a template for the teaching protocol used during the simulator training sessions.

3.2.5 Requirements Summary

The requirements capture aimed to determine the learning needs of novice veterinary students and to identify the virtual models and teaching protocol to be used in the simulator-based teaching tool. Information was gathered from veterinary surgeons, as teachers and experts, and from students, as learners. The participants contributed enthusiastically to the discussions and recognised the need to investigate ways of complementing existing training methods. The task analysis then provided detailed descriptions of the procedures identified as those novices needed to learn.

Based on these findings, the simulated environment for teaching bovine rectal palpation would need to include realistic representations of the cervix, uterus, ovaries with cyclical structures and pregnancies, positioned within the pelvic area and caudal abdomen. The teaching protocol would involve a series of steps, which would be taught using a range of scenarios each simulated using one or more of the models. During training the student would learn to orientate in three-dimensional space, to recognise objects using palpation and to develop search strategies. The initial learning outcome would be to combine these techniques to identify the pelvic landmarks and then locate the uterus in a range of positions, representing different cows. The student would then learn more advanced procedures including ovary palpation and pregnancy diagnosis. Initially, the teacher would provide step-by-step instructions for each procedure and then students would explore on their own to reinforce the technique, with assistance and feedback as required.

3.3 Design

When developing medical computer aided learning (CAL) packages an understanding of several disciplines may be required (Greenhalgh 2001). With regard to the bovine simulator the important areas included: the content material (clinical knowledge), the pedagogical aspects and the design process. The requirements capture established the range of anatomical models and steps that, when included in a teaching protocol, would support the learner's needs. The next stage was to develop the computer-based teaching package using a CAL design technique. The Activity-based CAL method (Montgomery-Masters 1998) has been shown to be of benefit during the production of computer-based teaching material and therefore, was used as a guide during the bovine simulator design phase. The method involves an iterative process where the teaching aims established during the requirements capture are incorporated into the design using Laurillard's conversational framework (Laurillard 1993). The CAL package is then implemented using the available resources and evaluated, with the feedback resulting in changes to the design, followed by further implementation and evaluation.

The conversational framework (Laurillard 1993) provides a model for teaching tool design in higher education. There are twelve steps through which the teacher and student advance as they progress towards the desired learning outcome. The conversational framework encourages the development of an interactive dialogue between the teacher and student and each step can be categorised according to the teaching mode/s to be used. There is human-human (H-H) interaction, which would be represented by the teacher instructing the student or the student asking a question either in lectures, laboratory practicals or during a simulator session. The human-computer (H-C) interaction relates, in the case of the bovine teaching tool, to the teacher selecting a simulation and then following the student's progress in the virtual environment on the computer monitor. At the same time the student palpates the virtual model (H-C) while initially receiving instruction in the procedure from the teacher (H-H) and then feedback on performance while repeating the task (H-C and H-H). The framework also allows for other types of interactions because a teaching goal is likely to be achieved through a range of methods, which would include the student learning about a topic while reading text books although, as already stated, in this case these provide a limited contribution. With regard to clinical skills training, interaction with the patient while under instruction from and following the actions of the teacher, the apprenticeship model (Halsted 1904), is a large part of the learning process (Kerr and O'Leary 1999). The aim of this project is to use the simulator as a supplement to pre-clinical teaching methods to prepare students for clinical training during their first EMS placement.

The simulator design needed to incorporate a range of anatomical models within a series of simulated environments or 'levels' to support the learning process. The training begins with basic orientation and recognition of landmarks, which is followed by development of a search strategy to locate the uterus in different positions. The student then progresses to perform the more advanced procedures of ovary palpation and pregnancy diagnosis. The proposed levels (classified as A, B and C), learning outcomes and simulations are listed in Table 3.1 below.

Level	Learning Outcome	Simulation
A	Orientate in three-dimensions Identify key landmarks	Pelvis and cervix Pelvic floor, brim, & cervix
B	Identify key landmarks Find the uterus in different positions Ovary Palpation	Uterus (B1) - in pelvis & flat (B1) - in pelvis & curled (B2) - in abdomen & flat (B3) Uterus in pelvis with ovaries (B1)
C	Pregnancy Diagnosis	Range of pregnancies

Table 3.1. The proposed levels for teaching the component parts of bovine rectal palpation, which are represented by a series of learning outcomes, and the supporting simulations.

The twelve steps of Laurillard's conversational framework as applied to the teaching bovine rectal palpation with a simulator have been detailed in an activity implementation chart (Appendix 3.3). The students would learn the anatomy and physiology prior to simulator training, which would be integrated into the course just before the first clinical EMS and act as a bridge between learning the theory and performing the manual task. The teacher and student repeat a series of the conversational framework steps for each of the levels, A, B and C, until the desired learning outcome, acquiring the basic skills to perform bovine rectal palpation, is achieved. The simulator has an advantage over traditional training as an effective dialog can be established between teacher and student. The teacher can watch the student's actions and give meaningful feedback on performance with regard to search technique and identification of structures palpated. Teaching each level involves running one or more simulations, each of which represents a different 'virtual cow'. The range of simulations available provides both flexibility and standardisation of the learning experience.

The teaching protocol for the simulator-based training environment has been summarised in a diagram in Figure 3.2. There is a series of teacher and student activities and learning outcomes which are associated with tasks to be performed while palpating the simulations. A series of simulations have been implemented to support the design (Section 3.4 below).

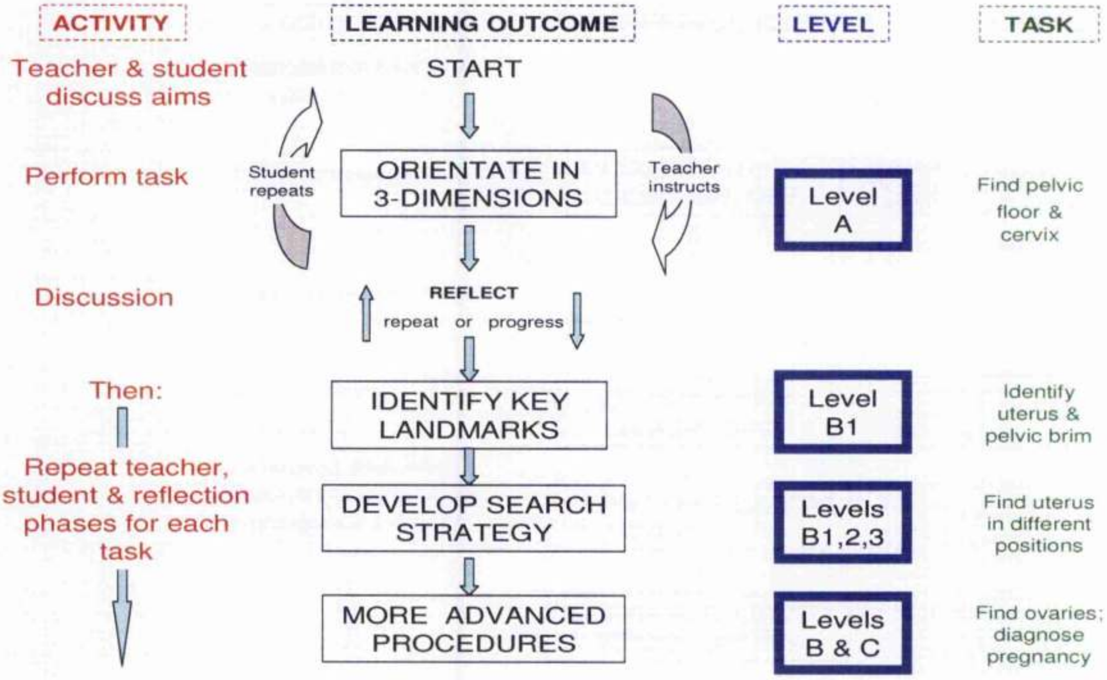

Figure 3.2. The teaching protocol for the simulator-based CAL package used to teach bovine rectal palpation. The protocol was based on Laurillard's conversational framework (Laurillard 1993). The teacher and student undergo a series of activities to achieve learning outcomes while using simulations to practice tasks at each of three levels: A, B and C.

3.4 Implementation

3.4.1 Overview

The simulations were created using the PHANToM 1.5 force feedback haptic device and the GHOST SDK (version 3.1) from SensAble Technologies. Three-dimensional virtual models were created to represent the pelvic area, the caudal abdomen and the reproductive tract. The programs were developed on a 700Hz dual Pentium PC with Windows 2000 operating system and the models were implemented in the programming language C++ using Visual Studio 6 and the standard GHOST libraries. Each anatomical structure was created from one or more geometric shapes. The haptic properties were set on the basis on the researcher's expertise as a cattle practitioner, combined with the experience gained using the PHANToM during the Master's project (Baillie 2003). A range of scenarios were created to support the different stages or levels of the student's learning process and these were accessed by the teacher from dialog boxes.

3.4.2 Creating the Virtual Environment

Haptic Device

A haptic device allows a user to interact with the virtual environment using the sense of touch. Bovine rectal palpation involves using the whole hand to examine and palpate anatomical structures and the fingers and thumb are used to manipulate or grasp structures to facilitate the examination. Initial consideration would suggest that a glove-type haptic device would provide the best means for modelling such a task. However, the whole-hand devices currently available support only a single degree of freedom (movement in one plane) for each finger, CyberGlove (Immersion Corporation 2005) and Rutgers Master II (Bouzit *et al.* 2002). This would allow the user to press a button or hold an instrument but not to perform a combination of three-dimensional movements (in the x, y and z planes) over an object's surface. The PHANToM force feedback device provides three degrees of freedom or movement through a single point of contact and high quality haptic interaction. The device has been used to model palpation procedures using the thimble gimbal attachment (Burdea *et al.* 1999; Crossan *et al.* 2001; Baillie 2003; Williams *et al.* 2003) and bimanual interaction has been provided by using two devices (Howell *et al.* 2005). There are several different sizes of PHANToMs available and the 1.5 device provides a workspace suitable for the pelvic dimensions of the cow, based on the measurements of Murray *et al.* (2002). The point of articulation, at the elbow, would support the range of movement needed for most exploratory tasks performed within the cow during rectal palpation.

The PHANToM 1.5 was chosen as the most suitable haptic device currently available for implementation of the bovine simulation and additionally, the hardware, software and expertise were on hand. Baillie (Baillie 2003) had shown that virtual bovine anatomical models could be created and some of these were rated by experts as good representations. The single point of contact was not ideal (discussed further later in this section) but the high fidelity 3D force feedback provided by the system was considered to be an important factor because during a palpation task, the fingers are in direct contact with living tissue not indirectly through an instrument.

Virtual Models

When creating medical simulations the objectives should be to provide good visual representation, support three-dimensional exploration and create organs that feel realistic (Basdogan 1999). While performing palpation-based skills the physician or veterinary surgeon needs to be able to identify the anatomical structures through the sense of touch. Therefore, the most important criteria when creating this type of virtual environment is to develop models recognisable through haptic exploration. The bovine simulations needed to be realistic enough that after simulator training students would be able to recognise anatomical structures in the cow based on the way the same structure felt in the simulated environment. However, exactly how realistic has not been defined and is unknown for bovine rectal palpation. A decision was made that the aim should be to produce virtual models that when palpated by experts would be assessed as at least acceptably realistic representations. During an internal examination, the structures palpated are not visible unless a specialised technique such as ultrasound or endoscopy is used. A visual representation may or may not be useful to the student but if the teacher was able to see the student's hand movements inside the virtual cow then providing effective guidance would be much easier.

The creation of virtual models of human organs is very challenging and has received considerable attention in haptic research (see Section 2.7 above). A range of methods have been developed to produce structures that feel right. Additionally, in the case of surgical simulators the models need to respond to instruments and produce physiological changes associated with, for example, blood loss. For palpation-based procedures, using direct manual contact rather than interaction through an instrument, there is a need for even greater realism. When palpating soft tissue, the surface should deform in response to pressure. Additionally, certain objects are not fixed and would move when touched or grasped. Incorporating all these factors in a virtual environment would provide a simulation closely resembling the real situation.

The first stage when creating a virtual haptic model is to identify and parameterise the tissues' properties either by using measuring devices applied *in vivo* or *in vitro* to organs of human or animal origin or by asking experts to use their experience to assign values. The virtual models, to be anatomically correct, need to include accurate representations of the shape, size, relative position as well as the feel, firmness or softness and organ content, solid or a fluid filled lumen. In the current work, expert knowledge was used because for a palpation-based procedure performed per rectum making instrument-based measurements would be particularly difficult, if not impossible. Therefore, the properties of the bovine models were set on the basis of the researcher's experience as a cattle practitioner, with additional input from other veterinary surgeons. While creating the simulations, the researcher performed examinations of cows on routine dairy herd fertility visits, in some cases accompanied by students and could make regular comparisons with and adjustments to the virtual environment.

The virtual environments were developed using the GHOST SDK Version 3.1 (from SensAble). A virtual simulation can be created by scanning an object and producing a VRML model composed of polygons, which would closely resemble the dimensions of the original structure. However, when an example of such a virtual model, a horse ovary, was palpated the edges of the polygons were discernable (even after using one of the standard GHOST smoothing algorithms) and this was very distracting for the user. Therefore, a decision was made to create the anatomical models using the geometric shapes supplied in the standard GHOST libraries ('gstCube', 'gstSphere', 'gstCylinder'), either singly or in combination. The properties of each object - the size and shape (width, height and radius) and feel - were set using standard GHOST functions. The object's position in 3D space was manipulated using standard GHOST functions for translation and rotation. The creation of the basic components of the virtual simulation is described in a table in Appendix 3.4. The graphic representations of these combined geometric shapes were presented to the teacher on the computer monitor and the student's current hand was represented by the cursor, which could be followed during the exploration of the virtual scene. The standard GHOST graphics package is quite limited but, as the representation was for the teacher not the student, a basic representation of organs, with regard to colour and appearances, was considered satisfactory. An improved version would use OpenGL to create more realistic graphic objects and allow for further manipulation of the graphic scenes but was not part of the current implementation.

The haptic properties of the anatomical structures are relayed to the student via the PHANToM force feedback device. The student places a finger in the thimble gimbal at the end of the mechanical arm. Each object's properties were created by combining the standard GHOST haptic functions: stiffness, friction and damping; and adjusting the parameters. The values used and resulting haptic properties varied considerably between tissue types. For example, the bones of the pelvis felt hard with an impenetrable surface whereas the pregnant uterus was perceived to be soft, with a thin wall and fluid in the lumen, deforming when pressed.

The stiffness function, which controls the perceived firmness (softness or hardness) of an object, uses the linear Hooke's law model:

Reaction Force (felt by user) = a constant (K) x penetration distance into an object

The stiffness function parameter is the value of K, or the KSpring, within a range of 0.1 to 1.0N/mm (Newtons/millimetre), the higher the value the harder the object. Bone would have a value close to 1.0 and the user would feel a large reaction force for a short penetration distance. The pregnant uterus (fluid filled) would have a much lower value and the surface could be balloted giving the impression of fluid content. The surface friction is the resistance to movement over the surface of an object. This is controlled by two functions, one relating to movement from stationary or first contact (static) and the other to ongoing movement (dynamic). The higher the parameter values for these functions the greater resistance to both types of movement and this can be used to control the perceived ease of movement over an object during palpation. The damping function controls the viscosity felt on an object's surface, a high parameter value simulates the feeling of a sticky surface, which is more difficult to move the hand away from. Low values were used for the bovine models because the real structures are covered by a moist smooth membrane and therefore, have a more slippery than sticky feel when moving over the surface.

The models that have been created are: the pelvis with the pelvic brim and the ventral abdominal wall extending cranially; several versions of the cervix with different size, length and shape depending on the position of the uterus; several versions of the non-pregnant uterus, flat or curled in the pelvis (Figure 3.3), and extending into the abdomen; ovaries with a follicle and a corpus luteum; early pregnancies. Additionally, the bony ridge at the cranial extent of the pubis was added to the pelvis after students asked about the structure during a farm visit. All the models were developed using an iterative approach: 'set properties, palpate virtual object, adjust properties' until a realistic representation was achieved.

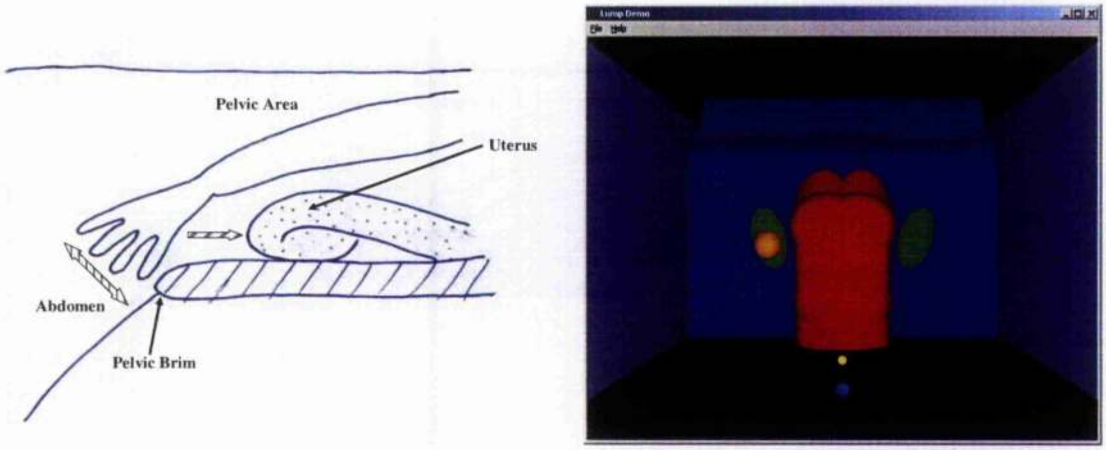

Figure 3.3. The intra-pelvic curled uterus: an illustration on the left, lateral view (from the side), and a virtual model on the right, dorsal view (from above). The student is instructed to sweep the hand from side to side along the pelvic brim and then move backwards along the pelvic floor until the uterus, which feels similar to two knuckles, is palpated behind the hand.

Implementation Decisions and Limitations

The simulated environment contained anatomical structures based on the objects originally developed by Baillie (Baillie 2003). A number of new simulations were created and others were modified using information gathered during evaluations with veterinary surgeons. Additionally, the experience gained with the virtual environment led to a better understanding of the best way to create a particular effect. Achieving a realistic feel for each anatomical structure depended on giving consideration to the combination of the haptic functions rather than adjusting only the parameter value of the function assumed to be closest to the desired effect. For example, the perception of softness was affected not just by the KSpring (stiffness function parameter) but also by the control on the user's movement on the object surface produced by the friction and damping functions. The perception of an object's haptic properties also appeared to be influenced by other factors including changes in an object's orientation and the effect of gravity. Additionally, the properties of one object can affect the user's impression of a neighbouring object. For example, moving rapidly off a slippery surface gave the impression that the next object encountered was harder than expected in relation to the KSpring value.

The workspace, set at the default size, was large enough to simulate the pelvic dimensions but did not support the range of reach required to palpate advanced pregnancies in the abdomen. Therefore, only the pelvis and caudal abdomen were simulated, which provided the space to position first trimester pregnancies and a non-pregnant intra-abdominal uterus; second and third trimester pregnancies were not represented. In the cow structures move in response to palpation and certain procedures involve manipulation. The simulated objects were all static and although a degree of mobility could have been developed using extra force fields or spring effects, this was beyond the scope of the current implementation. For novices, the movement of structures, although part of the real experience, might over complicate the initial interaction. The student was to be instructed to maintain contact with an object during palpation. This would be a useful skill for the real examination because if a structure moved the hand would be more likely to remain in contact. Also the continuous haptic feedback would help in determining a structure's identification, building a mental image of the object under the hand.

The single point of contact available with one PHANToM force feedback device could be considered to present a serious limitation when modelling a hand-based procedure. However, some aspects of the haptic exploration of an object can be approximated with one finger as the user can appreciate the firmness by pressing and when moving over the surface will be able to assess texture, volume and shape (Lederman and Klatzky 1987). Therefore, learning to search the three-dimensional environment and identifying structures including the pelvic brim, the cervix and the uterus and performing pregnancy diagnosis could be achieved with a single point of contact. Based on observations with veterinary surgeons, the middle finger appeared to mimic hand-based procedures better than the index finger, and therefore, students were instructed to place the middle finger in the thimble. However, certain tasks performed during bovine rectal palpation, including ovary palpation and 'membrane slip' (used as a means of diagnosing pregnancy), involve grasping, which requires at least two points of contact. Membrane slip is not performed by all practitioners because of the risk of causing abortion (Sheldon and Noakes 2002) and the technique is not recommended for inexperienced operators. However, ovary examination is central to fertility assessment and a way needed to be found to represent this with the simulator. One option would be to use two PHANToMs but this would increase the cost, reduce the workspace dimensions (Wall and Harwin 2001) and the two mechanical arms may collide. During ovary palpation, one or more digits act to stabilise the structure while the surface is explored with a different finger or the thumb. In the simulation, the ovary was fixed with the ventral third submerged in the pelvic floor and this representation, although not ideal, allowed the user to explore the surface of the stabilised ovary for cyclical structures with the single point of contact.

There are other aspects of the cow that were not included in the simulated environment. A virtual representation of the hand within the rectum and the presence of faeces and peristaltic waves passing over the hand and arm would be difficult to simulate. These factors make the interaction more life-like but also more difficult and take time to overcome. There are likely to be timetable limitations, which would affect the length of teaching sessions and therefore, without some of the 'life-like' distractions the student could spend the whole session concentrating on learning to find and recognise landmarks. Augmenting the simulation with physical structures, such as the preserved rectum used with the PHANToM horse (Von Künzel and Dier 1993), would make the interaction more realistic and could be considered in the future. In the meantime, the teacher informs students of the differences.

The Teaching Package

The virtual models were combined into a range of simulations to represent each of the stages in the novice's learning process, as identified in the design section (Figure 3.3 above). During the training session, the teacher launches successive menu options accessed from a dialog box (Figure 3.4). The student places the middle finger in the thimble gimbal at the end of the PHANToM mechanical arm and palpates the virtual objects. The teacher provides guidance while following the student's exploration in the virtual environment on the computer monitor. The PHANToM was positioned inside a fibreglass model of the rear-half of a cow as this arrangement would help the student to feel more immersed in the learning environment. The student and teacher progress through each stage of the procedure, with a teacher-led instruction phase followed by the student repeating the task with guidance and feedback as required. The aim was that training would be completed within a thirty minute session.

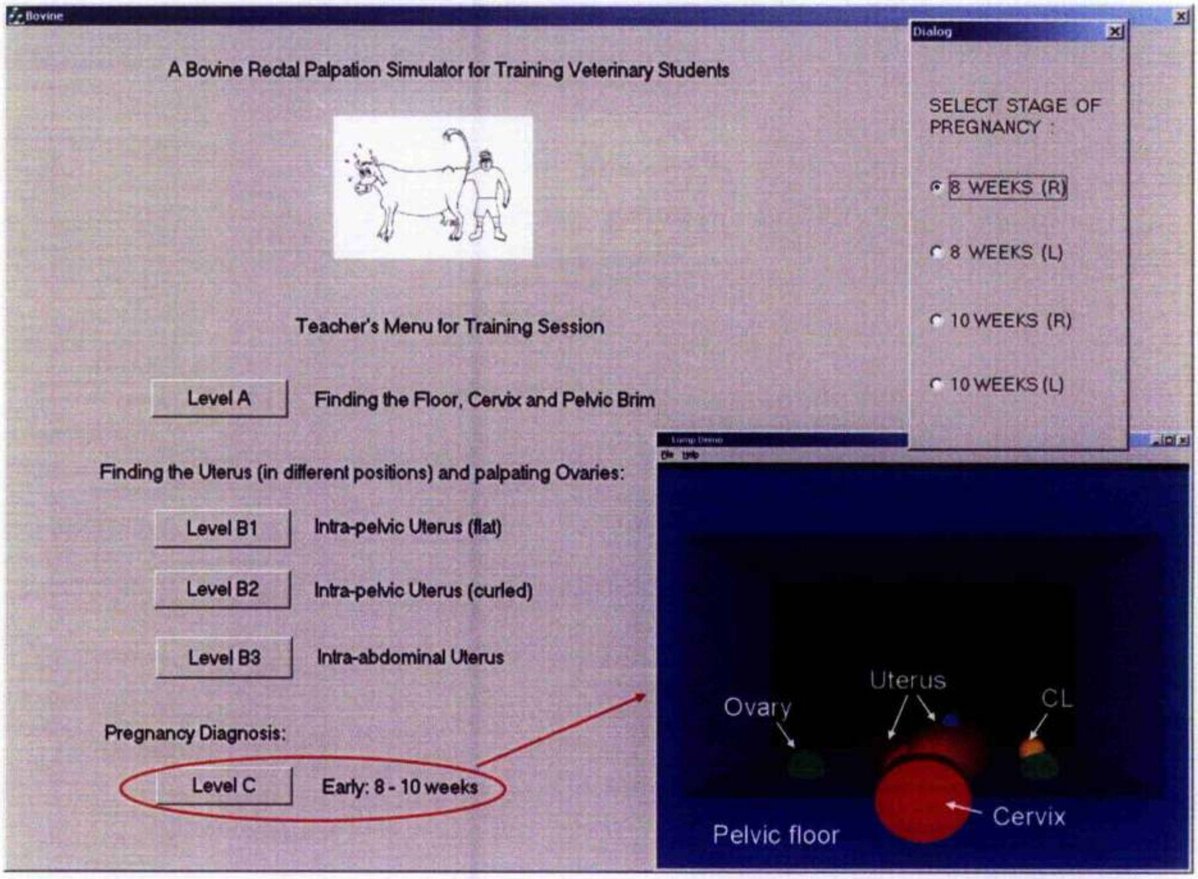

Figure 3.4. The teacher's menu with the three levels: A, B and C, representing the learning objectives. Each button launches a simulation (e.g. bottom right: an 8 week pregnancy implanted in the right uterine horn) with further menu options (e.g. top right) for the teacher to use while instructing the student to perform the steps for each task. The blue dot represents the student's hand position on the right uterine horn.

3.5 Evaluations

3.5.1 Overview

Nine veterinary surgeons from Clyde Veterinary Group in Lanark, the practice where students from Glasgow undertake part of the final year farm animal rotation, took part in the simulator evaluation. Three of the veterinary surgeons had been involved in the evaluation undertaken during by Baillie (Baillie 2003); the other six were new to the simulated environment. They assessed the degree of realism of the virtual environment (face validity) and the teaching protocol structure with regard the combination of steps and simulations that would support the novice's learning process (content validity). These criteria relate to the initial steps that should be undertaken when validating a simulator, as described by Neufeld and Norman (1985). The results are detailed in Appendix 3.5 and summarised in the following sections.

3.5.2 Evaluating the Models

The veterinary surgeons palpated each anatomical model and assessed the shape, size and feel, as a realistic, acceptable or not acceptable representation. The results are presented graphically in Figure 3.5 (next page). The cervix, pelvic floor, pelvic brim, the series of representations of the uterus, the ovary, the follicle, and the 10 week pregnancy were rated by all of the experts as either realistic or acceptable representations for all the criteria: shape, size and feel. The feel of the corpus luteum was rated as not acceptable by one veterinary surgeon and, as his and other participants' comments indicating that in many cases the structure would be softer, the value was adjusted; the shape and size were rated as acceptable or realistic. The shape and feel of the 8 week pregnancy were rated as realistic or acceptable but the size was rated as unacceptable by one veterinary surgeon and this, together with other comments suggesting that the model represented a pregnancy between 7½ and 8 weeks, resulted in the simulation being renamed. The ridge at the cranial aspect of the floor of the pelvis was not an acceptable representation and this finding, together with the view of five of the participants that the ridge did not need to be included resulted in a decision to remove the structure from the current version of the simulations. The comments made by the veterinary surgeons while evaluating the models were also used to improve the descriptions and instructions given by the teacher when students palpated the models. In particular, emphasising that the models were just examples from the wide range of possible findings would help to prepare the students for the variations between cows. The graphic representations were basic but were considered to be adequate, as they were for the teacher not the student. The fact that the teacher could follow the student's actions inside the cow was considered to be extremely useful.

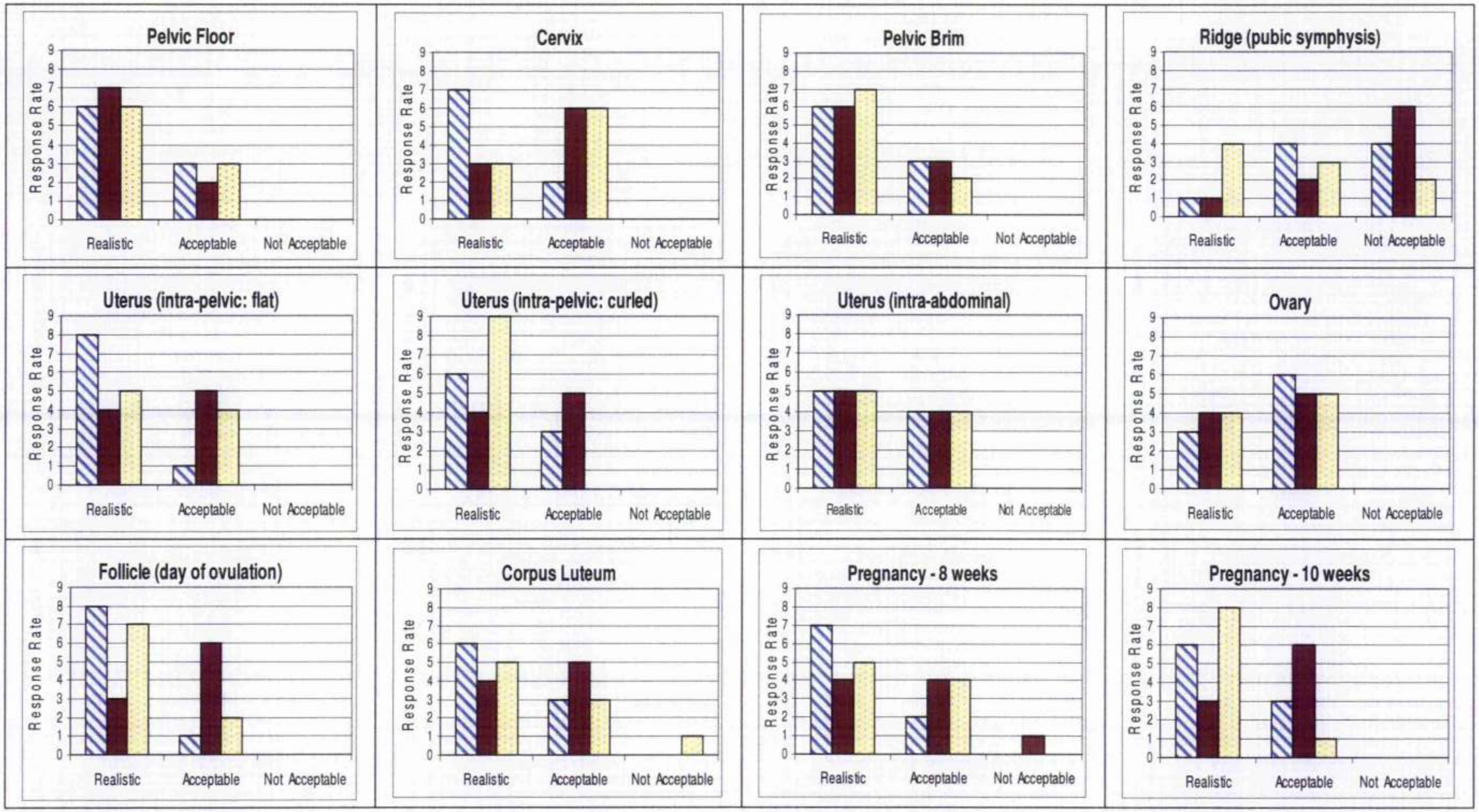

Figure 3.5. The results of the nine veterinary surgeons' assessments of the haptic properties of the anatomical structures. Each structure was assessed for three properties: size (hashed (blue) bars), shape (solid (crimson) bars) and softness (stippled (yellow) bars). For each property, the veterinary surgeons classified each structure in one of three categories: as a 'Realistic', 'Acceptable' or 'Not Acceptable' representation. The height of the bars represents the response rates: number of veterinary surgeons choosing each category.

3.5.3 Evaluating the Teaching Protocol

The veterinary surgeons were presented with a range of options for the structure of the learning environment and were asked to answer a series of thirty-three questions about the teaching protocol. The participants had to decide which steps should be included and to determine the step order that would support the novice's learning process. There was unanimous agreement for twenty-seven of the thirty-three questions and for the remaining six questions, the option chosen by the majority was selected as the one to be used. The teaching protocol had been developed with the aim of achieving the learning objectives identified in the requirements analysis. The evaluation by the veterinary surgeons indicated that the design was structured in a way that should support these aims. The veterinary surgeons considered that when providing training with the simulator, the important first steps were to learn to orientate in the pelvic area, finding the cervix and then the uterus. The pelvic brim is a key landmark because, if the student has been unsuccessful finding the uterus, sweeping along the brim helps in the decision to continue the search by exploring cranially into the abdomen or caudally into the pelvis. The more advanced techniques of ovary palpation and pregnancy diagnosis were considered to be useful techniques to learn in the simulator. Students are likely to have the opportunity to perform both procedures during the first EMS placement and some form of preparation would be helpful. The resulting teaching protocol to be used during training sessions is summarised below as a list of steps, together with the details of the technique used:

Step 1: Orientate in three-dimensional space

- Combine movements in x, y and z planes: down to the pelvic floor, then side to side to locate the cervix in the midline and then forward along the floor to the brim (becoming familiar with the pelvic landmarks and using the haptic device)

Step 2: Find and identify the uterus (three simulations, each with a different uterus in a different position)

- Find the cervix (as Step 1), follow the cervix forward to the uterus
- Identify the uterus based on palpation of the conjoined horns, as a double bump.
- If unsuccessful, move forward to find the brim, sweep from side to side, then depending of structures found move cranially into the abdomen or caudally to search the pelvis

Step 3: Palpate ovaries

- Follow the uterine horn round to the tip, then explore the surrounding area to locate the ovary
- Explore the surface of the ovary for cyclical structures

Step 4: Pregnancy diagnosis (first trimester)

- Sweep the hand over the two horns to appreciate the relative size and ballot the uterus to compare the fluid content of the implanted versus non-implanted horn.

The participants' comments emphasised the importance of training students to develop a search strategy because although veterinary surgeons may locate structures immediately, novice students will not. All the veterinary surgeons considered that during training sessions students should be guided by the teacher initially. Then students should be allowed to explore on their own, which would help to reinforce the procedure and allow students to reflect on their technique. During this phase, the teacher should provide feedback on performance as required, correcting errors in technique and confirming the identity of structures palpated.

3.6 Conclusions

After discussions with veterinary surgeons and students, there is no doubt that there is a need to find a new and more effective way of teaching bovine rectal palpation. Students' performance after traditional training is poor (as shown in Figure 3.1) and resources are increasingly limited. The situation is compounded by the fact that the student's actions inside the cow are not visible to the teacher, which makes providing effective guidance difficult. The students considered that providing training prior to the first examination of a cow would be particularly useful. The aim of the current project was to design a simulator-based teaching tool using haptic technology to teach the procedure to novice veterinary students. The simulator should enable the teacher to have a more effective input into student's learning process and equip students with skills that allowed them to make better use of the limited learning resource, the cow.

The teaching and learning needs of novice veterinary students were determined after considering the views of both veterinary surgeons, as experts and teachers, and students, as learners, and the information was used to design the teaching tool. In addition, a task analysis was conducted with experts as a way of determining each step of the procedure and providing the details for the teaching protocol. The virtual models and teaching protocol were developed and then assessed by nine veterinary surgeons. The models were well rated, indicating that the virtual environment was sufficiently realistic and establishing face validity. This was an important step because the virtual models needed to be realistic enough that on the basis of the way an anatomical structure felt in the simulator, students would be able to recognize the same structure in the cow. When the design of the teaching protocol was discussed with the veterinary surgeons, the feedback indicated that the component stages and steps of the task were represented and in the correct order. The evaluation of the design indicates that the simulator is structured in a way that should allow a teacher to train students to perform the key skills for the procedures of bovine rectal palpation.

A simulator has been developed that has passed the first important stages in validation: the environment was a realistic enough representation (face validity) and the teaching protocol included the steps of the tasks that novices need to learn (content validity). However, there is still the possibility that students trained with the teaching tool would just be learning to use a computer simulator. Therefore, the next important step is to determine whether the skills acquired during training transferred to the real task, examining cows, and an experiment to investigate this is presented in the next chapter.

Chapter 4: Validating the Simulator: Skill Transfer to the Real Task

4.1 Introduction

When producing new medical and veterinary training tools, developers should demonstrate that the tool is effective before considering widespread use either when integrated into a curriculum or released commercially (Berg *et al.* 2001; Magee 2003; Scalese and Issenberg 2005). The work presented in the previous chapter, addressed the issue of designing a simulator specifically to train novice veterinary students. The aim was to identify the students' learning needs and design a training tool to equip students with skills that would mean they would be better prepared for EMS placement training, which is the first opportunity that Glasgow students get to perform bovine rectal palpation. When validating computer-based simulators for medical training, there are a series of steps, originally defined by Neufeld and Norman (1985), that should be undertaken and these have been discussed in detail in Chapter 2 (Section 2.9). The first steps in validation involve determining whether the models are realistic enough representations of the patient or animal (face validity) and that the component steps of the task are included (content validity). Experts palpated a range of bovine models, and all those used in the teaching tool were rated as realistic or at least acceptable representations. The teaching protocol was discussed to ensure that the task was represented in a detailed and structured way and would support the learning objectives. However, even if a simulator is well designed, research still needs to be undertaken to establish the ultimate test of efficacy: after a simulator session, trainees should have developed skills that result in improved performance during the real task. If this is the case, there will be benefits for both the learner and the patient, human or animal.

There have been studies that describe undertaking one or more of the stages of validation for both surgical and other clinical procedure virtual reality (VR) simulators. However, only a limited number have demonstrated that training has resulted in improved performance during the real task, and all were in the areas of minimally invasive surgery and procedures. After training on the psychomotor skills device MIST-VR, alone (Seymour *et al.* 2002) or in combination with a laparoscopic simulator (Schijven *et al.* 2005), trainee surgeons showed improved performances when dissecting the gallbladder (cholecystectomy) in the operating room, compared with control groups. Another study, using a bronchoscopy simulator (AccuTouch) found training resulted in improved performance for novices undertaking the procedure on patients for the first time when compared with conventional training (Ost *et al.* 2001). However, a study looking at training for intravenous catheter placement using a virtual reality simulator found no beneficial effects when trainees subsequently performed the task on real people (Prystowsky *et al.* 1999), which illustrates that there is a risk of assuming a simulator will deliver benefits without proof.

There are fewer simulators developed specifically for palpation procedures. Several studies have demonstrated learning effects in the virtual environment for certain aspects of the tasks (Langrana *et al.* 1997; Crossan *et al.* 2002; Williams *et al.* 2004; Howell *et al.* 2006). Other work has investigated whether the skill levels can be differentiated when measuring performance with the simulator (construct validity). After training with a prostate simulator non-medical students performed better than urology residents when both were assessed in the virtual environment (Burdea *et al.* 1999). When the performance of experts and novices was compared using the Horse Ovary Palpation Simulator (HOPS) no differences were found (Crossan *et al.* 2001). In both cases the failure to discriminate between the levels of expertise accurately was attributed to differences between the virtual environment and the real task. This underlines the need to ensure the design is sound (face and content validity) before progressing on to other evaluations. Additionally, all the evaluations of the VR palpation simulators have either been undertaken in the simulated environment or have used bench tests for assessment and none have measured subsequent performance on real patients.

The bovine simulator developed by Baillie (Baillie 2003) was used to teach students and they indicated that training had a beneficial effect on their subsequent performance examining cows (Baillie 2003). However, the evaluation depended on students' assessment of their own performance because, as with teaching the procedure, the student's technique inside the cow is not visible. Additionally, students had a range of experience levels and performed the post-simulator examinations during EMS. In these circumstances, the examinations would be variable with regard to the time allowed and the assistance provided by veterinary surgeons. Therefore, when conducting the validation of the simulator designed specifically to teach novices, there is a need for standardisation of conditions and independent verification of performance.

The following sections detail an experiment conducted to assess whether novice veterinary students acquired skills during simulator training that transferred to rectal palpation in the cow; to ensure that students are being equipped with useful skills. This experiment presents the first attempt to validate a VR simulator designed for teaching a palpation skill (rather than a surgical skill) by measuring and verifying the subsequent performance during the real task.

4.2 Experimental Design

4.2.1 Task and Verification of Performance

The first issue to address was identifying a component of the procedure of bovine rectal palpation that could be used as a measure of performance. The simulator had been designed to equip novices with the component skills of the task and one of the first learning objectives was to find and identify the uterus. Students need to master this fundamental skill before progressing on to performing fertility examinations and diagnosing pregnancy. Therefore, locating the uterus was chosen as the task to be measured. The next stage was to determine how to verify student performance as the structure palpated is out of sight inside the cow. Ultrasound is used during fertility examinations and provides scans, or images, of the uterus, ovaries and pregnancies and therefore, could provide a means of verifying that the uterus had been identified correctly. However, ultrasonography is a specific skill requiring additional training and, therefore, a way had to be found to use the ultrasound probe passively.

A pilot study was carried out to investigate the practicalities of using ultrasound to verify the identification of structures palpated. Four final year students with previous experience of bovine rectal palpation were trained with the simulator and then examined cows on a farm. A standard bovine ultrasound scanner was used with a 7.5 MHz 65mm linear probe (Aloka, from BCF Technologies). The probe was taped to the middle of the palm of the hand. The students examined non-pregnant cows and were instructed to try to locate the uterus. The uterus identification was confirmed in nine of ten instances, demonstrating that ultrasound used passively was a suitable way to verify performance. However, the length of the probe was problematic for students with small hands, interfering with the movement of either the fingers or the wrist and therefore, another scanner was chosen with a shorter 40mm probe (Sonovet 600, from BCF Technologies (Figure 4.1)), which fitted within the palm. A range of adhesive tapes were tested, as the probe needed to be attached securely to prevent rotation during the examination. The most effective protocol was to attach the cable firmly to the forearm at the wrist and just distal to the elbow with high quality waterproof adhesive tape (SafaSilk, Plastod). The probe was held in position on the palm of the hand with a different type of tape (Omnifilm, Hartmann) containing a non-metallic adhesive, through which ultrasound would penetrate (Figure 4.1).

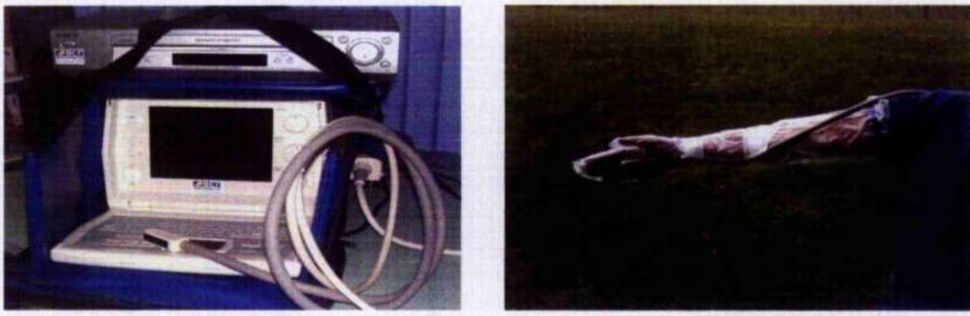

Figure 4.1. Left: the ultrasound scanner, probe and a video to record the scans. Right: the 40mm probe taped to the palm of the student's hand with the cable taped to the arm.

The format of the farm visits, both during the pilot study and in the following validation experiment, was typical of clinical teaching sessions at the University of Glasgow Veterinary School and during EMS. All the cows examined had been selected by the farmer for routine fertility checks. The researcher, a veterinary surgeon, examined each cow and was then followed by no more than two students, in compliance with the university's welfare guidelines (Parkins and Harvey 2001). The students taking part in the pilot study (all in the final year and experienced examining cows) had taken between 35 seconds and 3 minutes 25 seconds to locate the uterus. On the basis of these times and in the interest of animal welfare, a maximum of five minutes was set for the novices' examinations in the validation experiment. The design of the experiment was discussed with a Home Office Inspector and approved by the Ethics Committee, Faculty of Veterinary Medicine, University of Glasgow.

4.2.2 Participants

When recruiting students to take part in the experiment, certain factors needed to be standardised including: prior experience performing the procedure, and exposure to traditional teaching. Student volunteers were asked whether they had ever performed rectal palpation of cows or horses. Students were only considered eligible if they were complete novices, having no experience performing rectal palpation of cows or horses, to remove existing skill as a confounding factor. All the students were at the same stage of the course, the third year of the undergraduate curriculum, had completed the anatomy and physiology courses on bovine reproduction but had not started clinical EMS. Forty-nine students volunteered and thirty–one were eligible. Sixteen students were then randomly selected (using the random function in Microsoft Excel) and allocated to one of two groups: Group A would be trained with the simulator, and Group B would act as controls, having received traditional training only. The sample size of eight per group was estimated using Chi-squared and was based on the expected performance of simulator trained students (prior observations by the researcher). In Group A, there were six female and two male students, in Group B: five female and three male students.

4.2.3 Experimental Protocol

Training

The aim of the experiment was to compare the performance of simulator trained students (Group A) with those who had received traditional training only (Group B). The eight students in Group A received a training session on the simulator with a teacher (Figure 4.2). At the beginning of the training session the student was given an overview of the simulator-based training environment. The teacher then instructed the student in the procedure of bovine rectal palpation, following the teaching protocol and using successive simulations to achieve the learning objectives (Levels A, B and C, as described in Chapter 3). To reiterate, in brief, the training involved teaching the student to orientate in three-dimensional space, to develop search strategies and to identify anatomical structures using palpation. Initially, the student learned to identify basic landmarks in the pelvis and then, to develop the skills required to find the uterus in different positions, to identify other key anatomical structures and to perform pregnancy diagnosis (at the seven to ten week stages). The teacher identified each virtual object palpated by the student and described the characteristic properties the student needed to learn to recognise the same structure in the cow. After being guided by the teacher, the student repeated the task with feedback as required. The sessions lasted between twenty and thirty minutes. The eight students in Group B did not receive simulator training. All the students had undertaken the traditional training provided in the preclinical course.

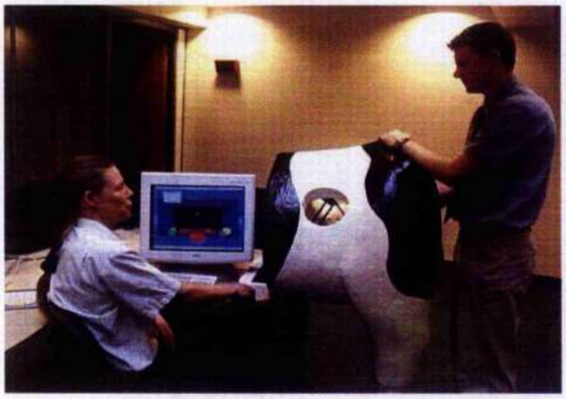

Figure 4.2: A simulator training session. A student palpates the virtual reproductive tract, receiving touch feedback from the PHANToM haptic device positioned inside the fibreglass model of the rear-half of a cow while a teacher follows the hand movements on the computer monitor and provides instructions. (Photo included by kind permission of Andy Price).

Farm visits

During a series of eight farm visits, the performance of the two groups of students was compared when examining cows for the first time. At each visit, two students, one from Group A and one from Group B, examined four non-pregnant cows and were set the task of finding the uterus during a five minute examination. On arrival at the farm, the researcher performed fertility examinations on the cows selected by the farmer (Figure 4.3). Cow details were recorded (cow ear tag number, uterus position and approximate size) and ineligible cows (e.g. pregnant) were replaced. In the meantime, before examining the cows, the students read the experiment instruction sheet (Appendix 4.1). The students were also shown a diagram of the bovine reproductive tract, from the second year anatomy course notes, in case Group A had an advantage as a result of revising the anatomy during the simulator training session.

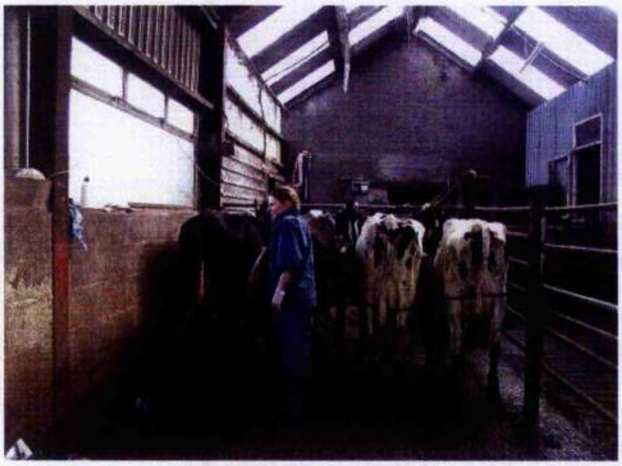

Figure 4.3. Examining the four cows on the farm. On arrival, the researcher, a veterinary surgeon, performed fertility examinations and assessed each cow's suitability for the experiment.

The students then examined the cows. Each student examined two cows first and two cows second, as performing the examination first could be advantageous. While one student was examining a cow, the other student sat in the car. Each examination was timed from the point at which the student's hand was through the sphincter and the ultrasound was recorded on a video tape. During the experiment, the researcher provided no feedback or instructions, other than explaining how to approach a cow safely and how to insert the hand into the cow's rectum. When the student reported locating the uterus, the time was noted and the researcher used the ultrasound to identify the structure palpated. The student was asked to describe the size and position of the structure, as the uterus could have been under the probe in addition to the structure the student was palpating. Each pair of students examined the same four cows and, therefore, if one cow proved particularly difficult to examine (for example, excessive peristalsis), this was matched for both students. Each examination was terminated after five minutes or when the student reporting finding uterus.

The experimental sessions were recorded by the researcher using a Dictaphone for subsequent analysis in conjunction with the video footage of the ultrasound. The ultrasound recordings were evaluated independently after the experiment by another experienced cattle practitioner, who was blinded to the group to which each student belonged. The independent observer was shown the video tape at the point at which the student described finding the uterus. The observer had to decide whether the ultrasound image on the tape was, or was not, the uterus and if not, to decide what was the most likely alternative.

4.2.4 Hypotheses

Hypothesis 1

Group A (simulator trained) would be no more able to find the uterus when examining cows for the first time than Group B (traditional training only). The performance was measured by successful uterus identification, verified using trans-rectal ultrasound and the student's description of the position and size of the structure palpated. The dependent variable was the ability to find the uterus. The independent variable was the type of training.

Hypothesis 2

Group A would be no faster at finding the uterus in real cows than Group B. The dependent variable was the time taken to locate the uterus. The independent variable was the type of training.

4.3 Results

Each student examined four cows and had up to five minutes to try to find the uterus in each cow. None of the examinations were terminated prematurely and none of the cows were withdrawn during the experiment for welfare or any other reasons. The uterus identification rates per four cows are shown in Table 4.1. The times taken for the successful examinations are shown in Figure 4.6.

Uterus identification rates

All the students in Group A found and correctly identified the uterus in at least one of the four cows examined compared with only one student from Group B. Within each pair (both students examining the same cows) the student from Group A was more successful, identifying the uterus in a higher proportion of cows, than the student from Group B. The total number of uterus identifications independently verified from the ultrasound for Group A was 18 out of a possible 32 (eight students examining four cows each), compared with 1 out of 32 for Group B (Table 4.1: columns 6 and 7 in bold).

	Student identification rates: 'uterus found / 4 cows'		Structure identified (from student description of size & position +/- ultrasound)		**Ultrasound verified identification rates: 'uterus found / 4 cows'**	
Pair	Group A	Group B	Group A	Group B	**Group A**	**Group B**
1	2	0	Uterus x 2		**1**	**0**
2	3	1	Uterus x 3	Rumen	**3**	**0**
3	3	2	Uterus x 3	Rumen x 2	**2**	**0**
4	3	1	Uterus x 3	Rumen	**3**	**0**
5	2	1	Uterus x 2	Bladder	**2**	**0**
6	3	1	Uterus x 3	Uterus	**3**	**1**
7	3	0	Uterus x 3		**2**	**0**
8	2	1	Uterus x 2	Rumen	**2**	**0**
Total	21	7			**18 / 32**	**1 / 32**

Table 4.1 Uterus identification rates per four cows for the eight pairs of students. The 2nd and 3rd columns are the rates reported by the students. The 4th and 5th columns in the centre of the table are the structures identified based on the student's description and / or ultrasound images. The 6th and 7th columns (in bold) are the identification rates verified independently using the ultrasound.

For Group A, in all cases the descriptions of the uterus size and position were similar to those made by the veterinary surgeon. There were three additional identifications reported by the students in Group A that could not be verified by ultrasound for various reasons: video not recording (Group A, pair 1), ultrasound image obscured by air under the probe (Group A, pair 3), or the probe had rotated (Group A, pair 7). In each of these cases, the student described the size and position of the uterus accurately but without independent verification these results were not included in the final analysis. Six students in Group B reported finding the uterus in one or more cows but all of these except one were incorrect and were identified from the descriptions and the ultrasound as other structures, including the bladder and the rumen. An example of an ultrasound image recorded when a student from Group A identified the uterus is shown in Figure 4.4.

Figure 4.4 An ultrasound image showing the two horns of the uterus (towards the top on the left and mid screen) as identified by a student from Group A.

The results for the performance of the two groups were analysed using McNemar's test (Petrie and Watson 1999). The test was used to assess whether the proportions of successes of the two groups were equal and to account for matching: same four cows examined by each pair of students (data in Table 4.2). The proportions were significantly different ($p < 0.001$), indicating that Group A were better at finding the uterus than Group B.

	Group B success	Group B failure	Total no. pairs
Group A success	1	17	18
Group A failure	0	14	14
Total no. pairs	1	31	32

Table 4.2. Results for the two groups in a format for McNemar's test. The table shows the frequency of the four types of pair for the two outcomes: success finding the uterus, failure to find the uterus in the 5 minute examination.

The number of successes finding the uterus in relation to the order in which the cows were examined for the students in Group A is presented graphically in Figure 4.5. Only one student found the uterus in the first cow examined. Students were more successful in subsequent cows: 5/8 in the second, 7/8 in the third, and 5/8 in the fourth cow examined. For one student in Group B who successfully found the uterus, this was in the second cow examined.

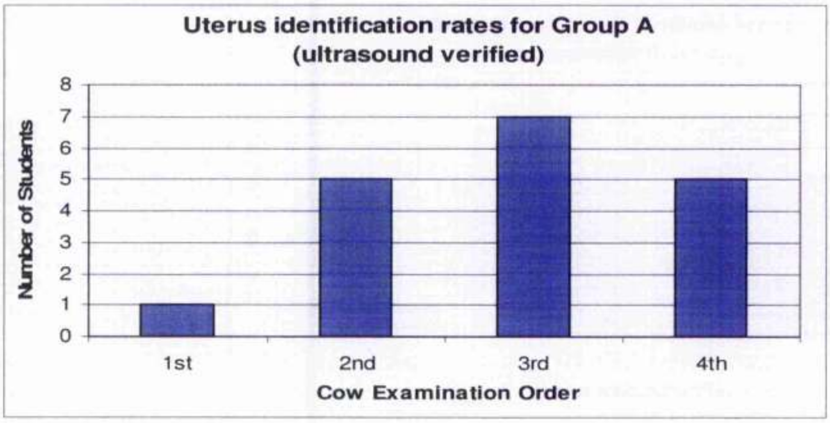

Figure 4.5. Ultrasound verified uterus identification rates for students in Groups A. The graph depicts the number of students finding the uterus in relation to the order in which the cows were examined: 1st, 2nd, 3rd or 4th.

Time to locate the uterus

The time taken by the students to locate the uterus was recorded and the values for those who were successful are shown in Figure 4.6 and detailed in Appendix 4.2. For Group A the times ranged from 45 to 238 seconds (18 observations, mean: 115.3 seconds, standard deviation: 62.2) and the one successful identification from Group B took 258 seconds, slower than all the times for Group A. Statistical tests to compare the two groups were not performed because there was only a single value for comparison in Group B.

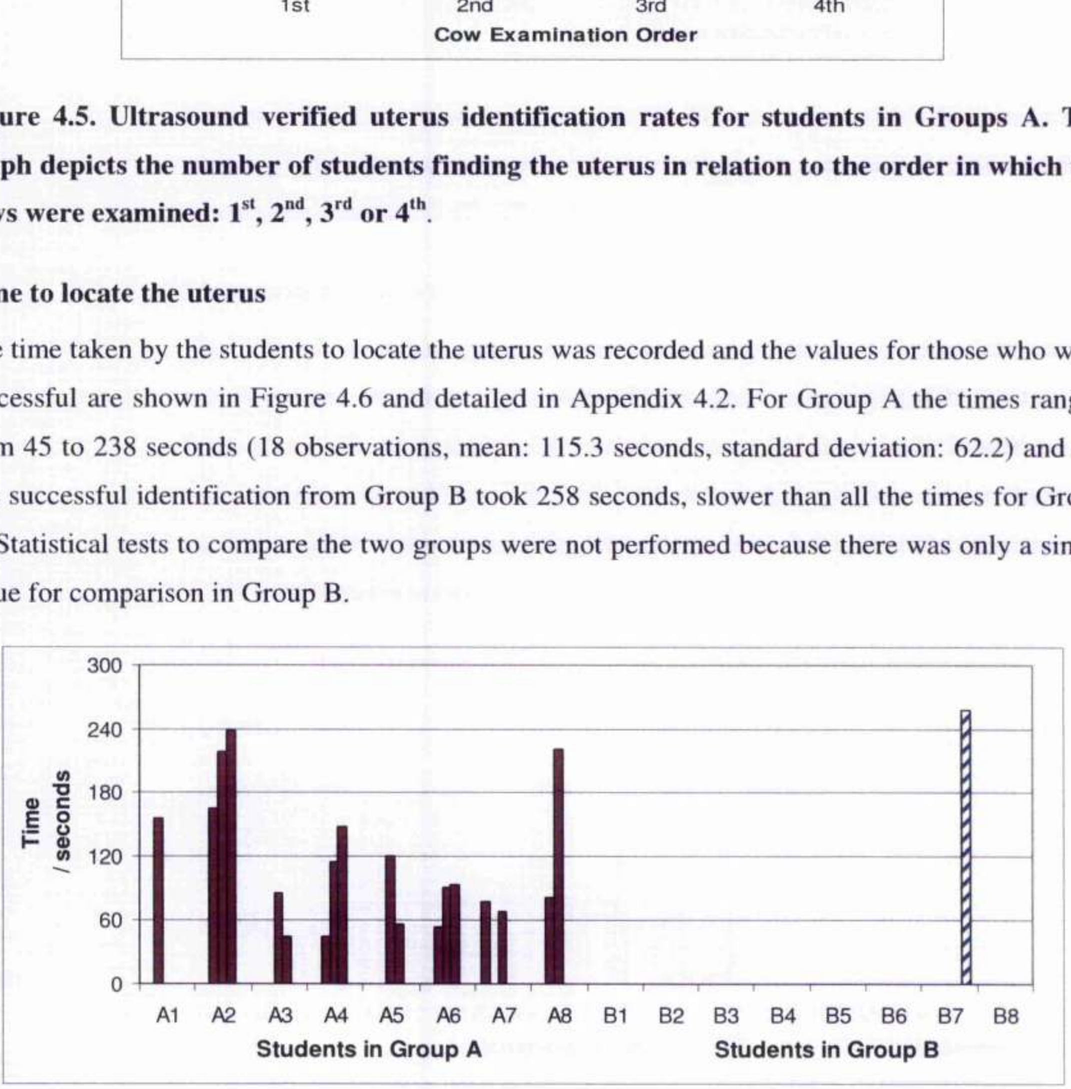

Figure 4.6. Times taken to locate the uterus based on the ultrasound verified data. Each student was allowed up to 5 minutes to complete the task. Group A (simualtor training, solid (crimson) bars) had 18 successful identifications, Group B (traditional training only, hashed (blue) bar) had 1 successful identification.

4.4 Discussion

The aim of the work was to determine whether training with a VR simulator equipped students with skills that would be useful when examining cows for the first time. An experiment was conducted to compare the performance of a group of students whose training had been supplemented with a simulator session (Group A) with a control group (Group B) who had traditional training only. The task, or performance measure, was to find and identify the uterus in four non-pregnant cows. Locating the uterus is a fundamental skill and is the first step for a range of procedures, including fertility examinations and pregnancy diagnosis, whether performed manually or using an ultrasound scanner. During the experiment, confirming the identification of structures palpated inside the cows by students was going to be difficult. One way to approach this problem would be to rely on students reporting on their own findings but this could be inaccurate and therefore, ultrasound, used passively, provided the means of verify performance.

Hypothesis 1, which stated that Group A would perform no better than Group B, has been rejected based on the results. Group A were significantly better at performing the task, locating and identifying the uterus as verified from the ultrasound images, than Group B. Therefore, the simulator training had equipped students with skills that enabled them to perform the task more effectively when examining cows for the first time than if they had received traditional training only.

Hypothesis 2 stated that Group A would be no faster than Group B at performing the task. The time available to examine cows under farm conditions is often limited. Therefore, being able to perform the examination quickly would be useful and has been considered to be one of the important reasons for providing training for bovine rectal palpation (Sprecher *et al.* 1994). If simulator training resulted in students performing faster then they would be more likely to achieve the task in the time available and would have time to practice other tasks, including finding the ovaries. However, Hypothesis 2 was not tested because there was only a single value in Group B for comparison with the eighteen values in Group A. It is possible that if allowed more time students in Group B might have found the uterus in more cows. However, a maximum time had been set for the experiment in the interest of animal welfare.

The results for Group A indicate that simulator training was a useful way to prepare students for the first examinations of cows. Additionally, the poor performance of Group B highlights how difficult the procedure is for students to perform after receiving only traditional training. The information provided by students using the teaching tool developed by Baillie (Baillie 2003) had indicated that traditional training was not very effective (Figure 3.1). This is supported by the results in the current study for Group B, who only found the uterus in one of the thirty-two cows examined. The students in Group A not only found the uterus more frequently but were also more accurate: when they said they had found the uterus they were correct. The students in Group A may have been more confident to try to identify the uterus as a result of undertaking simulator training before examining cows. However, the students were accurate in their identifications and this indicates that after feeling the uterus in the simulated environment the students were able to recognise the same structure in the real cow and therefore, that the virtual models were sufficiently realistic representations. However, the students in Group B, although reporting finding the uterus in seven cows, were only correct in one case. In the other cows, instead of palpating the uterus the ultrasound indicated the student had found the rumen or the bladder. The inaccuracy of Group B underlines the importance of using ultrasound as a means of verification rather than relying on the students reporting their own performance. Additionally, traditional training alone, where students would, for example, learn what a uterus looked like in anatomy lectures and practicals did not equip them with the required skills for performing bovine rectal palpation. Overall, the results indicate that simulator training had equipped students with two basic skills: performing a search to find the uterus, and identifying the uterus using palpation.

The success rates of Group A at locating the uterus varied between cows (Figure 4.5). Students were more successful in the second (5/8), third (7/8) and fourth (5/8) cows examined compared with the first (1/8). These observations are interesting but the numbers are small and the experiment was not designed to look at the effect of successive examinations on student performance and therefore, interpreting these findings requires caution. Students would be expected to learn from each examination and would build on this experience over time. This effect was most noticeable after the first cow probably because when examining the first cow the students had to become familiar with the aspects of the real cow that were not present in the simulated environment; the rectal wall, faeces and peristalsis. Further development of the simulator could address this issue with representations of more of the aspects of the real cow, including perhaps a preserved rectum added to the fibreglass cow.

When considering the level of success of both groups of students during the experiment this may have been less than when first examining cows during EMS or at university. Although the students were under the supervision of a veterinary surgeon, the guidance provided related to safety and welfare issues only, as responses to other questions would have been difficult to standardize and could have affected performance. In practice, more guidance would be given and therefore, even with traditional training alone, students might perform better than under the experimental conditions. However, the majority of the on farm training takes place in commercial practices when veterinary surgeons are undertaking their normal work and time for teaching can be limited. Additionally, as the student's actions are not visible, providing effective guidance can be difficult under any circumstances. The results from the experiment suggest that a simulator session prior to the first farm animal placement training would be beneficial. Students would then be able to practice the basic skills even if available help was limited and would be able to identify structures palpated, which would make giving further instruction easier for the supervising veterinary surgeon.

The work also highlights the potential value of ultrasound as a tool to help students learn the procedure. Using the probe passively, as in the experiment, has the advantage that students do not have to know how to use a scanner. However, there are certain limitations, particularly in relation to the conditions on a farm. Attaching the probe securely was time consuming and this would be particularly impractical during EMS although might be possible at university. Additionally, although the uterus could be identified successfully using the probe, when the student was lost, differentiating structures was often found to be difficult for the observing veterinary surgeon. Therefore, ultrasound would not be particularly useful for directing the student's movements. However, in most cases in Group B, when the student had the hand on a structure the researcher was able to make an identification. Therefore, the probe could be used in this way to help novices. For more experienced students, who knew the basics, ultrasound could be used to confirm the identification of structures palpated, which would be a helpful way of reinforcing knowledge.

There are certain considerations that should be made when interpreting the results in relation to using the simulator as a teaching tool for bovine rectal palpation. The task assessed was finding and identifying the uterus, and this needs to be considered in the context of the procedure as a whole. Locating the uterus is the first fundamental step that needs to be mastered but the teaching tool should also train students to perform a complete fertility assessment and perform pregnancy diagnosis. The teaching protocol has been designed to include the steps for the more advanced techniques and the associated range of virtual models have been assessed by experts as realistic enough representations (Chapter 3). However, further work needs to be undertaken to determine whether the simulator will deliver effective training in these areas. Additionally, the simulator was used by one teacher and a trial should be undertaken with several teachers to assess whether the simulator is a reliable tool in the hands of others. This would help to determine the contribution of the individual's teaching skills in the current experiment. Another consideration is that the simulator was used to teach only eight students, whereas most veterinary schools have in excess of one hundred students in a year. However good the results of a small trial the question remains: 'Can the simulator be used under real world conditions?' Therefore, there is a need to investigate the feasibility of using the simulator to teach a whole year of students. The following chapter presents work undertaken to integrate the simulator into the curriculum at the University of Glasgow Veterinary School.

4.5 Conclusions

A simulator has been developed that equips novice students with the skills required to find and identify the uterus in the cow, which validates the simulator as a teaching tool for this aspect of the procedure. The work represents the first time that skill transfer to the real task has been demonstrated for a VR simulator designed specifically for a palpation skill. Students trained with the simulator performed significantly better than those who had traditional training only and were therefore, better prepared for the first examinations of real cows. After simulator training, students would be equipped with skills that would enable them to make better use of cows as a learning resource, which is important when the opportunities to practice on farms are increasingly limited. Additionally, providing training that equips novices with skills prior to performing an invasive procedure for the first time is likely to have benefits for animal welfare. The simulator also has certain advantages over traditional teaching methods. The teacher can follow the student's actions inside the cow and therefore, have a more effective input into the learning process. The teaching protocol and range of simulations provide a means by which training can be standardized, which can be difficult to achieve during EMS placements. Overall, simulator training when used strategically in conjunction with examinations of cows has the potential to allow students to develop the skills required to perform bovine rectal palpation more efficiently than is achieved currently.

Chapter 5: Integrating the Simulator into a Veterinary Curriculum

5.1 Introduction

The work presented in the previous chapters has addressed the issues of designing a simulator specifically for training novice veterinary students and undertaking steps to validate the teaching tool. The simulated models were rated by experts as realistic enough representations and the teaching protocol was considered to support the learning objectives. The next key step was to demonstrate that simulator training equipped students with skills that were useful for the real task. Students whose training was supplemented with a simulator session were better at finding the uterus than a control group. However, only eight students were trained with the simulator and part of any validation process should also involve demonstrating that using the simulator is feasible under real world conditions (Neufeld and Norman 1985; Berg *et al.* 2001). Therefore, a project was undertaken to investigate the practicalities of using the simulator to teach a whole year of undergraduate students at the University of Glasgow Veterinary School.

The simulator had been designed primarily to teach novice students and prepare them for the first examinations of cows. At Glasgow, most students examine cows for the first time during farm animal EMS placements in third year. However, when considering integrating the simulator into the curriculum, the most feasible place in the timetable was in fourth year. Although students may have examined some cows, they still have the majority of their clinical experience to come and therefore, should still benefit from simulator training. Students were offered two sessions as part of the bovine reproduction course, one session at the beginning and one towards the end of the academic year. Feedback was gathered throughout the project using questionnaires, a focus group and during farm visits, which helped to identify issues that needed to be addressed.

5.2 Training Session One

5.2.1 Methods

The aim of the first training session was to equip all students with the basic skills, including learning to find and identify the uterus. The sessions were conducted by the researcher, an experienced cattle practitioner and holder of the Royal College of Veterinary Surgeons Certificate in Cattle Health and Production. Each student was allocated a timetabled session on a Monday afternoon either in Term 1 or at the beginning of Term 2. A set of notes was distributed at the beginning of the academic year and provided an introduction to bovine fertility examinations and a description of the techniques to be taught with the simulator.

The training sessions followed the same format as used previously when training the eight novice students in Group A (Section 4.2.3). However, in this case, each student was asked to describe briefly his or her experience examining cows during EMS, although the same training was delivered regardless of existing skill level. The session lasted twenty minutes during which time the student followed the teacher's instructions, practicing each of the key skills (Section 3.3), and then performed a limited exploration on his or her own

Questionnaires were used to gather feedback on the first training session and were designed following the format described for measuring learning resource outcomes by Brown *et al.* (1996). The first questionnaire (Appendix 5.1) was given to students immediately after the session and included an initial section to gather information about the student's experience examining cows and learning bovine rectal palpation prior to the simulator training. The students were also asked to rate various aspects of the simulator training, responding to statements by qualifying their answers on a 5 point Likert scale from 'Strongly Agree', 'Agree', 'Neutral', 'Disagree', to 'Strongly Disagree'. Questions were asked about other aspects of the training session, including the time allocation, and sections were included where students were given the opportunity to enter comments. A second questionnaire (Appendix 5.3), which used a similar format, was handed out after students had completed their next farm animal EMS to gather further feedback on the training.

5.2.2 Results

Ninety-four of the 97 students in the fourth year attended the training session and 69 of the first questionnaires were returned (details in Appendix 5.1). The students who responded had a wide range of previous experience with 48% having examined only five cows or less (20% (14 students) had never examined a cow), while 10% had already examined more than fifty cows. Of those students who had examined cows, 87% had done so during EMS, 31% on farms at times other than EMS and 5% at veterinary school, some students having examined cows in more than one situation. When asked how they had been taught, students were presented with three options and could indicate more than one method, just over two thirds selected lectures and veterinary surgeons teaching on farm, while less than half (45%) selected *in vitro* tracts (available as a teaching resource in the second year anatomy course). The students reported a range of existing confidence levels when performing bovine rectal palpation, tending towards the lower categories, with only two students reporting being confident. The students' responses to statements about the simulator training session are shown in Table 5.1. The modal response was in the 'Strongly Agree' or 'Agree' category for the all of the statements. All students who completed the questionnaire considered that simulator training had been helpful for learning bovine rectal palpation. The feedback also indicated that the simulator had helped students to develop a search strategy, increased their knowledge of the relative position and the feel of key structures. Ninety-seven percent reported increased confidence to perform bovine rectal palpation, although for pregnancy diagnosis the categorisation was more conservative (of the 88% reporting increased confidence more than half selected the statement response category 'Agree' rather than the 'Strongly Agree'). Guidance from the teacher was rated as being particularly helpful.

Simulator training:	SA	A	N	D	SD
Was helpful for learning bovine rectal palpation	54	15			
Provided a useful search strategy	57	12			
Increased knowledge of relative position of key structures	46	23			
Increased knowledge of the feel of key structures	32	34	3		
Guidance was helpful during haptic training	60	9			
Increased confidence to perform bovine rectal palpation	43	24	1	1	
Increased confidence to perform pregnancy diagnosis	25	36	7	1	

Table 5.1: Student responses (n = 69), immediately after the first training session, to statements relating to aspects of the simulator training. There were five response categories: Strongly Agree (SA), Agree (A), Neutral (N), Disagree (D) or Strongly Disagree (SD) with the statement.

The time allocated for training, twenty minutes, was considered to be either 'about right' (49%), a 'little short' (49%) or 'much too short' (one student), none considered that the session was too long. The speed at which the training was conducted was considered to be 'about right' by most (87%) and 'a little fast' by a few (13%). A high proportion of students (96%) entered comments in one or more of the allocated sections on the first questionnaire (Appendix 5.2). Those who had examined cows entered a range of negative comments about their experiences during EMS indicated that this represents a less than ideal learning environment. The difficulties related to: "you are never sure that what you're feeling is actually what you think it is" and "I always feel the pressure of time" and although veterinary surgeons were willing to help, "it's impossible for the vet to see" and therefore, getting useful guidance could be difficult. With regard to the simulator-based training there were repeated citations similar to "it was very helpful that the tutor knew where your hand was and could guide you" and that "it was useful in establishing a method and strategy for performing rectals" as well as "building confidence" and provided a "relaxed learning environment". However, some reservations related to the differences between the virtual environment and the cow as there were "no faeces and no contractions" the presence of which would have increased the realism of the whole experience.

The second questionnaire, distributed after the next farm animal EMS, was completed by 50 students (details in Appendix 5.3). The responses to statements about the effect simulator training had on various aspects of performance examining cows are shown in Table 5.2. The modal response for all categories was to 'Agree' with the statements, except for confidence to perform pregnancy diagnosis where the mode was in the 'Neutral' category. Overall, although the responses were positive the category selected was more conservative than immediately after the simulator training. The set of statements in the two questionnaires were not identical but for similar question types in the first questionnaire a greater proportion of responses were in the 'Strongly Agree' category. However, the responses indicated that students still considered that simulator training had been helpful for learning bovine rectal palpation, had improved their abilities to orientate in the cow, to find and to identify the uterus, increased the speed at which structures were found and increased confidence to perform bovine rectal palpation. The simulator training had been less useful for locating the ovaries and had limited effect on confidence to diagnose pregnancy. Most of the students returning the second questionnaire found the handout notes useful (94%) and wanted to use the simulator again (96%).

Simulator training:	SA	A	N	D	SD
Was helpful for learning bovine rectal palpation	16	29	5		
Improved your ability to orientate in the cow	15	33	1		1
Improved your ability to find the uterus	9	35	4	2	
Improved your ability to identify the uterus	9	30	9	2	
Improved your ability to locate the ovaries	4	18	15	10	3
Increased confidence to perform bovine rectal palpation	11	28	9	2	
Increased confidence to perform pregnancy diagnosis	3	18	20	8	1

Table 5.2: Student responses (n = 50), having undertaken farm animal EMS after simulator training, to statements relating to the effects of the simulator training on subsequent performance examining cows. There were five response categories: Strongly Agree (SA), Agree (A), Neutral (N), Disagree (D) or Strongly Disagree (SD) with the statement.

More than half the students (56%) entered comments on the second questionnaires (Appendix 5.4). Recurring remarks, made by those who had never examined a cow before the first training, related to being unprepared for some aspects of the cow that were not included in the simulator: "other structures that were in the way" and "the real cow pushes your hand out" with the suggestion that in future "this should be explained to students". Some reported that dealing with these factors had hindered their performance and that the procedure had been more difficult than expected. The majority of students (86%) had not undertaken further EMS until between one and six months after the training session and some comments related to having "forgotten" some of the training. A range of positive comments related to increased confidence "in explaining where I might be to the vet" and "to have a go". Other benefits of the training were that "I could approach the situation in a systematic way with a list of check points" and "the haptic cow is good for identifying landmarks". Many students reported they were still having difficulty locating the ovaries and a few made comments similar to: "if you were using two or more fingers" the simulation would be better. A range of extra simulations were identified for a further training session as well as options for a more student-centred learning experience.

5.3 Training Session Two

5.3.1 Overview

A second training session was timetabled for the summer of fourth year (Term 3), as most students who responded indicated that they would like to use the simulator again. Before running the second training sessions the project entered a further development phase to address issues raised by students, which involved modifying certain parts of the teaching protocol and developing new simulations. The design of the second session was based on the feedback after the first training session (Section 5.2.2) and input from students during a focus group and farm visits (Section 5.3.2 below). The aim was that the second session would support ongoing learning needs and would be customised for each student, to accommodate the wide range of experience and skill levels. Further feedback was gathered after the second session using a third questionnaire.

5.3.2 Methods

Focus Group

A focus group was conducted in Term 2 with eight students who had never examined a cow prior to the first simulator session but had all been out on farms since. First, the students discussed some of the physical difficulties experienced by novices when examining the real cow and the shortcomings of the training session in this respect. Although the teacher had mentioned some of the differences between the simulator and real cow, more time needed to be taken with novice students to prepare them more thoroughly for the first examination. The students were divided over whether they should have been told that the procedure was difficult. Some felt they might have been discouraged, although all agreed some preparation was necessary to enable students to undertake the first farm animal EMS with more realistic expectations. Similarly to the feedback on the second questionnaire, the students taking part in the focus group highlighted certain procedures that needed a higher priority in future training sessions. Ovary palpation had been covered briefly in the first session but the training provided had not equipped students with the required skills. Students considered that more time spent practising pregnancy diagnosis would be beneficial and the first training had limited effect on their confidence to perform the procedure. Again, this area had been covered in the first session but the simulations were limited to early stages of pregnancy and students had been under the teacher's direction rather than making a diagnosis based on what they palpated. The students also expressed an interest in using the simulated environment to practice problem solving with a range of scenarios representing typical on-farm fertility cases.

Farm Visits and Further Development of the Simulator

Farm visits were undertaken with more experienced students at the end of Term 2 and during the Easter vacation to investigate techniques students needed to learn and evaluate changes to the simulator training. The researcher examined cows selected by the farmer for fertility assessment or pregnancy diagnosis and then one or two students examined each cow. The initial aim was to investigate the technique used to locate the ovary. After locating the uterus, the veterinary surgeon palpated along one of the uterine horns from the bifurcation to the tip and then explored close to the tip. Sometimes students had difficulty locating both ovaries within the time allowed and the veterinary surgeon suggested a quicker technique, which involved 'jumping' the hand laterally immediately after locating the uterus. While trying to locate the ovaries, the hand is usually held vertically and an attempt is made to pick up the ovary from the broad ligament, between the thumb and the four fingers while sweeping from side-to-side, forward and back, between the uterus and the pelvic wall. The next stage was to determine how to palpate the cyclical structures. The ovary is mobile and therefore, has to be stabilised first, which involves using several digits and then the surface can be explored, often using the thumb.

On the basis of the findings, the teaching protocol and simulations were modified to teach ovary examinations. Palpation of cyclical structures as performed in the real cow involves manipulation of the ovary between the fingers and the thumb and requires more than one point of contact, which is not possible with one PHANToM device. Palpation of the rest of the reproductive tract had been approximated successfully by placing the thimble of the middle finger (rather than the index finger). However, for ovary examination a second point of contact would be required for stabilisation or manipulation. As this was not possible in the current simulation, a decision was made that the teacher would first demonstrate the hand positions and movements used. The student would mimic the teacher's actions and then use the simulator to appreciate the shape and feel of the ovary and any cyclical features protruding from the surface. In the simulated environment, the ovary was artificially stabilised by fixing it to the pelvic floor.

At another farm visit, students who had been taught ovary palpation using the new approach performed the procedure and discussed the influence of training, which was considered to be more helpful than the previous version. The students then performed pregnancy diagnosis on cows in the second and third trimester, while receiving instructions from the veterinary surgeon. The aim was to determine in detail the search strategy and key diagnostic features identified through palpation. The key steps involved: locating the middle uterine arteries in relation to the pelvic brim (often described in relation to a clock face at about 4 and 8) and appreciating the buzzing pulse associated with fremitus; finding the uterus in the abdomen and balloting the surface to appreciate the fluid content; palpating part of the calf; differentiating the pregnant uterus from the rumen; and feeling cotyledons (more than two) in the wall of the uterus by sweeping the flat of the hand over the surface (and differentiating these from the ovaries).

The findings were incorporated into the simulator training by further modifying the teaching protocol and developing new simulations of more advanced pregnancies. The pregnant uterus needed to be situated in the caudal abdomen rather than the pelvis, which required a larger workspace. The abdominal area was simulated by overriding the default workspace boundaries and this enabled use of the full range of movement available with the PHANToM mechanical arm, although there are slight distortions at the extremes in each axis. Models were created to represent: a four month pregnancy, which could be balloted; a final trimester pregnancy with cotyledons; and middle uterine arteries. Two non-pregnant options were included: one with the uterus in the pelvis, and the other representing a freemartin (in both cases the only abdominal structure simulated was the rumen). These provided important comparisons with the pregnancies. The simulations did not include representations of the foetus or fremitus.

A final farm visit was carried out with students who had been trained to perform both ovary palpation and late pregnancy diagnosis in the revised version of simulator-based teaching tool. The students examined a selection of cows, some were for pre-breeding checks and others had been dried off but had failed to calve to the expected date (although a bull ran with the cows). When the uterus was enlarged, due to endometritis or slow involution, and was situated in the abdomen the students had difficulty locating the ovaries. A different approach was required, compared with finding ovaries in the pelvic area, using a sweeping action with a flat hand on the abdominal wall. In the dry cows, the students successfully diagnosed those that were in calf and, in the others, were able to find the non-pregnant uterus.

The final stage in preparation for the second training session was to write a range of 'on farm' scenarios, in consultation with other bovine practitioners, to represent some of the common cases encountered during typical visits to a dairy or a beef herd. During training, the teacher would act as the farmer, providing a fairly monosyllabic history: "PD", "not seen her" or "she's just not right, you know". The students would have to try to elicit more information from the 'farmer' and then palpate a simulation of a cow representative of the scenario. The student would then make a diagnosis, recommend a course of action and where necessary discuss treatment options. The scenarios included some common but difficult situations students are likely to encounter shortly after graduation, and if dealt with incorrectly, not uncommonly result in negligence claims (VDS 2004). In the simulated environment, if the student made a mistake the teacher would then discuss a better way of dealing with the situation.

Second Training Session

Students were offered a twenty minute session in Term 3. These were scheduled in free periods, as the bovine reproduction course had been completed. A form was distributed to students at the beginning of term, which enabled them to select and prioritise the aspects of the procedure they wished to practice (Appendix 5.5). The options included: early and late pregnancy diagnosis, finding the uterus, finding ovaries, palpating ovarian structures, repeating the first training session. They could also choose to include practising problem solving using the on-farm scenarios as a part of the session. The sessions were then customised according to individual student's learning needs. After training, students were asked to complete a short questionnaire (Appendix 5.6) to provide feedback on the session.

5.3.3 Results

Fifty-four students attended the second training session and 43 questionnaires were returned. The results are shown in detail in Appendix 5.6. All students either strongly agreed or agreed that the training had increased their confidence to perform both bovine rectal palpation and pregnancy diagnosis, although once again with more reservation about the latter. The on-farm scenarios were well received and were rated as a beneficial way of learning (on a response scale: Definitely Beneficial 79%, Beneficial 21%, Neutral 0%, Not Beneficial 0%, Definitely Not Beneficial 0%). Again many students entered comments on the form (Appendix 5.7) and with regard to the on-farm scenarios the feedback was positive, including that this "made the whole learning experience real", "helped you think in a clinical way ... and what the consequences of your decisions and actions would be", "helped to put clinical knowledge and lecture info into 'palpable' context" and "created the 'stress' that a new vet will feel". When asked what other procedures should be taught with the simulator, the most popular response was equine colic, followed by equine reproduction.

5.4 Discussion

The simulator was successfully integrated into the curriculum and the trial period provided an opportunity to test, further develop and improve the teaching tool. After the training sessions, the student feedback was both positive and constructive indicating that students valued the simulator training, had found the experience useful for learning a range of skills and many of their comments provided valuable information for areas requiring modification. Additionally, the simulator enabled the teacher to provide instruction in the techniques for bovine rectal palpation to students with a range of previous experience examining cows and to give feedback on performance.

The students were trained to develop and practice a range of skills during simulator sessions. Students learned to orient themselves in the three-dimensional space inside the cow, to develop a structured search strategy within the pelvic area and caudal abdomen, and to identify structures through palpation. The student feedback on the first training session was positive both immediately after the session as well as after the next EMS, although with slightly more reservation in the latter case. The simulator training had been helpful for learning the basic skills, although for more advanced procedures, such as ovary palpation and pregnancy diagnosis the feedback highlighted the need for further investigation of teaching methods and for development of more simulations. Students reported that training had increased their confidence to perform the procedure, but this should be interpreted with some reservation as confidence is not necessarily linked to competence. When Morgan *et al.* (2002) compared medical students' self-reported confidence levels with an objective measure of skill they found that the two were not correlated. However, in the current situation, if students were more confident as a result of simulator training then they might be more prepared to make the most of the opportunities to examine cows on farms, which would be beneficial.

There are several possible explanations for the more reserved feedback about the first simulator training in the second questionnaire, after the students had examined cows during EMS. The students' comments, particularly from those who had never examined a cow prior to the training session, indicated that they had not been adequately prepared for the full experience of performing rectal palpation of cows, as the simulator did not include any representation of the rectum, faeces or peristalsis. Incorporating these physical aspects into the model would have been difficult, although, the addition of a preserved specimen rectum could be considered. Additionally, when the aim was to use the simulator to focus on learning a range of skills within the time available this would have been more difficult to achieve if the student had spent part of the session with, for example, the hand constricted by a peristaltic contraction.

Another limitation of the simulator relates to the single point of contact provided by the PHANToM haptic device, where the user interacts with the virtual environment using a thimble. Previous experience evaluating anatomical models with veterinary surgeons had indicated that using the middle rather than the index finger provided a better approximation for the hand and that palpation of structures then felt more realistic. Additionally, the work has shown that even using a single point of contact, the simulator equipped students with useful skills (Chapter 4). However, examining ovaries involves manipulating the ovary between the fingers and thumb, which cannot be represented. In the future, devices that provide high fidelity 3D feedback to each digit and the hand will become available and these would provide a more complete interaction and representation of the tasks. Until then, compromises need to be adopted to represent certain aspects of ovary examination, particularly grasping and manipulating the structure, and using alternatives, including physical models, will be necessary.

The interval between training and the next EMS was in most cases several months and this may have contributed to the reduction in the perceived effect of the teaching as some skills may have been forgotten during this period. In an ideal situation the simulator training would be timetabled immediately prior to the real examinations but there would be practical limitation associated with organising this for all students. Additionally, during simulator training, the teacher was present throughout the session specifically to provide instruction and feedback. Whereas in the on-farm situation, due to practical considerations and the difficulties providing instructions when the veterinary surgeon cannot see the student's hand inside the cow, the teaching can be both limited and variable.

The second training sessions were customised to the individual's learning needs. This enabled each student to focus on the areas that were considered to be the most important and the training could progress at a pace appropriate to the student's learning speed. The on-farm scenarios, included in these sessions, were well received by students and rated as a valuable way of learning. The students had the opportunity to act as the clinician solving typical problems including cases that represented examples of common but difficult situations a new graduate will encounter. The simulator represents a safe environment, if the student makes a mistake there are no consequences for the cow, the farmer, the new graduate or the veterinary practice. In these cases, the teacher and student would then discuss alternative ways of dealing with the situation. The on-farm scenarios required the students to practice integration of knowledge: anatomy of reproductive, pelvic and abdominal structures; physiology of the oestrus cycle; and pharmacology, selecting the drugs to treat the disease condition or manipulate reproduction. The second sessions were offered in the students' free time due to course restrictions, which proved more difficult to organise and, in spite of a high proportion of students indicating that they would like to use the simulator again the attendance rate for the second session was lower than the first.

Establishing the educational value on any new resource integrated into a veterinary undergraduate curriculum is important as such courses tend towards volume overload (Bushby 1994). Therefore, the inclusion of additional teaching material needs to be both justifiable and practical as other components may have to be sacrificed, if not from the curriculum then from the students' own study time. The work presented in Chapter 4 showed that simulator training had a beneficial effect on skill development and the current work has demonstrated that integrating the simulator into the curriculum was feasible. However, before a veterinary school made a decision to use this technology there are other factors to consider, particularly in relation to the resources required. Haptic devices are expensive although cheaper versions are emerging. The teaching sessions involve one-to-one tuition, which is also costly in both the teacher's time and dedication. Therefore, there is a need to optimise the simulator use with careful consideration of both the structure of the sessions and the timetabling within the curriculum. The student feedback indicated that customising the training for the individual's learning needs would be an efficient way of using the simulator. Certain aspects of the procedure could be covered in handouts, including an explanation of the differences between the simulator and the real cow with some instruction on how to deal with this, allowing the one-to-one sessions to focus on palpation of the virtual cows. All sessions should include an element of role-playing using the on-farm scenarios to allow students to practice dealing with typical clinical cases, making and thinking about the consequences of decisions. The sessions would be integrated into the curriculum timetable, rather than during free time for ease of planning and to facilitate attendance. Further training sessions, for students having problems or those interested in further developing their skills for farm animal work could be offered in a more flexible way depending on demand. There is a case for providing basic training prior to the first real cow examination and then all subsequent examinations would build on the skills developed with the simulator.

The simulator training has been delivered by one teacher throughout the project and therefore, there are factors to consider relating to the validation and to the use of the simulator in a real world situation. First, there is an issue as to whether the results would be repeated with other teachers and also, as the training relies on one-to-one teaching the costs in time and money may not be sustainable. As a potential solution, a prototype automated version has been developed with computer guidance replacing the teacher's role. The work to develop and evaluate the new version is presented in the next chapter.

5.5 Conclusions

The trial integration into the curriculum was successful both for providing training for bovine rectal palpation within the curriculum and gathering feedback, which helped to improve the design of the simulator as a teaching tool. The simulator has certain limitations with regard to the difficulties representing some of the physical aspects of the real cow but does provide a useful supplement to traditional training methods. The teacher is able to have an effective input into the learning process of a procedure that is at the moment, to some extent, self-taught. As opportunities to gain experience on farms have become increasingly limited in recent years, equipping students with at least the basic skills using the simulator will enable them to learn more from the cows they do get to examine.

The current work demonstrated that the use of the simulator in a curriculum was feasible, establishing another of the criteria defined by Neufeld and Norman (1985). The simulator continues to be used at the University of Glasgow Veterinary School. Fourth year students are offered one timetabled thirty minute session as part of the bovine reproduction course. At the beginning of the session, students are asked about their level of experience and the areas on which they particularly wish to focus. Then the teacher uses the simulator to train all students in the basic procedures: finding and identifying the pelvic landmarks and the uterus. For novice students, these are the key learning objectives. For students with more experience, the basic training serves two purposes: the student becomes familiar with the haptic device and simulated environment; the teacher can assess the student's strengths and weaknesses. These students are also given the opportunity to practice performing more complete fertility examinations including finding ovaries and palpating cyclical structures. All students are given the opportunity to practice some of the on-farm scenarios, as previous feedback had indicated that this was a particularly useful way to use the simulator. If time allows, students are taught to perform early pregnancy diagnosis, differentiating between the two uterine horns on the key properties of size and fluid content (or firmness). This was considered useful because these basic skills are important for palpation-based procedures in many species including, for example: appreciating a joint effusion; determining lump types (e.g. preliminary differentiation between a lipoma, cyst or carcinoma); assessing the pressure of a bladder (fullness); detecting a gastro-intestinal foreign body, to name but a few.

Additionally, relating palpation skills taught with the bovine simulator to clinical situations in other species helps to engage students who intend to do companion animal work in the learning experience. Attendance for the years 2004/5 and 2005/6 has been high, 97% in each case, supporting the ongoing inclusion of the training in the course and the value of the simulator as perceived by students.

Chapter 6: Development and Evaluation of an Automated Version of the Simulator

6.1 Introduction

In the preceding chapters, work has been presented that describes the development and validation of a simulator for training veterinary students to perform bovine rectal palpation. The key steps in the validation of a simulator used as a teaching tool for a clinical procedure have been undertaken and the work demonstrated that: the simulated environment was realistic enough; students were equipped with skills that transferred to the real task; and integrating the teaching tool into a curriculum was feasible.

Another point to consider is the simulator's reliability with regard to delivering consistent results for a range of learners and with different teachers. Many students have now been trained with the simulator and the benefits for skill development have been demonstrated as well as students providing positive feedback on the learning experience. However, all the teaching was conducted by one individual, the researcher, which standardised teacher factors for the experimental work but raises certain issues. The reliability and usability of the simulator as a teaching tool is untested in the hands of others. Additionally, some of the benefits of training may have related specifically to the researcher's abilities as a teacher and, are a consideration when interpreting the efficacy of the simulator. These issues could be addressed by training several members of staff to deliver some of the ongoing sessions timetabled as part of the bovine reproduction course and then, compare student skill development between instructors. Ideally, subsequent performance should be assessed during the real task, as in Chapter 4, but this would involve a large number of farm visits, requiring considerable time and resources. An easier option would be to ask students to give feedback on the effects simulator training had on their performance but self-reporting can be unreliable. There is also the issue of standardisation of pre-training experience as, for the fourth year students (currently receiving simulator training as part of the curriculum), this would be quite variable. In the previous work, when measuring skill transfer to the real task, only novice students were used, which removed existing skill as a confounding factor.

An alternative approach would be to remove the teacher from the training environment altogether by developing an automated version of the simulator, which students could use on their own. This would also address another issue: one-to-one teaching is expensive in time, effort and money, and an automated version would be cheaper. Additionally, if the simulator were available in a clinical skills laboratory students could practice in their own time. Training would be more flexible in relation to learning needs, for example, using the simulator prior to farm visits and to address specific skill deficiencies.

In the following sections, the design of a prototype automated version of the simulator is described, followed by an experiment to measure skill development by investigating students' subsequent performance examining cows. The results are discussed and compared with the previous work, which evaluated the teacher-led version, and the relative merits of the two approaches are considered. All the validation work is then discussed in the context of Neufeld and Norman's guidelines for computer simulators used in clinical training (Neufeld and Norman 1985).

6.2 Development of the Automated Version

6.2.1 Design Issues

The aim was to design an automated version of the simulator that students could use on their own, rather than requiring the presence of a teacher. First, there were various design decisions to be made. If students were given access to the simulations used by the teacher in the existing version, but without any instruction, it is likely that the benefits would be limited. Others have found that using simulators without adequate instruction fails to support skill development (Smeak *et al.* 1994). Therefore, a degree of guidance needs to be provided and this should include the key contributions that a teacher is able to make when using a simulator, compared with the situation on farms. When a student explores inside the virtual cow, the teacher can follow the hand movements. This enables the teacher to instruct the student to develop a search strategy to find the key landmarks. Additionally, when the student palpates an anatomical structure, the teacher can confirm the identification of the object and make the student aware of the distinguishing characteristics including: shape, size, position and feel (softness, firmness). Therefore, the automated version needs to provide instructions and feedback, the teacher's roles, through some form of computer-based guidance.

There are various ways in which computers can provide information and feedback to users. The most common means is through the graphic display and students could watch their hand movements on the computer monitor while palpating the virtual cow with the haptic device. However, students need to learn to develop search strategies and without instruction, novices do not know how to proceed. Therefore, the automated version will need to include some guidance with regard to the correct sequence of movements. Graphic traces of hand movements have been recorded using the HOPS simulation (Crossan 2004) and this functionality was used to assess the quality of a range of examinations. For teaching purposes, an expert's examination could be recorded and then used as a visual path for the student to follow. However, with the current set up, the graphics are not superimposed on the actual location of the objects palpated but are displaced, as the monitor is on the desk (see Figure 4.2). This can be confusing and students would have to learn how to relate the images on the monitor to the virtual models they were palpating inside the fibreglass cow. There is a system that provides collocated graphics, the Reachin API (Reachin 2004), using a semi-transparent mirror. If a hole were cut in the top of the fibreglass cow the visual display could be positioned such that the hand moving within the physical model would appear to be superimposed on the virtual representations. The development environment used to create the Haptic Cow does not include this functionality and as the real task is unsighted and students will need to perform examinations without visual cues, a decision was made to explore other ways of providing guidance.

Another common way of supporting human computer interactions is through the auditory channel. A simulated voice could be used to replace the teacher's role by providing instructions about how each part of the procedure is performed. For example: "To find the cervix sweep your hand from side to side across the pelvic floor..." and so on. Audio cues could also be used to provide information about objects in the scene, including the identification and a description of the haptic properties. The student would receive an instruction and respond with a hand movement, on completion of which the new position or structure palpated would be described. The next step would then be taken: audio instruction, student moves hand, further information. However, there are several problems associated with this approach. The sequence of instructions and movements must correspond and there would need to be some mechanism to deal with the situation when the student's exploration did not match the expected path. Also the student's actions and the audio instruction might prove difficult to synchronise as movements are rapid and the audio descriptions are relatively slow.

A potential solution would be to provide haptic guidance in addition to the audio instructions. This would involve using the haptic device to guide the user physically along a set path instead of allowing free movement within the scene. This functionality has been developed for the PHANToM using a playback algorithm where the device motors move the user's hand along a pre-recorded path, a 'bead pathway', and was used to guide limb movements as part of rehabilitation therapy for stroke patients (Amirabdollahian *et al.* 2002). A more recent version includes a control system to increase stability and is available as an open source library for use with a range of haptic devices (Crossan *et al.* 2006). Haptic guidance has been used to help subjects learn three-dimensional movements (Feygin *et al.* 2002). The user's hand was moved along a path by the haptic device and, when measuring subsequent performance recalling the task, the haptic guidance was found to have had beneficial effects. There are also examples of haptic guidance used in medical simulations, where the trainee is guided along the path of an expert's examination. This feature is include in the Virtual Haptic Back project (Williams *et al.* 2004) where the PHANToM motors move the trainee's hand along the path of an expert's examination. After the initial haptically guided phase, the trainee was then allowed to explore freely and tried to repeat the examination. Another approach, featured in an epidural injection simulation, was to use force feedback to keep the needle on the correct path by resisting deviations (Dang *et al.* 2001).

6.2.2 Development of a Prototype

When developing the automated version of the bovine simulator, a decision was made that computer assistance would be provided by using a combination of haptic guidance, to teach the student the correct movement pattern and audio cues, to replace the teacher's instructions. There would be no visual representation of the scene; the student would not see the monitor and the PHANToM would be inside the fibreglass cow. A prototype was developed, which novice students could use to learn some of the basic skills including finding the pelvic landmarks and the uterus in different positions. First, the student learned each procedure as the PHANToM device moved the hand along the path of an expert's examination. Each step was accompanied by audio instructions. The student then explored the virtual environment on his or her own. During this phase, some feedback would be useful and therefore, access to audio information was provided.

The simulated environment consisted of some of the anatomical models that had been used in the previous work. The haptic guidance functionality was delivered using the software libraries developed by Crossan *et al.* (2006). The first stage in the development was to use the PHANToM to record an expert (the researcher) performing the exploratory procedures in the virtual environment. Each procedure was then divided into small steps and each step was accompanied by an audio instruction written using text-to-speech technology (Microsoft Speech SDK 2005) and delivered by a simulated voice. When students undertook simulator training, before each step an audio instruction would play describing what was about to happen. Then the haptic device executed the step, moving the student's hand down, sideways, forward or over an object. This was followed by a further piece of audio, giving information about the new location or structure palpated. For example:

Step 'n'

- Audio: "Your hand will be moved down to the pelvic floor"
- Haptic device: Moves hand down to floor
- Audio: "You are now palpating the pelvic floor"

Step 'n + 1'

- Audio: "Your hand will be moved...."
- Haptic device: Moves hand...
- Audio: "You are now palpating... And so on...

After completing the haptically-guided section of the training, the student was allowed to explore the virtual environment freely. The PHANToM device, used in the current work, provides different types of information and feedback depending on whether the user's role is passive (when being guided by the haptic device) or active (when exploring freely). When the device moves a user's hand along a path, directing a passive exploration, only positional information is available. The trainee can learn the kinaesthetic components of the procedure, the movements that, when combined, represent a search strategy. In addition, the trainee will gain information about the location, shape and size of objects. When used in this way, the PHANToM does not relay information about the firmness of an object. However, when a user explores freely, performing an active exploration, all object properties including the feel (softness or firmness) are relayed via the PHANToM. In the second section of the training, students could spend as much time as they liked exploring freely, repeating the procedures, which would enhance learning. If lost or requiring guidance, the student could press a help key and the structure palpated would be identified by a simulated voice. These audio cues also emphasised the haptic properties of each object that needed to be learned as the basis for the recognition of the same structures in the real cow.

The prototype of the automated version of the bovine simulator consisted of two virtual environments. The first, a relatively simple simulation, was used at the beginning of the training session to enable the student to become familiar with the haptic device and the training environment. The student's hand was moved around following a pre-recorded route inside a virtual box, which had a cylinder in the middle of the floor. The student then explored the box without haptic guidance and practiced pressing a key to identify the object palpated: the cylinder, the box floor, the right wall, and so on. Keys were also used to enable the student to progress through the program: 'Start' for the haptically-guided section, 'Free' (to explore) for the self-guided exploration, 'Help' to identify objects, and 'End' to finish the program. At the beginning of each section, there was a brief verbal introduction. Additionally, when about to embark on the self-guided exploration, students were prompted to practice executing search strategies and identifying objects on the basis of their haptic properties: shape, size and feel. The initial simple simulation ran for about five minutes, depending on how long the student chose to explore freely. The second part of the training involved learning skills specifically for bovine rectal palpation and lasted about twenty minutes. The student's hand was moved along the path of the expert's examination. During this part of the training, students learned to find and identify the pelvic landmarks, the cervix and the uterus when positioned in the pelvis or in the abdomen. At the end of the program, a piece of text played that reiterated the key steps undertaken to perform the procedures. Additionally, some of the differences between the simulated environment and the real cow were explained, as in the past novices had indicated that some information should be provided by way of preparation. More advanced procedures, including pregnancy diagnosis and ovary palpation, were not included in this first version of the prototype.

6.3 Evaluation of the Automated Version

6.3.1 Experimental Design

An experiment was conducted to assess whether training using the automated version equipped novice students with skills that transferred to the real task. The experimental protocol was similar to that used in the previous experiment to evaluate teacher-led simulator training (detailed in Chapter 4). The participants were all third year veterinary student volunteers who had never performed rectal palpation of a cow or horse. Sixteen students were randomly selected (using the random function in Microsoft Excel) and allocated to two groups, C, simulator trained, and D, traditional training only. There were five female and three male students in each group.

The students in Group C undertook a training session using the automated version of the simulator. Before starting the training, the researcher explained how to use the PHANToM. The students were also given a sheet that summarised the session and described the function of each of the keys: to start, advance or end the program and access help (Appendix 6.1). Each student completed the two sections to the training, first inside a simple virtual box and then inside the virtual cow. As stated above, initially the device would move the hand around and then the student would be free to explore.

The subsequent performance of the students was assessed when examining cows for the first time and compared with the other group, traditionally trained only. A pair of students, one from Group C and one from Group D, accompanied the researcher on a farm visit. The students examined four non-pregnant cows (the same four cows for both students) and were set the task of finding the uterus during a five minute examination. As before, an ultrasound probe was taped to the palm of the hand and the images were used to verify that the uterus had been identified correctly. The ultrasound was recorded with a video and was assessed subsequently by another veterinary surgeon, who was blinded to the student identification and training method.

At the end of the experiment, the students in Group C filled out a questionnaire (Appendix 6.2). The aim was to gather information about the users' experiences with the simulator and the effects of the training on their subsequent performance examining cows. The students were asked to respond to statements by qualifying their answers on a 5 point Likert scale from 'Strongly Agree', 'Agree', 'Neutral', 'Disagree', to 'Strongly Disagree'. Students were also given the opportunity to enter comments in several sections. As the automated version of the simulator was a prototype, the feedback would be useful when making improvements and considering further development options.

6.3.2 Hypotheses

Hypothesis 1

Group C (simulator trained) would be no more able to find the uterus when examining cows for the first time than Group D (traditional training only). The performance measure was the number of successful uterus identifications, verified by ultrasound and the description of position and size. The dependent variable was the ability to find the uterus. The independent variable was the type of training.

Hypothesis 2

Group C would be no faster at finding the uterus in real cows than Group D. The dependent variable was the time taken to locate the uterus. The independent variable was the type of training.

Hypothesis 3

Group C (automated version) would be no more able to find the uterus when examining cows for the first time than Group A (teacher-led version). The performance measure was the number of successful uterus identification, verified by ultrasound and the description of position and size. The dependent variable was the ability to find the uterus. The independent variable was the version of the simulator.

6.4 Results

All students completed examinations of four cows, none of the cows needed to be withdrawn during the experiment for welfare or other reasons. The uterus identification rates for the two groups are shown in Table 6.1. Of the eight students in Group C (simulator trained), seven found the uterus in at least one of the four cows compared with two students in Group D (traditional training only). Group C found the uterus in twelve of a possible thirty-two cows while Group D found the uterus in only two cows. These findings were verified by the ultrasound and the descriptions of the position and size of the uterus were all similar to those made by the veterinary surgeon. There were four other instances when students in Group C indicated finding the uterus but these were not verified by ultrasound for various reasons: air under the probe; probe moved (one case: rotated, one case: slipped backwards); student (number seven) indicated finding the uterus with the fingers but lost the position when moving forward to provide an ultrasound image (which was necessary because the probe was on the palm of the hand). In these cases, the students' descriptions of the uterus were accurate (except student number seven, who was unable to make a full description) but without independent verification based on ultrasound none of these values were included in the final analysis. Students in Group D reported finding the uterus in seven cases but in all but two, the identification was incorrect. Using the ultrasound and / or the descriptions of the size and position, the structures were identified as the rumen, the bladder or the cervix.

	Student identification rates: 'uterus found / 4 cows'		Structure identified (from student description of size & position +/- ultrasound)		**Ultrasound verified identification rates: 'uterus found / 4 cows'**	
Pair	Group C	Group D	Group C	Group D	**Group C**	**Group D**
1	2	2	Uterus x 2	Rumen x 2	2	**0**
2	1	0	Uterus x 1		**1**	**0**
3	2	1	Uterus x 2	Uterus	**2**	**1**
4	3	0	Uterus x 3		**2**	**0**
5	3	2	Uterus x 2	bladder, uterus	**2**	**1**
6	2	1	Uterus x 2	Cervix	**1**	**0**
7	3	1	(1st?) Uterus x 2	Cervix	**2**	**0**
8	0	0			**0**	**0**
Total	16	7			**12 / 32**	**2 / 32**

Table 6.1 Uterus identification rates per four cows for the eight pairs of students. The 2nd and 3rd columns are the rates reported by the students. The 4th and 5th columns in the centre of the table are the structures identified based on the student's description and / or ultrasound images. The 6th and 7th columns (in bold) are the identification rates verified independently using the ultrasound.

The results for the performance of the two groups were analysed using McNemar's test (Petrie and Watson 1999). The test was used to assess whether the proportions of successes of the two groups were equal and to account for matching: same four cows examined by each pair of students (data in Table 6.2). The proportions were significantly different ($p < 0.01$), indicating that Group C were better at finding the uterus than Group D.

	Group D success	Group D failure	Total no. pairs
Group C success	1	11	12
Group C failure	1	19	20
Total no. pairs	2	30	32

Table 6.2. Results for the two groups in a format for McNemar's test. The table shows the frequency of the four types of pair for the two outcomes: success finding the uterus, failure to find the uterus in the 5 minute examination.

The number of successes finding the uterus, in relation to the order in which the cows were examined for the students in Group C, were 2/8 in the first, 3/8 in the second, 4/8 in the third, and 3/8 in the fourth cow. As with the previous experiment (results for Group A), the success rate in the first is less than all the subsequent examinations, but with such a small number of observations no analysis was undertaken. The two successes in Group D were in one of the third and one of the fourth cows examined.

The time taken to find the uterus was recorded and the results are shown in Appendix 6.4. The times for the students in Group C ranged from 47 to 270 seconds (12 observations, mean 133.4 seconds, standard deviation 79.4). The two values for Group D were 121 and 282 seconds. However, as in the previous experiment, with so few values in the traditional trained group (D) for comparison, a statistical analysis to investigate differences between the two groups, with regard to the rate at which the task was completed, was not performed.

The performance (ability to find the uterus) for the students trained with the automated version, Group C, was compared with the students who had been trained in the previous experiment by a teacher using the simulator, Group A (Section 4.3). The results for the uterus identification rates, verified by ultrasound, are shown in Table 6.3. Group A were more successful, finding the uterus in eighteen of a possible thirty-two cows (56.3%) compared with twelve (37.5%) for Group C, a difference of nearly twenty percent. The results were analysed using a Chi squared test. There was no significant difference in the performance of the two groups ($p = 0.20$).

	Group A (teacher-led)	Group C (automated version)	Total
Uterus found	18	12	30
Uterus not found	14	20	34
Total cows examined	32	32	64
Percentage success rate	56.3%	37.5%	

Table 6.3. The uterus identification rates, ultrasound verified, for the two simulator-trained groups: Group A, teacher-led, and Group C, automated version.

All the students in Group C completed a questionnaire after the experiment to provide feedback on their experiences using the simulator. As the automated version was a prototype, information from the first group of users would be useful for future developments. The responses are detailed and presented graphically in Appendix 6.2. Students found the simulator easy to use, had no difficulty working through the training session using the keys, were not confused by the haptic device moving their hand around and considered the preliminary short training simulation to be necessary. The level of audio input was about right but students were divided over whether the best option would be to use a recording of a human voice rather than the simulated voice, or perhaps a mixture of the two. Only one student considered that seeing the hand moving inside the cow on the computer monitor would have been better, the rest were not in favour of this option. All students reported finding the part of the training where they explored on their own useful. All except one student used the 'Help' key at this stage and most of them rated this function as valuable. When asked about the effects of simulator training on learning skills for the real task, including finding and identifying key structures, the responses were in the 'Strongly Agree' or 'Agree' categories, from all or the majority of students, for each statement. All the students entered comments on the questionnaire and these are detailed in Appendix 6.3. The students mentioned other objects that should be included in future versions: the rumen, the bladder and other representations of the uterus. Additional instructions about "how far to go into the real cow" would be helpful. In the general comments section, the simulator training was repeatedly referred to as "helpful" and "useful". All students selected 'Strongly Agree' in response to a statement asking whether they thought that the simulator would be used if available in a clinical skills laboratory.

6.5 Discussion

6.5.1 Automated Version

The aim of the work presented in this chapter was to develop an automated version of the simulator that students could use on their own. The computer needed to take over the teacher's roles providing instructions, guidance and feedback. A decision was made to use a combination of haptic guidance, with the PHANToM device moving the trainee's hand along the path of an expert's examination, and audio instructions, to replace the teacher's voice. Eight students underwent training with a prototype automated version, which included training environments designed to equip students with the skills to find and identify the pelvic landmarks and the uterus. These are the first skills that students need to master when learning to perform bovine rectal palpation. The efficacy of this version of the simulator was determined by measuring skill transfer to the real task and the results were also compared with previous findings using the teacher-led version. Additionally, feedback was gathered from students on their experiences using the simulator.

Hypothesis 1 stated that the group trained with the automated version of the simulator, Group C, would be no better at finding and identifying the uterus than the group who had traditional training only, Group D. This hypothesis is rejected as the simulator trained students were significantly better at finding the uterus when examining cows for the first time than the other group. The automated version had provided a training environment that students could use on their own to learn the skills for this task.

Hypothesis 2 stated that there would be no difference in the time taken to complete the task between the two groups. However, as Group D only made two successful identifications of the uterus (of a possible thirty-two) in comparison with the twelve successes of Group C, this hypothesis was not tested. If given more time, there might have been more successes for both groups but a maximum of five minutes per cow was set in the interest of animal welfare.

A comparison was then made between the two groups of students who had received simulator training: Group A, teacher-led and Group C, automated version. Hypothesis 3 stated that there would be no difference between the two groups when measuring their subsequent performance finding the uterus in cows. The analysis supported this hypothesis, which indicates that the automated version provided as effective a means of equipping the students with the skills to find and identify the uterus as when a teacher used the simulator to deliver the training. However, there was a difference of nearly twenty percent between the two groups, the teacher-led group being better than those trained with the automated version. The group size was set to evaluate the effects of simulator training when compared with traditional training, not specifically to compare the two different versions of the simulator. The results found that there was no significant difference but further analysis should be considered with larger numbers of students.

When students examined cows on the farm, in both of the experiments a pair of students, one from each group, examined the same four cows. This was because cows vary both with regard to the ease of locating and identifying the uterus and the difficulties of performing the examination. Therefore, the differences were matched when comparing the performance of simulator trained students with traditional trained students. However, this was not the case when comparing between simulator versions, Groups A and C, as the students examined different cows. This could have had an effect on the performance levels achieved and therefore, the interpretation. The differences between the cows would have particularly affected the time taken to perform the task and therefore, the times for Groups A and C were not analysed. If the two training methods were to be compared further and the speed of the examination investigated, each pair of students, one trained on the simulator by the teacher and one using the automated version, should examine the same cows.

A questionnaire was used to gather feedback from the students on their experiences using the automated version of the simulator. The simulator had been shown to be effective for equipping students with the skills to locate the uterus but, in the future, would need further development to include training for a wider range of skills. Feedback from users is an important part of the development process and would help identify usability issues, support or refute design decisions, and highlight areas that needed modification. The students' responses indicated that the simulator was easy to use and they favoured haptic guidance and audio cues without visual information on a monitor as the means of providing the training. However, there are certain modifications that could be considered. The instructions were delivered using a simulated voice, which is monotonous. Another option would be to use a pre-recorded human voice either throughout or in parts, perhaps to emphasise certain points. The initial design used a simulated voice, created using text-to-speech technology, because editing was easy whereas a human voice would have had to be re-recorded. The students did not favour graphic guidance, and an argument could be made for the exclusion of graphic cues when the real task is unsighted. However, collocated graphics, where the student would see the hand moving over the simulated objects *in situ*, could be included in a future development and the effects of visual information on learning could be investigated.

The students also suggested making certain modifications to the simulated environment. The automated version only included representations of the pelvic landmarks and two examples of the uterus. When examining cows, other structures may be palpated including the rumen and the bladder, which could be confused with the uterus initially and, although there were verbal references to these objects, students suggested virtual models should be included as well. The size, position and feel of the uterus vary considerably between cows and the students suggested that more examples would have been helpful. Also more instruction or emphasis was needed on how far to advance the hand into the cow. There is considerable variation between cows in the position of even basic landmarks, including the pelvic brim, and therefore, absolute distances are not particularly useful. When the students were examining cows on the farm, the researcher noticed that, when unsure of how to proceed, students often tended to advance too far into the cow. One of the students in Group C failed to find the uterus in any of the four cows examined, being too far forward in each case. When the teacher was present using the simulator, students were often observed to keep moving forward when lost. The teacher would point out that under these circumstances the pelvic brim should be located as this was a useful landmark and should be used to work out whether to move forward or backwards to find the uterus. The automated version needs to include more emphasis on this point in the future.

There are likely to be other benefits of having a teacher present, not least of which is that for many people the most memorable parts of their education have been related to the ways certain individuals have been able to teach. The automated version had the advantage of being developed after the full evaluation of the teacher-led version. Therefore, the design had included some of the findings from the previous work, for example, not forgetting to emphasise some of the physical differences between the simulator and the real cow. When a teacher is present, the training can be adapted to the individual's learning needs, and although when using the automated version students could choose to practice exploring as frequently as they considered necessary, the learner is less able than a teacher to direct practice to the required areas. Additionally, the teacher-led sessions were more dynamic as the instructor could intercede and correct mistakes, providing formative assessment, which is an important part of the learning process. The teacher-led sessions also included 'on farm' scenarios, which were popular and considered to be a beneficial way of learning. If possible, these should be included in an automated version although this would involve addressing the challenging design issues of supporting a dialogue between the student and the computer, the latter taking on the role of the farmer.

The work undertaken to develop and evaluate an automated version has demonstrated that the simulator could be modified for students to use without a teacher. Additionally, the students were able to use the training tool to learn skills that were useful for examining cows. There are several advantages of an automated version including reducing the costs of the training package as a whole by removing the expense of one-to-one teaching. Also, the automated version would be a more accessible to students, as use of the simulator would not be restricted to the times when a teacher was available. The version evaluated in this chapter was a prototype, developed to explore the potential of providing automated training, and only included relatively simple simulations. The student feedback and experimental results were encouraging and therefore, indicate that further development would be worthwhile.

6.5.2 Validation of the Simulator

The work presented thus far has addressed the challenges of developing and validating a simulator, the Haptic Cow, for teaching veterinary students to perform bovine rectal palpation using haptic technology. The initial aim was to design a teaching tool that would equip novice students with the required skills and enable the teacher to have a more effective input into the student's learning process. The virtual models needed to be realistic enough that on the basis of the way an anatomical structure felt in the simulator, students would be able to recognize the same structure in the cow. An expert's knowledge was used as the basis for the feel of each structure, in a highly iterative design process, together with input by other veterinary surgeons. The teaching and learning needs were determined after considering the views of both veterinary surgeons, as experts and teachers, and students, as learners. A teaching protocol was designed with a structured series of levels and steps (determined using a task analysis), which provided the teacher with a format to use during training sessions. The teacher could follow the student's actions inside the cow on the computer monitor and therefore, provide guidance and feedback on performance.

An important part of simulator development is validation and this should be undertaken before the simulator is recommended for widespread use. Validation involves measuring certain criteria that establish whether the tool is designed correctly and is effective for the specified task (Neufeld and Norman 1985; Berg *et al.* 2001). If the simulator is used as a training tool, validation involves demonstrating that the simulator equips students with the required skills. If the simulator does not provide the skills, students remain untrained and in the worst case scenario, if learning inappropriate skills, the patients, animal or human, may be put at risk. Simulators are also used to provide objective assessment of skill and, in these cases validation involves establishing the credibility of the device as a measuring tool. Whatever the simulator's function, the first step in validation involves demonstrating that the simulation created is realistic enough (face validity). Then the simulator must be shown to include the component steps of the task being represented (content validity) and to perform in a reliable way in different situations. The simulator can be evaluated with regard to the measurement of skills, including demonstrating that when different operators use the simulator their existing skill levels can be differentiated, experts performing better less experienced individuals (construct validity). Measurements should correspond to those using other methods (concurrent validity) and skills developed or measured on the simulator should predict subsequent performance (predictive validity). Ultimately, for simulators used as teaching tools, validation should include demonstrating that training has equipped students with skills that transfer to the real task. There are practical issues to address as well, including demonstrating that simulator use would be feasible under real world conditions within, for example, any limitations of resources and the constraints of a curriculum.

In the case of the Haptic Cow, the simulator was designed as a teaching tool for training novice veterinary students to palpate the reproductive organs of cows, and the research work addressed the validation criteria relevant to this application. A realistic enough virtual environment has been created (face validity), as determined by experts. The design of the teaching protocol was considered to support the component steps required to achieve the learning needs (content validity). These are important steps that should be undertaken before considering further work. In previous studies, with other virtual reality palpation simulators, the failure to validate the simulator by demonstrating one or more of Neufeld and Norman's criteria was considered to be due to a lack of realism of the virtual environment. This was the case for both a prostate simulator, where experts failed to outperform novices (Burdea *et al.* 1999), and similarly for HOPS (Crossan *et al.* 2001), and in both cases face validity had not been established. Additionally, with both these simulators, when assessing skill development the researchers had used either the virtual environment (Burdea *et al.* 1999) or post mortem specimens (Crossan *et al.* 2003) rather than real patients: the ultimate test.

After establishing Neufeld and Norman's criteria that indicated that the design of the Haptic Cow was sound, work was undertaken to investigate whether simulator training equipped novice students with skills that were useful when examining cows for the first time. An experiment was conducted to compare the performance of two groups of eight students who had never performed rectal palpation of a cow or horse. One group received only the traditional training, while the other group's training was supplemented with a simulator session with a teacher. The students were then set the task of finding and identifying the uterus when subsequently examining cows for the first time. Ultrasound images were used to identify structures palpated, which overcame the difficulty encountered when trying to verify performance for an internal procedure. All the cows belonged to the same herd and students were paired, one student from each group examining the same four cows, to minimise the effect of cow variability on performance. The students trained with the simulator performed significantly better than those who only had traditional training. This indicated that the teacher had been able to use the simulator to train students to develop the required skills for the task and that the virtual models were realistic enough for students to identify structures in the cow correctly, further establishing the face validity of the virtual environment. These results validate the simulator as an effective training tool for equipping students with the skills needed to locate the uterus when examining cows for the first time.

After demonstrating that the training was effective, there were still practicality issues to address with regard to the simulator's use in a real world situation (Neufeld and Norman 1985). The project to integrate the Haptic Cow into the farm animal course at the University of Glasgow Veterinary School investigated the feasibility of using the simulator within the constraints of a curriculum. The feedback and comments from students were particularly helpful for identifying problems, omissions and areas requiring further development. The simulator continues to be included in the farm animal course at Glasgow and distribution to other veterinary schools is currently underway.

One criticism of the above work relates to the fact that all the training was delivered by one individual, the researcher, and the usability and efficacy in the hands of others has not been tested. Also the simulator should be evaluated at other veterinary school, where the existing training methods and the structure of the curriculum may present additional challenges. Therefore, work could have been undertaken to investigate the skill development of students trained by other teachers and at other institutions. However, another approach was taken. An automated version was developed with the teacher's role replaced by computer guidance. This new version was developed as a prototype and delivered basic training for complete novices in preparation for the first examination of a real cow. A training tool that does not require the presence of a teacher would also address other practical issues: making the simulator more accessible and reducing the cost. The current chapter presented work to design an automated version of the Haptic Cow using a combination of haptic guidance and audio cues. The new version was validated by demonstrating that students learned skills that were useful for the real task and therefore, computer-assistance can be used to provide an effective replacement for a teacher.

Another consideration is that the results need to be placed in the context of the procedure as a whole. The task assessed was finding and identifying the uterus. This is a fundamental skill, the importance of which cannot be overstated, because students need to be able to find the uterus before progressing on to performing a full fertility examination, diagnosing pregnancy or even putting a scanner in the right place. Simulations had been developed for the more advanced procedures of ovary palpation and pregnancy diagnosis and experts had assessed the virtual models as realistic enough representations. During the curriculum integration work, fourth year students had been taught the more advanced techniques and some aspects of the teaching protocol were modified as a result of student feedback. However, further work needs to be undertaken to determine whether the simulator actually equips students with the required skills by demonstrating improved performance during the real task. If further skill development were demonstrated, then the automated version should be extended to include all the features of the teacher-led version, with the aim of providing a training tool for a wide range of skills in an accessible, versatile and more affordable format.

The work has also highlighted how difficult the procedure is for novices. Part of the motivation for the development of the simulator had been to provide a more effective way of training students. Feedback from students during and after the Master's project by Baillie (Baillie 2003) had indicated that traditional training was not very effective. The students in Groups B and D, who had only the traditional training provided at the University of Glasgow Veterinary School before examining cows, performed very poorly, supporting the previous reports (Baillie 2003). The majority of farm animal experience takes place during EMS but, for various reasons, the help that students receive can be limited. This is partly because the veterinary surgeons are trying to teach at the same time as conducting their commercial work and, as the procedure is unsighted, providing help can be difficult under any circumstances. The results from the experiment suggest that a simulator session prior to the farm animal placement training would be beneficial. Students would then be better able to make use of the learning opportunities provided during EMS and, if able to identify structures palpated, could have a more effective dialogue with the veterinary surgeon.

In addition to providing users with touch related interaction in virtual environments, haptic devices have other functions and can be used to investigate various aspects of a user's performance during tasks. Therefore, as well as being used for teaching, the bovine simulator could have a role as an assessment tool. When examining cows, the student's actions are not visible, which not only makes teaching difficult but also means performance cannot be assessed accurately. Developing the simulator to include a way of measuring skills objectively would be useful. All the work to date has been directed towards developing a teaching tool, supporting the teacher's role and the student's learning needs. Therefore, further development would be necessary and a list of performance metrics would need to be defined. Further validation would also need to be undertaken and would include Neufeld and Norman's criteria for simulators used as assessment tools establishing whether: the simulator discriminates between different levels of expertise (construct validity), the measurements correlate with performance during the real task (concurrent validity), and those scoring highest in the simulator test would also then have the best performance during the real task (predictive validity). In an era where the health professions are increasingly required to assess a student's clinical skills objectively and to revalidate clinicians, then a project to investigate the simulator's potential in this area would be worth considering.

Another way of making use of the technology as a measuring device would be to use the simulator to find out more about how we perform palpation-based procedures. Experts have difficulty articulating exactly what they are doing and this is compounded further when the procedure is internal and therefore, the expert's technique can not be watched by the trainee. In the simulated environment, the device can record and playback the expert's path. This functionality was used in the automated version of the bovine simulator to guide students and in the Horse Ovary Palpation Simulator to evaluate performance (Crossan 2004). Additionally, a test environment can be created to investigate various aspects of an individual's perceptual abilities. In the next chapter, work is presented that uses the simulator in this way to answer a question raised by students. When teaching, students often asked the researcher: "Which hand should I use *(to perform rectal palpation of a cow or horse)*?" because some veterinary surgeons were advising the use of the left hand, although the justification for this was uncertain. Most people, if given the choice, would prefer to use their dominant hand to learn a new manual skill. An experiment to test the abilities of the two hands for certain tasks, which were considered to be important skills for performing bovine rectal palpation, has therefore been undertaken using the simulator (Chapter 7).

6.6 Conclusions

In human and veterinary medicine, there is an increasing need to find new and more effective ways of training the health professionals of the future and simulators, in their many forms, represent one possible solution. The aim is to develop teaching tools that will equip trainees with the required skills and reduce risks to patients. Validation, which involves demonstrating that a simulator is effective, is a very important part of the development process without which the benefits cannot be guaranteed (Neufeld and Norman 1985; Berg *et al.* 2001; Magee 2003; Scalese and Issenberg 2005). The majority of virtual reality (VR) based simulators have been developed for minimally invasive surgery and minor procedures but there are only a few examples of research that demonstrates that training has beneficial effects on subsequent performance during the real task. The MIST-VR simulator, a basic surgical skills training environment, has been shown to result in improved performance in the operating room when surgeons performed cholecystectomy, either when MIST-VR was used in isolation (Seymour *et al.* 2002) or in combination with a simulator designed specifically for laparoscopic procedures (Schijven *et al.* 2005). An endoscopy simulator has also been shown to provide effective training for medical residents (Ost *et al.* 2001). There are only a few VR simulators developed specifically for palpation procedures and, although some have demonstrated training effects in the virtual environment (Crossan *et al.* 2002; Howell *et al.* 2006), no work has been undertaken to measure skill transfer to the real task.

The work undertaken in this thesis has validated the bovine simulator by demonstrating that: the training environment was sufficiently realistic; a teacher was able to use the simulator to equip students with skills that transferred to the real task (finding and identifying the uterus in the cow); and simulator training could be integrated successfully into a curriculum. Even though the work had shown that the simulator was an effective and useful tool, there were certain areas that still needed to be addressed. The one-to-one teaching was expensive and had relied on one individual. The work presented in this chapter described the development of an automated version that students could use on their own and this has been validated for the basic skills. There are also issues relating to the more advanced procedures performed during bovine rectal palpation, including pregnancy diagnosis and fertility examinations. The simulator-based representation of ovary palpation is, to a certain extent, limited by the single point of contact of the PHANToM haptic device. Additionally, further validation work needs to be conducted to ensure students are learning the required skills. In spite of these reservations, the more advanced techniques have been taught as part of the fourth year simulator-based training and have been well received by students.

Overall, the work has established more of the criteria defined by Neufeld and Norman (1985) for validating simulators used in medical education than any other virtual reality simulator developed for a palpation-based procedure. Importantly, training with the simulator has been shown to equip students with useful skills that transfer to the real task. The teaching environment provides standardised training for the basic skills and gives access to a variety of cases and learning opportunities. The automated version could be made available in a clinical skills laboratory for all novice students to use prior to the first examinations of cows. The teacher-led version offers considerably more functionality and would be particularly useful to address individual student's learning difficulties or skill deficiencies. Additionally, for students wanting to work in farm animal practice, one-to-one sessions could be included as part of a farm animal clinical rotation and used to reinforce and further develop existing skills.

Chapter 7: Investigating Aspects of Palpation-Based Skills with the Simulator

7.1 Introduction

Certain veterinary palpation-based tasks, including rectal examination of cows and horses, are single-handed procedures. When teaching with the simulator students often asked: "Which hand should I use?" There are practical reasons that could favour either hand under different circumstances and some students commented that during EMS some practitioners were advising using the left hand. However, when palpating the Haptic Cow simulations, without being told to use of one hand or the other, most students chose to use their dominant hand. The motivation for the work presented in this chapter was to gather evidence to answer the students' question through a survey of practitioners, information from the literature and an experiment to investigate the performance of the right and left hand for veterinary palpation-based tasks using the simulator.

7.2 Survey of Veterinary Surgeons

A survey was conducted to assess the ratio of right and left hand use by veterinary surgeons when performing rectal palpation of cows and horses. Anecdotal evidence from the profession had suggested that the ratio of hand use was different to the ratio of right- to left-handers, with a number of right-handers using the non-dominant hand. In populations, right-handers greatly outnumber left-handers and a large survey conducted in the early 1990s found that the incidence of left-handedness was about one in ten (Perelle and Ehrman 1994). A short questionnaire was used to gather information from veterinary surgeons, who were asked: which was their dominant hand; which hand was used to perform a rectal examination; to comment on the reasons for the choice. Feedback was obtained from 78 veterinary surgeons and the results are summarised in Table 7.1. Of the respondents, 82% were right-handed, 13% left-handed, and 5% classified themselves as ambidextrous. The percentage using the right hand to perform rectal palpation was 53%, left hand was 35% and 12% used both. Of the 64 right-handers, 30% were using their left hand, 58% were using the right hand and 12% used both. Only one of the 10 left-handers used the right hand.

Question: Are you…			Question: Which hand do you use when performing rectal palpation of cows & horses?			
Right-handed	Left-handed	Ambi-dextrous	Hand used:	Dominant	Non-dominant	Both
			R-handers	37	19	8
64	10	4	L-handers	8	1	1
82%	13%	5%	Ambidextrous	3 use R, 0 use L		1

Table 7.1. Results of a survey of 78 veterinary surgeons on handedness and hand use when performing rectal palpation of cows and horses.

Seventy-five of the 78 veterinary surgeons had written a reason when asked about the choice of hand. The comments are detailed in Appendix 7.1. The common reasons right-handers stated for using the left hand were: being told to, the left hand was more sensitive, the right hand was then free for other (dextrous) tasks. The common reasons why right-handers used the right hand included: this was easier, the arm was stronger, more confident. The reasons for being able to use both were often practical and related to times when changing hands was useful. The reasons for left-handers using the left hand included: easier, stronger, more dextrous. The left-hander who used the right hand played tennis with the right hand and felt this arm was stronger.

The survey did support the suspicion that a higher proportion of the profession used the left hand than were left-handed. As well as most of the left-handers, just under a third of the right-handers used the left hand. However, when considering the range of reasons for the choice, a case could be made to justify using: the right hand, the left hand, the dominant hand, the non-dominant hand or being able to use both hands. The dominant hand was favoured by left- and right-handers because it was easier, stronger and individuals felt more confident. The superior dexterity of the dominant hand was used as justification either for leaving the dominant hand free for other tasks or for examining cows, when dexterity would also be useful. Many individuals, particularly the right-handers using the left hand, stated their reason as being 'told to' or 'taught to', which does not add much to the debate but does indicate that the belief is being passed down. The reasons for the hand choice did not clearly justify the use of one hand in preference to the other. Therefore, on the basis of the survey, the hypothesis that the left hand should be used to perform bovine or equine rectal palpation could not be supported or refuted.

7.3 Evidence from the Literature

Further information was gathered by searching the literature for evidence that might indicate which hand, if either, would be superior for learning or performing palpation-based tasks. Palpation involves sensory components, which provide information about objects and the environment as well as the motor functionality required to perform the procedure. There is a large body of research that has looked at various aspects of hand performance, some of which dates back many years. For example, in the 19th century Weber performed experiments that suggested that the left hand was more sensitive to weight and temperature (Weber 1834: translation 1978). For the current study, the aim was to relate the findings of experimental work to the component skills used when performing bovine rectal palpation. There have been two papers that have presented and reviewed relevant work and these were used as the source of information to link hand ability to the required skills (Summers and Lederman 1990; Fagot *et al.* 1997). The findings, which were predominantly from right-handers, are summarised in Table 7.2. There are categories for the skill, the hand with the superior performance, and the relevance to bovine rectal palpation. In some cases, the findings for hand performances for a particular skill were conflicting and the review authors indicated that this may be related to various factors including the tasks used to test the skill, the means of recording results (verbal, written, other), the handedness of participants and gender.

Skill	**L / R / =**	**Relevance to bovine rectal palpation?**
Pressure	L, =	Assess firmness / softness of anatomical structures
Position sensing	L	To orientate inside the cow?
Roughness	=	Relevance? As most surfaces are smooth
Retain a sequence	R, L	Search strategies, a sequence of touch-based events
Braille	L, =	Relevance?
Line orientation	L	Relevance?
Tactual maze learning	L, =	Learn series of moves for search inside cow
Motor learning	=	Motor component of palpation and manipulation
Form / object discrimination	R, L, = L, =	- Letters: relevance? - Non-sense shapes: cow tract objects?

Table 7.2. Hand abilities for palpation-based skills. In the first column the skills assessed are listed. The column headed 'L / R / =' indicates which hand, if either (=), had the superior performance (where findings vary there is more than one entry). In the third column, the skill's relevance to bovine rectal palpation is considered. (Information collated from the reviews by Summers & Lederman (1990) and Fagot *et al.* (1997)).

The evidence based on experiments conducted predominantly with right-handers, although in parts conflicting, indicated that for most of the sensory-based skills there was either a superior performance by the left hand or no difference between the hands. However, there are also motor components to bovine rectal palpation including, for example, manipulation of the reproductive tract and ovaries. The dominant hand is more dextrous and will be more able, at least initially, to perform these tasks. The dominant arm is also stronger and less likely to fatigue. Therefore, for right-handers, a case could be made for using either hand. The superiority of the left hand for certain aspects of the task would have to be balanced with the advantage of the right dominant hand for the motor and dextrous components. There was not enough information for left-handers to determine the most appropriate hand choice although the dominant hand would be more skilled for the motor components of the procedure.

The findings so far indicate that there are a range of factors to consider when choosing which hand to use to perform bovine rectal palpation. There are practical issues to consider, as mentioned by the veterinary surgeons, in addition to the abilities of the two hands for the component skills. The hand advantages for palpation-based skills as described in the literature tend to suggest that for right-handers the sensory components the choice may not matter (equal abilities) or there may be an advantage for the left hand. For the motor components, the dominant hand has the advantage. However, the research work was carried out in a range of environments and for tasks that were not directly linked to the procedure as performed by veterinary surgeons when examining cows. There would be practical issues that would make investigating hand performance during the real task very difficult. An experiment was conducted in the simulated environment to investigate perceptual abilities of right-handers. They were assessed while undertaking some of the component skills used for bovine rectal palpation and the performance of the left and right hands was compared.

7.4 Experiments to Investigate Hand Performance: Size and Softness Perception

7.4.1 Test Environment

Pregnancy diagnosis was chosen as the task on which to base the investigation. This was because manual palpation of pregnancies is a skilled technique and requires considerable practice to make accurate diagnoses. The foetus implants in one uterine horn (ipsilateral to the ovary from which the egg was derived). The implanted horn then increases in size relative to the non-implanted horn. In the first trimester, manual pregnancy diagnosis involves palpating the uterus and assessing the relative size and softness (fluid content and wall thickness) of the two uterine horns. An experienced cattle practitioner can appreciate these changes from about 35 days of gestation and can age early pregnancies to within a few days.

The experiment was conducted in a virtual environment using the PHANToM. The two components of the task – assessing relative size, assessing relative softness – were investigated separately using a technique from psychophysics (the branch of psychology that deals with the relationships between physical stimuli and sensory responses), see Section 7.4.3 below. The uterine horns were modelled as two parallel cylinders, a more simplistic representation than in the teaching environment and the cow. The previous simulations used combinations of stretched spheres, which vary in width and therefore, were not suitable for the experiment. In one experiment, the diameter of one cylinder was set at a value to represent a non-pregnant uterine horn and the diameter of the other was larger, representing various stages of early pregnancy. In the other experiment, the softness (the stiffness or KSpring value) of one cylinder represented a non-pregnant uterine horn while the other cylinder was softer (lower stiffness or KSpring value), representing various stages of early pregnancy. The abilities of the left and right hands to differentiate between the two cylinders were assessed for each property: size, softness.

7.4.2 Measuring Perceptual Abilities in Virtual Environments: Related Work

Other work has been undertaken to investigate perceptual abilities similar to those needed to perform pregnancy diagnosis using virtual environments that incorporate haptic feedback from a PHANToM. A study by O'Malley and Goldfarb (2002) found that subjects had comparable performance when assessing the size of both real and virtual objects (rectangles and cylinders), indicating that the virtual environment provided a realistic enough representation and interaction. A small study, with three participants, measured the ability to detect height differences between two virtual surfaces (Walker and Tan 2004). The smallest difference that could be detected, which is also termed the just noticeable difference (JND), was small (0.17 – 0.63mm) and was affected by the stiffness of the surface, the firmer the surface the smaller the detectable difference. When assessing the relative curvature of two virtual spheres, a difference in the radius of at least 11% was required for the two objects to be accurately differentiated (Provancher *et al.* 2003). Another experiment also looked at participants' abilities to differentiate between the curvatures of two virtual spheres (ranging from 2.5 to 6.5cm in radius) and the effect of changing the surface properties of hardness, texture and friction (Jansson and Pieraccioli 2004). The JNDs in the radii of the two spheres ranged from just under 2mm to just over 3mm (exact values not stated) for the different conditions. Only texture was found to affect this level of performance significantly, making differentiating between the spheres more difficult. They also observed that in the experiment where the degree of hardness was altered, participants initially had difficulties assessing the curvature of soft spheres accurately but then adapted their technique. In another study investigating subjects' abilities to judge the curvature of a cylinder, the level of performance was found to be affected by surface friction (Christou and Wing 2001). Subjects tended to overestimate the size when friction of the surface was low and underestimate when friction was high. There have also been studies to measure perceptual abilities when differentiating between stimuli or objects on the basis of the relative softness or hardness. This is measured either as the compliance, the ability of the object to yield (in mm/N), or the stiffness, a physical property of the object (in N/mm). When participants probed virtual objects with a stylus, an 8 - 12% change in stimulus stiffness was required for the difference in the objects to be noticeable (DeGersem 2005). A compliance difference of between 14 and 24% was observed when pressing objects with a finger in a thimble, a larger difference being needed the softer the reference object (Dhruv and Tendick 2000). Additionally, when students were learning to locate areas of abnormality represented by changes in compliance during training with the Virtual Haptic Back, the smallest differences or JNDs that could be detected were in the range of 9 to 21% (Howell *et al.* 2006).

The findings of these studies have implications for the current experiments to assess the performance of each hand in a virtual environment. The PHANToM has been used successfully to run experiments to test perceptual abilities for a range of object properties including those used during pregnancy diagnosis (size and softness discrimination) and therefore, provides a suitable environment for the current work. When assessing dimensional properties, such as height or curvature, quite small differences between objects were detectable. Similarly for softness, the percentage differences were less than 25%, although quite a range was observed. The values for some of these tests were expressed as percentages or Weber fractions as defined by Weber's law (Weber 1834: translation 1978). The law states that, for a given object property or stimulus type (size, stiffness, etc.), the JND is proportional to the reference stimulus intensity, and is expressed as:

$$\Delta I / I = c$$

where 'I' is the intensity of the reference (or standard) stimulus and 'ΔI' is the JND between the two stimuli being compared and 'c' is a constant (the Weber fraction). The perception of many object properties has been found to follow Weber's law. Therefore, the JND values from the literature provide a guide for the current experiments both for the design, which needs to include the expected range over which the results are likely to occur, and to provide a standard against which to compare the results. Another finding from some of the above experiments was that when measuring the abilities to discriminate between objects for one particular property, this was affected by other object properties. Therefore, in the current work, properties other than the one under investigation would be standardised.

7.4.3 The Staircase Method for Investigating Perception

The aim of the work was to investigate whether there was a difference in the abilities of the left and the right hands when performing the component tasks of manual pregnancy diagnosis. Individuals' perceptual abilities can be measured using a range of methods from psychophysics (Gescheider 1997). These methods are designed to determine sensory responses to physical stimuli and can be used to measure an absolute threshold or a difference threshold (the just noticeable difference (JND) referred to previously in Section 7.4.2). In the following experiment, a difference threshold was determined using the staircase or up-down method (Cornsweet 1962; Levitt 1970). This method was chosen for two reasons. First, a staircase is classified as an adaptive method, which is an efficient way of determining a threshold as the stimulus intensity for any given test is calculated on the basis of the preceding test value and the participant's response. Second, during the real task, the veterinary surgeon feels for differences between the two uterine horns as part of the diagnostic process.

During an experiment that uses a staircase, the participant is asked to differentiate between two stimuli or objects on the basis of a particular property, for example, the diameter of the two uterine horns. One of the stimuli, the standard or reference (in this case, a cylinder representing the non-pregnant uterine horn), remains the same throughout the experiment while the other, the comparison (the pregnant uterine horn), changes. Initially the participant is presented with two stimuli that are very different. As the experiment progresses the difference between the two narrows until the difference is barely detectable. In the following experiments, the two stimuli (cylinders) were presented side-by-side on a platform (Figure 7.1) and the task was to determine whether the comparison object was on the left or the right.

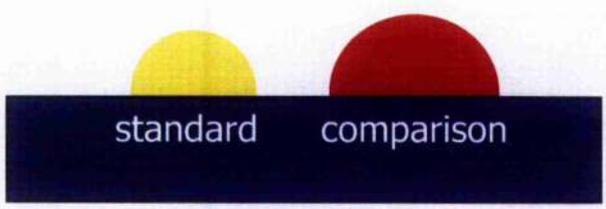

Figure 7.1 An illustration of the experimental environment used to assess participants' abilities to differentiate between objects on the basis of size (diameter). Two cylinders, the standard (representing a non-pregnant uterine horn) and the comparison (representing the larger pregnant uterine horn) were presented to the participant. The cylinders were randomly allocated to the left and right sides. The task was to identify the position of the larger comparison cylinder.

In the original staircase described by Cornsweet (1962), the comparison stimulus changed after one success (correct answer) or failure (wrong answer), a 'one-up one-down' staircase. In the following experiments, a modified version was used (Levitt 1970), described as a 'one-up 'n'-down' staircase, where 'n' is more than one. After 'n' correct responses ('successes') the next test becomes more difficult - the difference between the stimuli decreases. If the participant makes one mistake or wrong answer ('failure'), the next test becomes easier - the difference between the stimuli increases. When the difference between the two stimuli increases or decreases the staircase direction reverses. The modified version of the staircase was used because this provides a more reliable estimate of the difference threshold, as more than one correct response is required at a given stimulus intensity before the stimulus is changed. A 'one-up three-down' staircase (e.g. Figure 7.2) was chosen as a practical compromise between achieving higher test reliability (than with one or two successes) and an overly long experiment (with four or more successes required for a stimulus change). When there is a large difference between the stimuli or objects, participants should differentiate correctly 100% of the time. When the performance is reaching the perceptual limit, the stimuli or objects will appear to be the same and a single answer will have a 50% chance, or probability, of being correct. At this point on the staircase, the Probability(up) = Probability(down) = 0.5. Therefore, in a 'one-up 'n'-down' procedure, the probability of the stimulus level decreasing is Probability(down) = p'n', where p is the probability of a correct response. This is expressed as:

$$\text{Probability p (of answer being valid)} = 0.5 \wedge ^{(\text{no. incorrect responses / no. correct responses})}$$

Therefore, for a 'one-up one-down' staircase p = 0.5, for a 'one-up two-down' p = 0.71 and for a 'one-up three-down' p = 0.79 ($0.5 \wedge ^{(1/3)}$) (Levitt 1970).

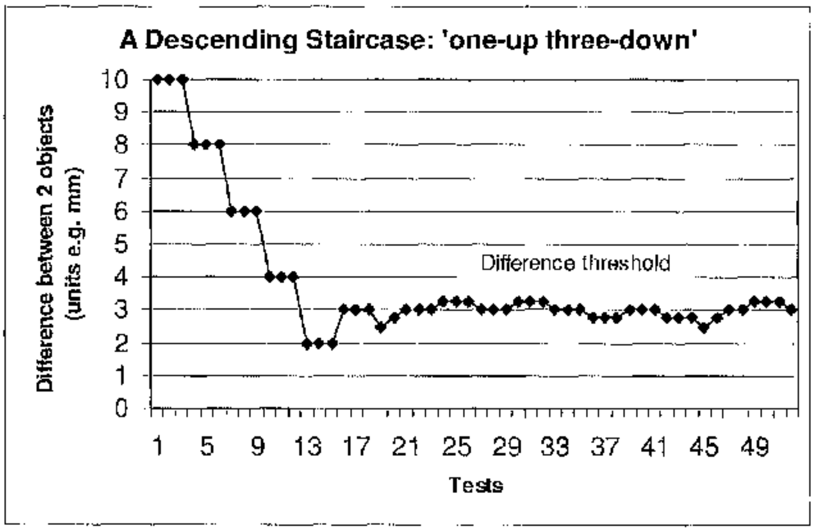

Figure 7.2. An example of a 'one-up three-down' descending staircase used in the size experiment. The differences between the values of the standard and comparison stimuli or objects are plotted on the y axis. After three correct responses, the next test becomes more difficult, the difference between the standard and comparison objects is reduced by one step. After a mistake, the staircase changes direction (reverses) and the difference between the two stimuli increases. In this example, the initial step size is 2 units. This value is then halved after each reversal in the staircase direction until a minimum step size (0.25 units) is reached. The experiment finishes after a set number of reversals at the minimum step value (eight reversals in the current experiments). The difference threshold is calculated as the average of the values of the reversals at the minimum step value.

The initial size of the staircase step has a predetermined value and, as the experiment proceeds, the steps bring the value for the comparison stimulus or object closer to the value for the standard and the participant's perceptual limit. The step sizes change after reversals (success after failure, failure after success) (Figure 7.2), which enables the staircase to converge on the threshold more quickly than if the step size was to remain the same (Levitt 1970). Additionally, throughout the experiment, the participant is forced to make a choice even when unable to differentiate between the two stimuli ('don't know' is not an option). The experiment finishes once a predetermined number of reversals have occurred. An individual's difference threshold is calculated by averaging the intensities of the stimuli at the reversal points. This is when the participant has reached his or her perceptual limit and can no longer detect a difference between the two stimuli. In the current experiments, this will be when the two objects are perceived to have the same size (diameter in mm) or softness (stiffness or KSpring value in Newtons/millimetre). The number of reversals used to calculate the difference threshold will be a compromise between increasing the number of values and extending the experiment to a point that might lead to fatigue or boredom.

A further classification of a staircase relates to the direction. When the comparison stimulus has a higher value than the standard (Figure 7.2 above), the staircase is descending. When the comparison object has a lower value than the standard (Figure 7.3 below), the staircase is ascending. The size discrimination experiment used a descending staircase as the standard stimulus or object represented the non-pregnant uterine horn and the comparison represented the pregnant uterine horn, which has a larger diameter. The softness discrimination experiment used an ascending staircase, the standard stimulus or object represented the non-pregnant uterine horn and the comparison represented the pregnant uterine horn, which would be softer (a lower stiffness or KSpring value).

The experimental procedure employed in the current study is classified as a 'two-interval, one-up three-down, forced choice adaptive procedure'. This classification is based on all the criteria described above: comparing two stimuli or objects; using a 'one-up three-down' staircase; and the participant being forced to make a choice, even when unsure. The values for the staircase range and the step sizes need to be established and for the current work were determined during pilot experiments (Section 7.4.4 below).

7.4.4 Pilot Experiments

The virtual environments consisted of two half cylinders, which represented the pregnant and non-pregnant uterine horns, resting on a platform. The values for the size and softness of the virtual models were based on those used in the teaching environment, which had been established by experts. Pilot experiments were run with four veterinary surgeons and six veterinary students to provide data on the performance of the left and right hands for the two tasks. These findings were also used to establish values for the staircase: the initial difference between the standard and comparison objects, an estimate of where the difference threshold was likely to occur, and the step sizes (Table 7.3). In each experiment only the property under investigation, size or softness, differed between the two cylinders and all other haptic property values were standardised (see values in bottom section of Table 7.3).

Criteria	Size Experiment	Softness Experiment
Staircase ('one-up three-down')	Descending	Ascending
Standard object	30 mm (diameter)	0.3 N/mm (KSpring)
Comparison object	40 mm (diameter)	0.18 N/mm (KSpring)
Initial step size	2 mm	0.02 N/mm
No. step sizes	4	4
Minimum step size	0.25 mm	0.0025 N/mm
No. reversals at min. step	8	8
Parameter values used for the other haptic properties of the virtual objects:		
Cylinder diameter	(see above values)	40 mm
Cylinder stiffness (KSpring)	0.25 N/mm	(see above values)
Static friction	0.5 N	0.5 N
Dynamic friction	0.2 N	0.2 N

Table 7.3. Values for the staircases and virtual objects for the size and softness experiments. These were determined during pilot experiments with veterinary surgeons and veterinary students. The haptic properties that were not being assessed were kept constant throughout each experiment and are given in the bottom section of the table.

For both size and softness, the range of each staircase (the difference between the standard and the initial value of the comparison object) was wider than (and therefore included) the values that might be expected on the basis of Weber fractions observed by others. For size, others have noted a required difference in excess of 11% for the difference in the size of two spheres to be detectable (Provancher *et al.* 2003). The range in the current experiment, set at 30 mm diameter for the standard cylinder and 40 mm for the comparison, includes such a difference. For softness (measured as stiffness or compliance), a percentage difference or Weber fraction of up to 25% between two objects was needed for the difference to be detectable (Dhruv and Tendick 2000; DeGersem *et al.* 2005; Howell *et al.* 2006). The range set for the softness experiment, with a stiffness or KSpring of 0.3 N/mm for the standard cylinder and 0.18 N/mm for the comparison, is wide enough to include the likely difference threshold.

The values for the difference in the abilities of the left and right hands of the veterinary surgeons and students were used to estimate the sample size. This indicated that approximately 37 participants would be needed for the experiment to assess size (mean difference 1.15 mm, standard deviation 2.41, $\alpha = 0.05$, power 80), and 35 for the experiment to evaluate softness (mean difference 0.15 N/mm, standard deviation 0.22, $\alpha = 0.05$, power 80) to detect a difference between the hands if present. During the pilot experiments, participants did both experiments with each hand (four staircases) and the results showed that, in some cases, performance deteriorating towards the end, suggestive of fatigue or boredom. Therefore, a decision was made that in the main experiments each participant would be tested on only one of the parameters, size or softness, not both.

There were differences in the ways that some participants performed for the two parts of the pilot experiments. When differentiating between the objects on the basis of size, participants, both veterinary surgeons and students, rarely made a mistake before reaching the difference threshold (their perceptual limit). However, in the softness experiment, half (three) of the students made mistakes prior to the difference threshold, 'pre-difference threshold' mistakes, and then would improve again. This did not happen with the four veterinary surgeons with either hand. This indicated that some students were adapting to the task and were learning how to assess softness as the experiment progressed. This could relate to becoming more familiar with the haptic device as learning effects have been demonstrated before when using the PHANToM (Jansson and Ivas 2000; Jansson and Pieraccioli 2004). A practice session had been included as part of the pilot experiments to allow participants to become familiar with the test environment. However, even after training, some of the students were still adapting during the main part of the softness experiment, whereas the experts did not. Therefore, although the standard staircase was suitable for the size experiment, a decision was made to use a modified version for the softness experiment that included an additional adaptive technique involving some extra rules for changing step sizes (Levitt 1970). An example of this type of adapting staircase is shown in Figure 7.3.

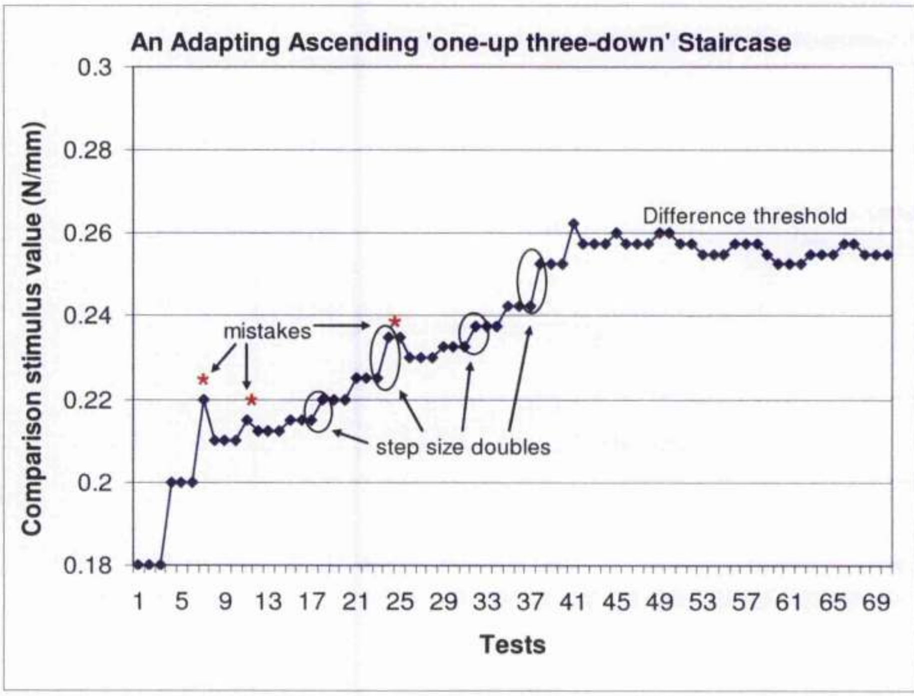

Figure 7.3. An example of an ascending 'one-up three-down' staircase, with additional adaptive techniques, used in the softness experiments. The comparison stimulus has an initial stiffness (or KSpring) value of 0.18 N/mm; the standard stimulus was less soft with a stiffness value of 0.3 N/mm. After mistakes (*) below the difference threshold, the participant adapts and performance improves. If a failure is followed by a run of successes, the step size will increase. The difference threshold was calculated as the average of the last eight reversals at the minimum step value.

In the softness experiment, the criteria used were that after the participant made a mistake, if this was followed by two consecutive correct responses (where a correct response was three correct answers at a particular stimulus value) then the step size would increase (double). This would be repeated, if the participant continued to be successful, until the maximum (initial) step size was reached, after which there would be no further doubling of the step size. There was no adaptation to successive mistakes, which did not result in a change in step size. The adaptive component of the staircase was no longer triggered after two successive reversals at the minimum step value. The formula for the adaptive staircase was developed after reference to the literature (Levitt 1970; Gescheider 1997) and looking at the way participants made mistakes, adapted and reached their perceptual limit during the pilot experiments, with the aim of reaching the threshold efficiently.

7.4.5 Hypotheses

Hypothesis 1 There would be no difference in the ability, measured as the difference threshold, of the left and right hands when assessing the relative size of the two cylinders (virtual representations of the two uterine horns). The dependent variable was the difference threshold (the just noticeable difference (JND)) in size (diameter in mm) between the two cylinders. The independent variable was the hand used to perform the test.

Hypothesis 2 There would be no difference in the ability, measured as the difference threshold, of the left and right hands when assessing the relative softness of the two cylinders (virtual representations of the two uterine horns). The dependent variable was the difference threshold (the just noticeable difference (JND)) in softness (KSpring in N/mm) between of the two cylinders. The independent variable was the hand used to perform the test.

7.4.6 Participants

The participants volunteered to take part in the experiments and were all right-handed female veterinary students with no prior experience performing bovine or equine rectal palpation. This subgroup of students was chosen for various reasons. There was a need to standardise the experimental groups with regard to certain criteria. There are gender differences that might affect the results as males are more lateralised than females and controlling for gender in experiments to investigate handedness is recommended (Summers and Lederman 1990). There are also differences between right- and left-handers, the latter, for example, tending to have superior spatial and visuomotor skills and left-handers are overrepresented among top sportsmen and women (Raymond *et al.* 1996). Therefore, the dominant hand needed to be consistent throughout the experimental groups. Additionally, the aim of the work was to clarify the situation for right-handers, as the literature and practical considerations indicated that there could be a case for left-handers using their dominant hand but for right-handers the position was more ambiguous (Sections 7.2 and 7.3). There were also practical reasons for choosing female right-handers because of the need to recruit sufficient numbers of participants (populations: approximately 90% right-handed; veterinary students: >70% female). Students were randomly selected (using the random function in Microsoft Excel) and allocated to the two experimental groups.

7.4.7 Experimental Procedure

For each experiment, the participants performed the task with one hand and then the other, counterbalanced for initial hand used in case of learning effects or fatigue. Each participant's handedness was assessed using a standard test, the Edinburgh Handedness Inventory (EHI)

(Oldfield 1970). The participants answered questions about hand preference for ten tasks (Appendix 7.2). This provided a means of determining the dominant hand and only participants who were rated as right-handed on the EHI test took part in the experiments. During the experiment, the participant was seated on a chair in front of the PHANToM with the elbow supported on a cushion on the armrest (Figure 7.4). The participants were given an instruction sheet (Appendix 7.3) and then underwent a training session. This allowed them to practice palpating objects, which they did with the middle finger in the PHANToM thimble, and to become familiar with the device and the layout of the virtual environment. The training session consisted of a total of 20 tests and was divided into two parts: first, the participant performed 10 tests while able to see both the PHANToM and the objects on the monitor; then the participant repeated the training without any visual cues, the monitor was turned away or covered and a box was placed over the PHANToM. The experiment was conducted in the unsighted format to prevent the participant gaining information from visual cues. Throughout the experiment the participant wore headphones to block out extraneous noise. After completing the experiment with one hand the participant rested and then repeated the training and experiment with the other hand.

Figure 7.4. Experimental set up for the size and softness experiments. The participant sits in front of the PHANToM haptic device (covered by a box and hidden from view by a curtain) and palpates the virtual objects with the middle finger in the thimble gimbal. The test involved identifying the comparison object: the larger (size experiment) or softer (softness experiment) cylinder as the object on the right or left of the virtual environment. The participant recorded the answer by pressing a key. The images on the computer monitor were out of sight (monitor turned or covered). (Photo included by kind permission of Caroline Walker).

During the experiment to assess size, the standard cylinder, representing a non-pregnant uterine horn, had a diameter of 30 mm, which remained the same throughout. The comparison cylinder, representing the pregnant uterine horn, was larger having an initial diameter of 40 mm. The softness of each cylinder was the same (stiffness or KSpring value of 0.25 N/mm). For the softness experiment, the size remained the same (40 mm) whereas the softness changed. The standard cylinder, representing the non-pregnant uterine horn, had a stiffness or KSpring of 0.3 N/mm. The comparison cylinder, representing the pregnant uterine horn, had a value of 0.18 N/mm at the start of the experiment and therefore, was perceived to be softer than the standard initially. Participants had to try to identify the location of the comparison object (the larger cylinder in the size experiment; the softer cylinder in the softness experiment) as being the object on the left or right. The cylinders were allocated randomly to the left and right positions. After making a decision, the participant recorded the answer by pressing the appropriate key, marked 'L' or 'R'. There was no feedback on whether the answer was correct and the participant had to make a decision (forced choice), guessing if uncertain. As the experiment progressed, the value for the comparison cylinder changed in response to the participant's answers. The values of the size or softness for each test were recorded and used to plot the staircase graphs from which the difference threshold was calculated.

7.5 Results

7.5.1 Size Experiment

Thirty-six female right-handed veterinary students started and completed the experiment with the left and right hands, counterbalanced for the initial hand used. The difference threshold was calculated for each hand of each participant by averaging the last eight reversals on the staircase. This was expressed as the number of millimetres that the comparison object's diameter was larger than the standard object. The results are detailed in Appendix 7.4, with tables that present each participant's difference thresholds for the left and right hands (with a note of which hand went first and which went second), the values of the last eight reversals, and the Edinburgh Handedness Inventory (EHI) score. All 36 participants were classified as right-handed on the basis of their EHI score. Eighteen participants performed better with the left hand, 17 with the right hand and one participant had equal performance with both hands. The mean difference threshold for the left hand was 4.54 mm (standard deviation: 2.13 mm) and the median was 3.97 mm. For the right hand the mean difference threshold was 3.87 mm (standard deviation: 1.64 mm) and the median was 3.53 mm. In other words, on average for the left hand, the comparison object needed to have a diameter of 34.54 mm to be noticeably different to the standard object (diameter 30 mm). For the right hand, the comparison object needed, on average, to have a diameter of 33.87 mm to be noticeably different. The results can also be expressed as Weber fractions ($\Delta I / I = c$, see Section 7.4.2 above). Based on the mean difference threshold, the values are 0.15 for the left hand and 0.13 for the right hand (or when expressed as percentages: 15% and 13% respectively).

The experiment had been counterbalanced for the initial hand used to perform the experiment in case there was an advantage associated with going first (second hand performance affected by operator fatigue or boredom) or going second (second hand benefits from learning taking place during the first part of the experiment). Fifteen participants performed better with the hand going first and 20 with the hand going second. The mean value for the difference threshold for the 1st hand was 4.25 mm (standard deviation: 2.04 mm) and the median was 3.75 mm. For the 2nd hand the mean difference threshold was 4.15 mm (standard deviation: 1.80 mm) and the median was 3.46 mm. Boxplots of the results are presented in Figure 7.5.

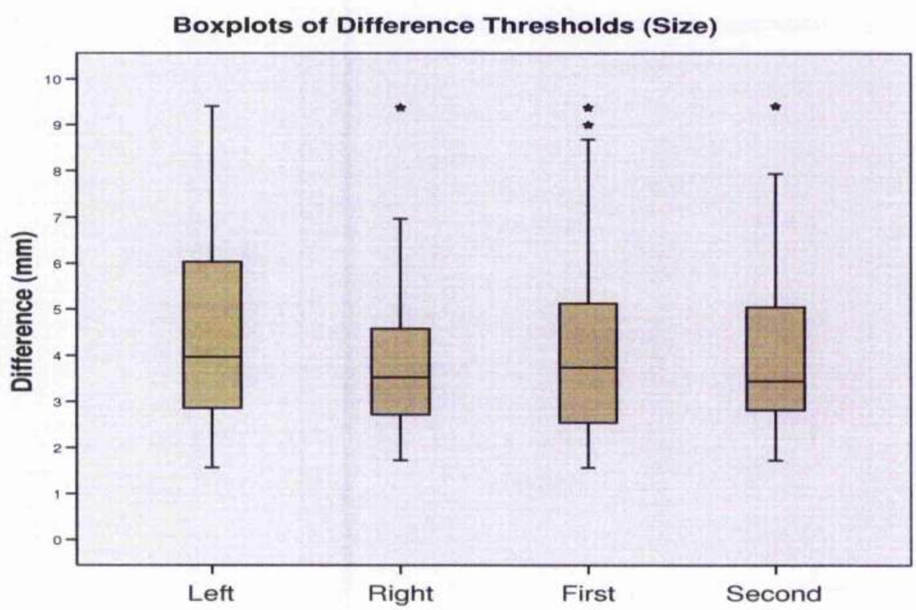

Figure 7.5. The difference threshold values (in millimetres) for the size experiment. The data are presented as boxplots of the difference threshold values for the 36 participants for: the left hand, the right hand, the hand going first, and the hand going second.

The data were not normally distributed on the basis of an Anderson-Darling Normality Test and when plotted graphically the skew was to the right. Therefore, a logarithmic transformation was applied, which resulted in normalisation of the data. The results were then analysed using a

General Linear Model (GLM) ANOVA (Coolican 1999) to analyse the performances on the basis of the hand (left or right), the order (hand performing the experiment first or second) and the interaction between the two variables (hand and order). There were no significant differences between the hands for either criteria ($F_{L,R} = 1.79$, $p = 0.19$; $F_{1st,2nd} = 0.00$, $p = 0.96$) and there was no significant interaction ($F_{Int} = 1.98$, $p = 0.16$).

7.5.2 Softness Experiment

Another 36 female right-handed students completed the softness experiment with the left and right hands, counterbalanced for the initial hand used. Thirty-eight students started the experiment but two did not finish and the data from these staircases were not included in the results. The difference threshold was calculated for each hand of each participant by averaging the last eight reversals on the staircase. This was expressed as the difference in the softness (stiffness or KSpring value in N/mm) between the comparison object and the standard object. The results are detailed in Appendix 7.5, with tables that present each participant's difference thresholds for the left and right hands, the values of the last eight reversals, and the Edinburgh Handedness Inventory (EHI) score. All participants were rated as right-handed on the basis of the EHI score. Fourteen participants performed better with the left hand and 22 with the right hand. The mean difference threshold for the left hand was 0.056 N/mm (standard deviation: 0.028 N/mm) and the median was 0.045 N/mm. For the right hand the mean difference threshold was 0.053 N/mm (standard deviation: 0.025 N/mm) the median was 0.053 N/mm. Therefore, for the left hand the comparison object needed to have a stiffness or KSpring value of 0.244 N/mm on average to be noticeably softer than the standard object (0.300 N/mm) and for the right hand the difference was detectable on average when the comparison object had a KSpring of 0.247 N/mm. The Weber fractions, based on the mean difference threshold values for the two hands, were 0.19 for the left and 0.18 for the right (or 19% and 18% respectively). The experiment had been counterbalanced for the initial hand used, similarly to when assessing size differences. Eighteen participants performed better with the hand going first and 18 with the hand going second. The mean value for the difference threshold for the 1st hand was 0.0544 N/mm (standard deviation: 0.0266 N/mm) and the median was 0.049 N/mm. For the 2nd hand the mean difference threshold was 0.0538 N/mm (standard deviation: 0.0263 N/mm) and the median was 0.052 N/mm. Boxplots of the results are presented in Figure 7.6.

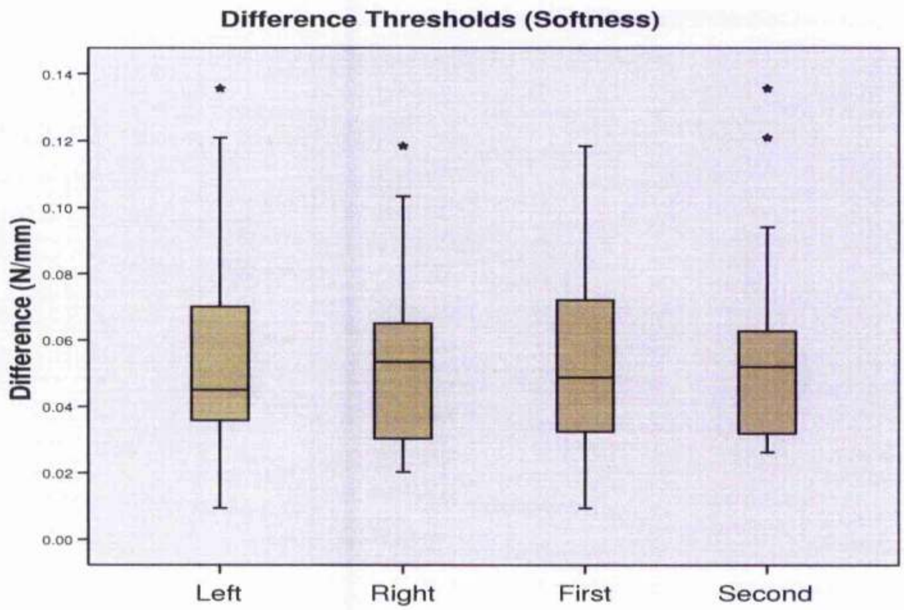

Figure 7.6. The difference threshold values (in N/mm) for the softness experiment. The data are presented as boxplots of the difference threshold values for the 36 participants for: the left hand, the right hand, the hand going first, and the hand going second.

The data were not normally distributed on the basis of an Anderson-Darling Normality Test (skewed to the right). A logarithmic transformation resulted in normalisation of the data. A GLM ANOVA was used to analyse the performances on the basis of the hand (left or right), the order (hand performing the experiment first or second) and the interaction between the two variables (hand and order). There were no significant differences between the hands for either criteria ($F_{L,R} = 0.14$, $p = 0.71$; $F_{1st,2nd} = 0.02$, $p = 0.90$) and there was no significant interaction ($F_{Int} = 0.35$, $p = 0.56$).

During the pilot experiments, when assessing softness some students had been observed to make 'pre-threshold' mistakes before reaching their perceptual limit and then adapted but this did not happen when assessing size (Section 7.4.4 above). Mistakes were qualified as 'pre-threshold' if they occurred at a point on the staircase at least one step (at the initial, maximum value) above (size) or below (softness) the difference threshold. During the main experiments, the number of staircases in which such mistakes were recorded was 27/72 (26 participants, left and right hands) for softness compared with 8/72 when assessing size. When analysed with a Chi-squared test, there was a significant difference between the size and softness experiments in the number of staircases with mistakes occurring prior to the difference threshold ($p < 0.001$).

7.6 Discussion

The current work was undertaken to try to answer a question raised by students: "Which hand should I use *(to perform rectal palpation of a cow or horse)*?" There was a suggestion from the profession that there may be a case for using the left hand although the justification for this was uncertain. When learning new technical skills, such as bovine rectal palpation, most people prefer to use their dominant hand, which will be the right hand for about 90% of the population. A range of approaches were taken to try to answer the students' question. First, a survey was conducted to gather information from veterinary surgeons about hand use for bovine or equine rectal palpation and this found that, of the seventy-eight respondents, nearly a third of the right-handers were using their left hand. When asked about the choice of hand (left, right or being able to use both) there was a wide variety of reasons given. Many respondents stated that they had been 'told to' use the left hand and a range of practical considerations were also mentioned. The dominant hand was favoured by right- and left-handers because of confidence, strength, dexterity and ease of performing the task. However, a definitive case was not made for using one particular hand and therefore, further evidence was gathered from reviews of the literature on handedness. For the range of skills that could be considered relevant to bovine rectal palpation, previous work undertaken predominantly with right-handers indicated that for the sensory components either the two hands had equivalent performance or there was an advantage for the left hand. However, the task also involves various motor skills, including manipulation of the reproductive tract, for which the dominant hand would have an advantage. Therefore, when considering the relative advantages of each hand for the motor and sensory components of the task it was unclear as to which hand should be recommended for right-handers. There was not enough evidence from the literature to make recommendations for left-handers. The simulated environment was used to investigate the issue for right-handers by measuring the perceptual abilities of the two hands for certain palpation-based skills. As there are relatively small numbers of left-handers in populations, investigations for this subgroup were not undertaken but could be addressed in another study. Manual pregnancy diagnosis was chosen as the task on which to base the investigation as this is a skilled technique that involves assessing the relative size and softness of the two uterine horns.

Experiments were undertaken to test the perceptual abilities of female right-handed veterinary students when differentiating between two cylinders (virtual representations of the two uterine horns) on the basis of size or softness. The results showed that there were no significant differences between the performance of the left and right hands for either task (measured as the difference threshold using a psychophysical staircase method). Therefore, both Hypothesis 1 and

Hypothesis 2 are supported. However, there are certain limitations that should be considered before extrapolating from these findings to the students' question about hand use for performing rectal palpation of cows or horses. The task was based on a real procedure, manual pregnancy diagnosis, and the range of values for the simulated models' size and softness were based on those established previously by clinicians. However, the uterus was represented by a pair of cylinders rather than the more anatomically correct models (combinations of stretched spheres and cylinders) used in the Haptic Cow teaching tool. Also the simulated test was more simplistic than the real task, when the clinician assesses both size and softness at the same time and may use additional techniques, such as membrane slip. In the virtual environment each participant assessed only one property, either size or softness. There would be an argument for assessing both together as this more closely represents the real task. In such an experiment, the superior hand (left or right, if either) would have been identified for a simulated version of pregnancy diagnosis. However, this approach would have hidden the abilities of each hand for the component skills, which could have been additive or contradictory, and there are also reasons for investigating skills individually (discussed in the next paragraph).

Another reservation about the overall impact of the results in relation to hand use relates to the fact that the experiments only evaluated the perceptual abilities for two of the skills used during one task: manual pregnancy diagnosis. Veterinary surgeon will undertake a variety of tasks when performing rectal palpation of cows or horses and will use a wider range skills. However, some of the tasks will include some of the same component skills and therefore, a case could be made for looking at individual skills rather than procedures as the findings would have a wider application. Further work could be undertaken to identify a set of 'core palpation skills' and to assess hand abilities for each component. This would provide a more complete evaluation of handedness for bovine rectal palpation, a more valid answer to the students' question and could have implications for other palpation-based skills. Another consideration relates to the experiments being restricted to female right-handed participants because of the need to control for gender and dominant hand. However, the interpretation is then limited to this subgroup of the population. The perceptual abilities of males and left-handers could be investigated in further experiments in the future.

Other reservations relate to using the PHANToM haptic device, which provides single point interaction with a virtual environment. The experiments were performed using the middle finger in a thimble to palpate the virtual objects with participants moving over the surface to assess size and pressing to assess softness. This involves using two of the exploratory procedures described by Lederman and Klatzky (1987) for determining object properties: 'contour following' and 'pressure' (Section 2.2). However, size can also be assessed by judging the distance between two or more digits when holding an object ('enclosure') and softness may be determined when gently squeezing a structure. Although participants could determine the size and softness of the virtual models using the current version of the simulator, during the real task a combination of approaches (using single and multiple contact points) would be used. Therefore, further work could be considered using a glove-type device or with two PHANToMs, with one thimble on the thumb and one on a finger. Additionally, any investigation in a virtual environment may produce different findings to those recorded during the real task, depending on how closely the virtual mimics the real. A direct comparison with the real task in this case would present considerable practical difficulties. As an alternative approach, the performance of experts and novices could be compared in the virtual environment. This would represent one way of establishing the validity of the test environment in relation to the real task, as experts would be expected to have a superior performance. Both veterinary surgeons and students did take part in the pilot experiments but the numbers were small and therefore, a larger study would need to be undertaken.

With regard to handedness and the previous work reviewed by others (Summers and Lederman 1990; Fagot *et al.* 1997), there was either a left hand advantage or equal performance for the skills that were considered to be similar to those used during bovine rectal palpation. The current work found no significant difference in the perceptual abilities of the right and left hands, from which it could be implied that the choice of hand does not matter for these particular skills. However, the dominant hand does have certain advantages that are particularly relevant for learning a new manual skill. These include having superior dexterity, which would be useful when manipulating the reproductive tract. Additionally, the greater strength or fitness of the dominant arm would be important during long fertility sessions, when fatigue can become an issue. Also novices would probably be more confident in the abilities of their dominant hand, which would be an advantage when learning new skills. There would also be certain individual variations relating to, for example, injuries to hands and other joints, and arm diameter, a very wide forearm (more commonly the dominant arm) making examining some cows difficult. Additionally, circumstances on particular farms (e.g. the facilities for examining the cows) may mean that a particular hand will be easier to use. These individual and farm-related considerations could be used to make a case for being able to use both hands. However, even after considering the limitations of the current work and the range of other factors that affect each individual's decision, the results suggest that right-handed female students should consider the dominant hand to be their default choice. Further work should be undertaken to investigate the abilities of male and left-handed individuals.

The current findings also add to the body of work where virtual environments have been used to investigate human perceptual abilities. Others have looked at the abilities in relation to a particular object property or stimulus rather than specifically investigating the issue of handedness. One way to compare any findings associated with touch-related perceptual abilities is to apply Weber's law (Weber 1834: translation 1978). This states that for a particular property the change in stimulus required for the difference between stimuli to be perceptible is a constant. The constant or Weber fraction (expressed as a decimal or percentage) can therefore be used to compare experimental work for a particular stimulus. For size, the nearest comparable work would be that by Provancher *et al.* (2003) when participants had to differentiate between two spheres on the basis of size. A change in diameter of 11% or more was required for the two spheres to be noticeably different. The current work found a difference in the diameter of 13 and 15% was required (on average for the right and left hands respectively), although the objects were cylinders rather than spheres. For softness, other work has found that when probing objects with a finger in the PHANToM thimble (as in the current study), Weber fractions for compliance have ranged from 14 to 24% (Dhruv and Tendick 2000) and 9 to 21% (Howell *et al.* 2006). Another study, using a stylus rather than a finger to probe objects, found a Weber fraction of 8 to 12% for stiffness (DeGersem 2005). In the current work, when palpating two cylinders representative of the two uterine horns with the middle finger in the PHANToM thimble, the Weber fractions for stiffness (the KSpring value) were on average 18% for the right hand and 19% for the left hand. These values are within the range of results from the other studies. However, there were certain differences in the test environments and experimental designs between the studies. These included the type of PHANToM end effector used, with a lower Weber fraction being observed for stiffness when probing objects with the stylus (DeGersem 2005) than when palpating objects with the thimble (as in the current work). The softness or hardness of an object can be measured in terms of compliance or stiffness, which although yielding similar results are not directly comparable. Dhruv *et al.* (2000) and Howell *et al.* (2006) measured compliance, while DeGersem (2005) and the current work measured stiffness. Additionally, measurements were made over different ranges of parameter values. The current work used a range of values that had clinical relevance for pregnancy diagnosis. Whereas Howell *et al.* (2006) used values typical of musculoskeletal abnormalities detected during osteopathic examinations (a firmer feel than a pregnant bovine uterus). In spite of certain differences in the experimental designs, the findings of the current work are similar to those of others, which support the validity of the environment for an investigation of handedness for palpation-based skills.

Another interesting finding to emerge from the work was that students performed differently when assessing size and softness. Some participants had difficulty differentiating between the softness of the two uterine horns (cylinders) and made 'pre-threshold' mistakes before reaching their perceptual limit (the difference threshold). Others have made a similar observation when participants were trying to differentiate between two soft spheres (Jansson and Pieraccioli 2004). After initial mistakes, the participants would work out how to distinguish between the two objects (adapting to the test) and the performance would improve again until the perceptual limit was reached. However, in the experiment to assess size this type of behaviour happened in only a few cases and the occurrence of 'pre-threshold' mistakes in the two experiments (assessing size and assessing softness) was significantly different. This finding suggests that, in addition to the perceptual component of the task, determining softness may require more of a cognitive, or learning, element than determining size. Also there may have been a difference between experts and novices in this respect. In the limited number of trials undertaken with the experts (four veterinary surgeons in the pilot experiments), none of the participants made mistakes in either test prior to their perceptual limits. This could further support the possibility that differentiating between objects on the basis of softness requires practice. However, there are several factors to consider when interpreting these observations. First, the effects may be applicable only to the simulated environment. Additionally, further studies should be undertaken to determine if the findings with the small number of veterinary surgeons (n = 4) are indeed indicative of expert behaviour. If the findings were supported, there would be interesting implications for the learning and therefore, teaching of these two basic skills: assessing size; assessing softness. Also the difference between the veterinary surgeons and students may relate to knowing the safe operating range or how hard you can press without causing damage. This would have interesting implications for further developments of the simulator where providing guidance about the use of safe and effective levels of force would be helpful to students as well as having potential benefits for animal welfare.

7.7 Conclusions

The work presented in this chapter tried to provide an answer to a question often posed by students: "Which hand should I use *(to perform rectal palpation of a cow or horse)*?" There is confusion about the choice as some practitioners advocate using the left hand but people tend to prefer to use the dominant hand to learn new manual skills. The aim of the work was to find some justification for either allowing students to use their dominant hand or advising an alternative choice. From the initial investigations based on a survey of veterinary surgeons and evidence from the literature, it appeared that there were a range of factors that should be considered before making a decision. When considering the relative advantages for the components of the task and other practical considerations raised by the veterinary surgeons, the choice for right-handers was not as clear, with for example, contradictory hand advantages for motor and sensory components of the task. The experiments, conducted with female right-handed students, found that for two of the component skills of manual pregnancy diagnosis (assessing size and softness), there was no advantage for either hand. In which case, the choice of hand might not matter. However, in answer to the students' original question, the advice would be that the results should be taken together with other practical considerations that have been raised. Trainees should consider the following factors when making their decision: the advantages of their dominant hand, which relate to confidence, strength, and dexterity; individual considerations such as injuries; the need to be adaptable to the circumstances on individual farms; and perceptual abilities. Overall, the dominant hand is likely to be the best choice for female right-handed students. There was not enough evidence from the literature to make a recommendation for left-handers and this was not investigated in the current study. Further work could be undertaken to address this subgroup of the population. Additionally, the hand choice for male students, both left- and right-handers, should be investigated. After a more complete investigation, guidance could be provided for all students. Another approach would be for individuals to measure their perceptual abilities in the virtual environment.

This work not only addressed an issue that concerned the students but also expanded the simulator's research potential as a measuring device, making use of a psychophysical method in an investigation of veterinary skills. By finding out more about how we perform tasks as experts and novices, there will be benefits for learning and teaching. A further extension of this work would be to look more specifically at the skills we use and need to learn, with the aim of identifying the core skills that are the building blocks for a range of palpation-based clinical procedures. Therefore, as well as being used as a teaching tool there are future research opportunities building on the work presented in this chapter. These include investigating and assessing skills in an objective way and gathering data that could inform future practices in certain areas of veterinary education.

Chapter 8: Conclusions

8.1 Summary

In this final chapter, the work presented in the thesis will be summarised, the contributions and limitations discussed and finally, some ideas for future work presented. A simulator has been developed using haptic technology to provide a training environment for veterinary students to learn bovine rectal palpation. The procedure has been identified by veterinary surgeons and students as a clinical skill that is difficult to teach and to learn. In the veterinary undergraduate curriculum, the opportunities to gain farm animal experience are increasingly limited, which presents problems when trying to ensure all students achieve the required level of proficiency by graduation. Additionally, there are animal welfare concerns associated with students learning an invasive procedure on live animals when there has been insufficient prior training. The simulator was designed to equip novice students with the skills to perform the first rectal examination of a cow and work was undertaken to validate the teaching tool.

A review of the literature was conducted, first to define haptic exploration and then to look at the computer technologies that provide touch-related interaction within virtual environments. For a palpation-based procedure that is internal and unsighted, the sense of touch is very important to the clinician and providing good quality haptic feedback as part of a training environment is crucial. A range of devices is now available that supports touch-related interaction and these have found a wide variety of applications, with an increasing number used as simulators for medical training. When designing these training tools, there are certain challenges that need to be met. These include creating a virtual environment that is realistic enough and can be used by trainees to learn the procedure. A very important part of the development process for any new teaching method or technology is validation, without which there are no guarantees of training efficacy, and this should be undertaken before considering widespread use. The component steps for validating computer simulators used in medical training have been defined (Neufeld and Norman 1985). These criteria have formed the basis for evaluations performed by developers of a range of medical simulators and were used in the current work when trying to validate the bovine simulator as a teaching tool.

The simulator was designed to enable a teacher to have a more effective input into the learning process and to equip trainees with the required skills. Bovine rectal palpation is unsighted and is therefore difficult to teach and learn. Additionally, information available in the literature is not detailed enough for students to determine exactly how to perform the procedure. The first part of the work addressed the need to determine the specific learning needs of novice veterinary students and the detailed steps used to perform the procedure. These were elicited after consultations with veterinary surgeons, as teachers and experts, and students, as learners. A design method for computer aided learning packages was used to integrate the information gathered into the structure of the simulator-based teaching protocol. The virtual models needed to be a good enough likeness that after simulator training students would recognise the same structures inside the real cow. This was achieved using an iterative design cycle where expert knowledge was an integral part of the process. The first steps of the validation involved determining whether the design was sound, with veterinary surgeons assessing the virtual environment and the teaching protocol. As the simulator was developed as a teaching tool, the next key steps were to undertake work that established that training equipped students with useful skills for the real task and that using the simulator in a veterinary curriculum was feasible.

After establishing that the simulator delivered the required training and was usable in a real world situation, the work was expanded to address certain questions that had arisen. The teacher had been an integral part of the training environment and a question remained as to whether the tool would be reliable in the hands of others. Rather than test this, for various reasons, an alternative approach was taken with the teacher's role being replaced by computer guidance. A prototype automated version was developed and skill acquisition was evaluated, which found benefits when trainees subsequently examined cows. The new version of the simulator, which students would use on their own, has certain advantages: more accessible, no longer dependent on a teacher, and less expensive (in staff time). Another question posed frequently by students related to the choice of hand when performing bovine or equine rectal palpation. There appears to be an element of controversy surrounding this issue in the profession with some anecdotal evidence supporting the use of the left hand. As simulators can be used to investigate performance as well as providing training environments, the final part of the work made use of this functionality. The simulator provided an environment in which to assess the perceptual abilities of the two hands for some of the skills used when performing bovine rectal palpation.

8.2 Contributions

Validation, as already stated, is a very important part of the development process of any simulator. The majority of medical virtual reality (VR) simulators have been developed for minimally invasive surgery and minor procedures. Although there are many descriptions of the development stages, only a very few have been validated to the point where benefits have been shown when trainees subsequently perform the real procedures. There are a small number of VR simulators developed specifically for palpation–based procedures but none of these have been validated during subsequent examinations of real patients. Validating a simulator by measuring performance during the real task represents the gold standard. Without this, it is possible that the trainee could be learning skills that are only applicable to the computer simulation. If the skills developed are useless or even inappropriate, this could put patients at greater risk. The work presented in this thesis, to validate the Haptic Cow, represents the first time that a palpation simulator has been shown to deliver the required training, with beneficial effects found when students subsequently examined cows.

The validation work focussed initially on the design of the simulator-based teaching tool. The virtual models were realistic enough (face validity). The teaching protocol was structured in a way that allowed an instructor to use the simulator to teach the component steps of the procedure (content validity). The level of realism provided by any alternative to the real patient - physical or virtual model - is important and continues to challenge developers. When modelling internal palpation-based procedures, the level of realism is particularly important because touch is the only sense available to the clinician. Other VR palpation simulators failed to deliver the expected results and the reason could have been due to a lack of realism as face validity had not been established (Burdea *et al.* 1999; Crossan *et al.* 2001). Therefore, demonstrating that the bovine models were realistic enough was considered to be an important initial step and a prerequisite to further work. The models were created by the researcher, whose combined skills as developer and clinical expert provided a unique opportunity. A highly iterative design process was used and this approach proved to be a very effective way of creating a virtual environment. The level of realism achieved also demonstrates that the PHANToM haptic device can provide the high fidelity interaction required to represent the anatomical structures palpated when performing rectal palpation of cows. This also indicates that the technology would have potential for modelling palpation-based procedures in other species.

The demonstration of skill transfer to the real task was the next crucial step in the validation. The experimental design, which followed a typical EMS structure on farm (complying with current welfare guidelines) allowed for skill acquisition to be tested under real conditions. Ultrasound images provided a way of verifying performance, which is one of the difficulties when trying to assess an internal procedure. The work demonstrated that simulator trained students were equipped with useful skills. They were more able to find the uterus than a group of their peers, whose training had not been supplemented with a simulator session. The simulator was only validated for one skill, finding the uterus, but this is a basic and fundamental part of the procedure as a whole. Until mastered, the student cannot perform other techniques including fertility examinations and diagnosing pregnancy (both manually and using ultrasound) as all of these depend on being able to find the uterus. The work also supported the suggestion that the traditional training available at the University of Glasgow Veterinary School was not a very effective way of preparing students to perform bovine rectal palpation as the control group performed particularly poorly. This underlines the need to provide some form of complement to existing training methods.

Work was then undertaken to try to make simulator training more widely available. First, the practical challenges of integrating a new teaching tool into a curriculum were addressed. The simulator was included as part of the farm animal course at the University of Glasgow Veterinary School and was well received by students. The student feedback indicated that simulator training increased their confidence to perform the procedure and equipped them with the skills to find and identify key structures. One of the benefits of having the opportunity to teach a whole year of students related to the insights gained into teaching and learning through the students' comments and the teacher's personal experiences. This led to improvements in the teaching format and, as a result, the simulator training was refined and continues to be used in the curriculum. A new development was then undertaken to create an automated version, which students could use in their own time. The teacher's role was replaced by haptic and audio guidance. An evaluation was then undertaken using the same experimental design as for the teacher-led version. When the performance of simulator trained students was compared with those who had only the traditional training available at the University of Glasgow Veterinary School, the simulator-trained group were significantly better at finding the uterus when examining cows for the first time. This demonstrated that the automated version was effective at equipping students with certain skills. The new version demonstrated the potential of using computer guidance as a way of providing at least basic training and further developments are planned.

Overall, the validation of the Haptic Cow has provided several contributions to simulator research and veterinary training. The work followed an established evaluation method, described by Neufeld and Norman in 1985, and has served to illustrate that establishing that a simulator is designed correctly should always be a precondition to further evaluations. After that step, the effects of training can be tested and, in this case, were shown to be beneficial. Training with the simulator has benefits for students, equipping them with skills that allow them to be better prepared for the real task. The teacher can have a more effective input into the learning process compared with standing beside a cow, when the student's actions are not visible. The problems experienced when teaching in the traditional way have been compounded by the current trend to increase the intake of students and the reduction in access to clinical material, for welfare and financial reasons. For a veterinary school, the simulator therefore provides a useful complement to existing training methods and addresses some of the concerns about providing enough training to equip students with the required skills by graduation. Another benefit for the university is that when using the simulator, the teaching is standardised and development of a basic set of skills could be guaranteed. For students, the simulator represents a safe training environment, allowing a 'trial and error' approach to learning, as mistakes carry no serious consequences. The simulator also provided a range of fertility cases, the on-farm scenarios, which allowed students to practice applying and integrating their knowledge in a clinical context.

There are also likely to be benefits for animal welfare of using a simulator and this is in keeping with the current drive to reduce, refine and replace animals as educational resources. The live animal is still a very important part of the learning experience and therefore, the real cow will never be replaced. However, with strategic use of the simulator to provide training, the use of cows could be reduced and refined. For example, if novice students are taught the basic skills on the simulator there would be certain benefits. Replacing cows with the simulator as this stage of the learning process would be advantageous as untrained operators, as well as failing to perform the procedure effectively, could do harm. Also the number of cows needed to achieve the primary learning objectives would be reduced. The simulator could also be used for more experienced students to reinforce and further develop their existing skills, and would complement the use of real cows at this more advanced stage of the learning process.

The final part of the thesis presented work where the simulator was used in a different role. Instead of providing training, the virtual environment was used to measure various aspects of performance. There is some debate within the profession about which hand should be used when performing palpation-based procedures and the simulator provided an environment in which to determine the perceptual abilities of the left and right hands for certain tasks. The results, when taken together with other practical considerations, provided trainees with guidelines that could be used to decide which hand to use when learning bovine rectal palpation. This work illustrates the simulator's potential as a measuring tool and this functionality could be explored further. For example, in veterinary medicine, there is a move towards finding ways of assessing skills more objectively and, for certain tasks, the simulator could provide a suitable test environment. Additionally, when using simulators as measuring or recording devices, the information gathered will help us understand more about how we perform procedures and could be used to improve teaching methods in the future.

8.3 Limitations

There are a number of limitations to the work, which will be considered in two categories relating to the simulator development and the research undertaken.

8.3.1 Simulator Development

The simulator has several limitations with regard to its capability to provide an environment and an interaction that resemble all aspects of the cow and the procedure. The PHANToM provides a single point of contact through the thimble gimbal at the end of the mechanical arm. The procedure is hand-based and ideally a device that supported the hand and each digit should have been used. However, at the moment there are no devices that provide both whole hand interaction and the level of fidelity required. Therefore, to accommodate the shortcomings associated with the single point of contact various adaptations were made. Trainees placed the middle finger rather than the index finger in the thimble, as the former was reported by veterinary surgeons as providing a better representation of the feedback associated with using the whole hand. There are certain aspects of the task that cannot be represented using one finger, particularly where there is an element of manipulation, which requires two or more points of contact. This would apply to ovary palpation and therefore, during training sessions this part of the examination was taught outside the simulated environment with the teacher demonstrating the finger movements with a physical model. Eventually, a high fidelity whole hand haptic device will become available and then, a simulation could be created that provides a more complete interaction and training experience. At that time, the existing simulations and teaching protocols could be used to inform the development of the new environment. This would mean that the next generation simulator would benefit directly from the work to date.

There are also certain physical aspects of the experience of examining cows on farms that were not included in the simulator-based training environment. A fibreglass model of the rear-half of a cow was placed over the haptic device, which helped to immerse users, both learners and experts, in the experience. However, other aspects, including palpating the reproductive tract through the rectal wall and faeces, and dealing with peristalsis, were not represented. A preserved rectum, similar to that used in the equine colic simulator developed in Vienna (Von Künzel and Dier 1993), could have been added to the fibreglass model but was not included in the current training environment. Training time is limited and including the rectum would have made the interaction more realistic but also more difficult and slower. As a compromise, students were informed of the differences and given a hand out with instructions on how to deal with some of the physical challenges faced when examining real cows. The simulator provided a more relaxed training environment than the situation on a farm, particularly in relation to experiences during EMS. Students considered this to be an advantage because they were more able to focus on the learning objectives. Providing more realistic representations and designing a teaching tool that prepares trainees more thoroughly for the real task will continue to be a priority and a challenge during the development of future versions of the simulator.

The simulator training sessions were resource intensive involving one-to-one tuition. The teacher was able to have an effective input into the learning process, which students considered to be particularly helpful. However, providing this type of training raises various issues including sustaining the cost of staff wages, the teachers' dedication and motivation, and access to the simulator being limited to the times when a member of staff is available. The automated version was developed to investigate the possibility of providing training in the absence of a teacher and the success of the prototype indicated that, with further development, many of the limitations associated with the teacher–led version could be addressed. However, the PHANToM is a costly piece of hardware and therefore, even the automated version of the package would be relatively expensive. The current work has been limited to certain procedures in one species and therefore, a greater range of simulations should be developed. This would provide a more viable option, with one device delivering training for a wide range of procedures in a variety of species.

8.3.1 Research Work

The primary motivation for the research was to validate the simulator as a teaching tool by demonstrating that the training was effective. The simulator was developed to equip novice veterinary students with the basic skills before they examined cows. The research work undertaken validated the teaching tool for one of the fundamental skills: finding and identifying the uterus, but this is only one part of the procedure as a whole. Virtual models were developed to represent pregnancies and ovarian cyclical structures and these were rated as realistic enough representations by experts, establishing the first step in any validation, face validity. However, the next step, to assess training benefits by measuring skill development, was not undertaken. The whole range of simulations was used in the fourth year sessions to teach basic skills, pregnancy diagnosis and fertility examinations. The training was well received by students but, without demonstrating that skills transfer to the real task, the benefits cannot be guaranteed and therefore, further validation should be undertaken.

The training was delivered by one individual and at one veterinary school. This presents certain questions: 'Is the simulator usable in the hands of others?' and 'Would the same results be delivered?' A decision was made, for various practical reasons, to circumvent this issue by developing an automated version and thereby, removing the teacher from the training environment. However, in an ideal situation the simulator would be available to students in both formats. Novices would use the automated version to learn the basic skills before examining cows. Later in the course, students wishing to focus on farm animal work could be given the opportunity to benefit from the teacher-led training. This could be used to address problem areas, further develop existing skills and practice examining typical fertility cases using the on-farm scenarios. If the simulator is to be used in this way, further work should be undertaken with other teachers to ensure that this part of the training can be delivered effectively, irrespective of the individual. While other teachers were using the simulator, any usability issues could be recorded and addressed, and a training package would need to be produced. There is also the question of whether the results would be the same if the simulator was used as part of the training offered at other veterinary schools. If the existing training methods are different, then the benefits of using a simulator might also differ. Each veterinary school would also present different challenges when addressing the practicalities of integrating the simulator into a curriculum. Another issue to address relates to the work to validate the automated version which involved a small number of students. Similarly to the curriculum integration project undertaken with the teacher-led version, further work should be undertaken to investigate any practical issues associated with making the simulator available for all students in a clinical skills laboratory under the limited supervision of the laboratory technician.

There are certain limitations to the work that was undertaken to investigate which hand should be used to perform bovine or equine rectal palpation. The evaluation was conducted in a virtual environment and was more simplistic and abstract than the real task in several ways. The investigation was based on the skills used during manual pregnancy diagnosis but bovine rectal palpation includes other procedures and involves a wider range of skills. Additionally, the skills (assessing relative size and softness of two objects) were measured individually whereas in the real task the two skills have an integral and combined role to play in the diagnosis. Overall, a student's decision about which hand to use should be based on a number of considerations including the circumstances on farms and personal factors such as dominant hand, existing injuries and arm size. This work did however open up an interesting avenue for future simulator-based research. It providing a window into some of the more intangible aspects of the palpation-based tasks that we learn as veterinary students and become skilled at as veterinary surgeons. However, on a cautionary note, any interpretation should always be considered in relation to its relevance to the real task. Findings in a virtual environment are likely to be, at best, a good approximation to the situation in the real world.

8.4 Future Work

8.4.1 Two-PHANToM project

One of the limitations of the current simulation is that there is only one point of contact, which prevents full representation of certain aspects of the procedure. One option would be to use one of the whole hand devices developed, for example, by Immersion Corporation although, in this case, the finger movements are limited to one degree of freedom. This allows a user to press a button or hold an object but not gain realistic feedback while moving over a 3D surface. Therefore, a project is being proposed to investigate the use of two PHANToM haptic devices to provide two-point interaction with the anatomical models of the bovine reproductive tract. This would enable new actions to be modelled including grasping and manipulation. Users would also be able to assess an object's global shape and size through hand movements rather than just contour following using one finger (Lederman and Klatzky 1987).

There would be new design challenges to address when developing a virtual environment in which the user has two points of interaction. First, when using two devices in one workspace there can be physical clashes between the mechanical arms and the devices would need to be mounted in a way that minimised unwanted interactions. Additionally, there is a reduction in the overall size of the virtual environment (Wall and Harwin 2001). For the veterinary simulation, the 3D space would need to be large enough to represent at least the dimensions of the inside of the cow's pelvis. In the current simulation, the models are static but the new representations would need to be mobile and respond to the two-point interaction in a realistic way.

After developing a two-point interaction and overcoming the above challenges, the simulator could be used as a training tool for veterinary students to learn aspects of the procedure that are not represented in the current version of the Haptic Cow. Some of the new tasks that could be represented would include manipulating an ovary, retracting or uncurling the uterus as part of a fertility examination and membrane slip (used by some to diagnose pregnancy). Research work would need to be undertaken to validate the new version by demonstrating that the interaction using two devices was realistic and included the range of movements used to perform the procedures naturally. The beneficial effects of training should also be assessed by demonstrating skill transfer to the real task. In addition, research could be undertaken to investigate various aspects of performance. This would provide information about how, for example, experts carry out the more complicated aspects of ovary palpation, which could then be incorporated into the teaching protocol.

8.4.2 Skill Assessment using the Simulator

In human medicine, there is a move to use simulators to provide objective assessment of skill (Moorthy *et al.* 2003b) and the bovine simulator could fulfil a similar role. When trying to assess students' performance or diagnostic skills while performing rectal palpation of cows, the examiner faces the same challenge as when teaching because the task is unsighted. This makes determining the student's level of proficiency very difficult. One procedure where objective assessment of skill would be useful is pregnancy diagnosis. The procedure is difficult, requires a great deal of practice and is one of the commonest reasons for negligence claims against new graduates (in farm practice), after 'non-pregnant' cows have been aborted. A prototype self-assessment version has been developed (on the PHANToM Omni) to illustrate the technology's potential in this area but further research would need to be undertaken to establish the validity of the simulator as an assessment tool. This would involve undertaking one or more of the steps described by Neufeld and Norman to validate simulators used as measuring tools (Neufeld and Norman 1985).

8.4.3 Core Skills Training

As well as providing procedure specific training, the simulator could be used to equip students with the core skills used during any palpation-based examination. In medicine, the MIST-VR simulator (Mentice 2004) has been developed to equip surgeons with the components skills used when performing minimally invasive surgery. Training with the simulator has been shown to provide effective preparation for the real task (Seymour *et al.* 2002; Schijven *et al.* 2005). The idea of core skills training was used in the current work as a way of engaging all students, irrespective of their long term interests, in the bovine training sessions. Students were informed of the relevance of the skills they were learning to a range of tasks in other species. For example, when performing pregnancy diagnosis, students were learning to judge the relative size and softness of the two uterine horns and these particular skills are applicable to a range of procedures. Similarly, in the handedness experiment only two skills were assessed but, as these were core skills, the findings are applicable to a wider range of tasks. When clinicians diagnose conditions using palpation, they will assess, for example, the size of a dog's prostate, the presence of a fluid effusion in an injured joint, and will try to identify different types of lump on the basis of how soft or firm they feel (abscess, lipoma and so on).

Research work would need to be undertaken to identify the core skills and then develop a virtual environment that provided the required training. The simulations used in the handedness research represent such an environment for the skills required to perform manual pregnancy diagnosis in the cow. Once a complete core skills simulator had been developed, further research would need to be undertaken to validate the teaching tool. Initially, this would involve confirming that the core skills had been identified correctly. The concept of construct validity (Neufeld and Norman 1985) could be applied here. If a defined core skill is valid, then experts would be expected to be more proficient at the skill than novices. A more challenging aspect of the validation would be to establish whether the sum of the core skills equalled the whole procedure. If the training environment was valid, then proficiency at the core skills should lead to improved performance during real tasks. A well designed and validated core skills simulator has the potential to equip students with skills that represent the building blocks for a range of procedures and thereby, provide a more efficient way of delivering training than when teaching each task individually.

8.4.4 One Device: Many Procedures, Many Species

Following the success of the Haptic Cow, further simulations are under development for other procedures in a range of species. When students were asked if there were other procedures they considered should be taught with the simulator, the most frequent request was for an equine colic simulation. Rectal palpation is an important part of a colic examination, helping to determine if a case is medical or surgical. However, there are risks associated with performing the examination, including causing a rectal tear (which can be fatal), and clients are often reluctant for students to practice on their horses. Students have few, if any, opportunities to practice prior to graduation and therefore, providing training in a virtual environment before examining a real case would be beneficial.

There are a range of procedures that could be simulated in small animals. A single point of contact would be suitable for examination of the canine prostate (and a prototype has been developed on the PHANToM Omni). The two-PHANToM project could be expanded to include simulations for palpation of the canine or feline abdomen. This technique is used by clinicians, for example, to detect an intestinal foreign body or abdominal mass, to assess renal changes in older cats, and to determine the state of the bladder after road traffic accidents. In the future, instrument-based procedures could also be simulated by modifying the attachment to the mechanical arm and improving the graphic representation with, for example, tissue appearing to bleed when incised with a scalpel.

In the long term, one haptic device could provide training for many different palpation- and instrument-based techniques in a range of species. In addition to the procedure- and species-specific simulations, the simulator could also be used to teach the core skills, which form the basis of many clinical examinations. As stated previously, the device also has the functionality to provide objective assessment of skill. This is likely to become an increasingly important role for such technology in the future and could be incorporated into future editions of the software.

8.5 Conclusions

In conclusion, the thesis has presented a body of work that led to the development and validation of a haptic simulator that provides an environment in which veterinary students can learn some of the skills required to perform bovine rectal palpation. The work included a structured approach to establish the requirements, while focusing primarily on the learning needs of novices. The findings were then integrated into the design of the computer-based learning package. The validation followed the steps outlined for simulators used as teaching tools in medical training. The research demonstrated that a virtual environment that was sufficiently realistic could be created using haptic technology and that, when the range of simulations were used together with the teaching protocol, a teacher or computer could deliver effective training. The original challenge and motivation had been to address some of the issues in clinical training in the modern veterinary curriculum. There are increasingly limited opportunities to practice and ensuring all students are equipped with the required skills using only traditional methods is difficult. The simulator provides an effective supplement to the existing training and therefore, will allow students to make better use of the limited learning resource, the cow. This will have benefits for students, veterinary schools and animal welfare.

In the context of simulator research as a whole, the work represents the first time that a VR palpation simulator has been validated for the real task. Training resulting in improved performance when students were set the task of finding and identifying the uterus in cows. Additionally, teaching with the simulator was successfully included in a curriculum. The work also presented some preliminary investigations in other areas of simulator research and development. The automated version addressed some of the problems associated with one-to-one teaching. The work to investigate perceptual abilities illustrated that psychophysical methods could be applied in a simulated environment to investigate veterinary skills. In summary, the veterinary simulator project has helped to establish the role of haptic technology in providing a versatile and flexible teaching resource and as an environment in which to learn more about performance, teaching and learning.

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Appendix 3.1: Interviews

Summary of the interviews conducted with four farm animal veterinary surgeons as part of the requirements capture (Chapter 3). The interviews aimed to establish the details of the current training available to veterinary students. Each interviewee's experiences teaching students on farms were discussed including the problems encountered (with particular reference to novice students from University of Glasgow Veterinary School who would be performing rectal palpation of cows for the first time in 3rd year when embarking on their first extramural studies (EMS)). The interviewees were also asked to consider the potential for using a simulator as a complement to existing training. The interviewer followed a series of questions to ensure all the topics were covered, while also allowing discussions to develop to enrich the information gathering process.

<u>Questions</u> (used as guidelines for the interviews)

1. What training have students received at university prior to the first EMS?
2. Could you describe your experiences during the first farm EMS with a 3rd yr student:
    a. What can they do?
    b. What do you let them do?
    c. What problems are encountered?
3. Is the current training satisfactory?
4. What are some of the implications of the current system (and its failings)
5. If we used a simulator for 3rd year students:
    a. What would be the aims of the training to prepare students for the first EMS
    b. How would you teach novice students to perform the procedure/s
    c. What structures and scenarios would need to be represented
6. What would you see as the advantages of such a training environment?

The interviews were recorded and transcribed and then analysed using the method described by Coolican (1999), which involves identifying facts in each interview and then classifying them according to one of a number of categories. The researcher, familiar with the subject area, created the categories. The analysis was performed by the researcher and an independent analyser who was not a veterinary surgeon. The interviews were conducted in confidence and therefore, the veterinary surgeons are not named but are referred to as I1, I2, I3 and I4.

Categories
Current Training (relating to training available to students at the moment)
At university
they don't get to examine any cows before final year these days (I1); (*preparation for examining cows during EMS)* students haven't really been trained at all at vet school (I1); (*teaching before EMS)* anatomy and physiology lectures and some lab sessions (I1); they should get some PM tracts we did some tracts in anatomy and some cows at vet school in second year, but that doesn't happen now (I2); they haven't had training before they come to us (I3); traditional training teaches from text (I3); *(examining cows before EMS*) not any more, previously second years used to but no they don't get their hand in a cow now (I4); anatomy and physiology in second year (I4);
In EMS
they usually follow the vet (I1); we try to tell them what to do while standing beside the cow (I1); in the parlour then there is another cow waiting to follow (I1); try to remind the student what the tract is like, the cervix, the brim (I2); a cow that's well in calf, then I let them feel the head so they can get to feel something (I2); in beef practice they will get quite a range (*of pregnancies*) (I2); (*dairy practice)* will be early pregnancy and fertility checks (I2); if I have enough time and the farm has lots of time, I can let them take the time to find things (I2); *(on farm)* try to get them to describe where they are, what they are touching (I2); *(anatomy)* sometimes try and remind them of this in the car (I2); *(doing the first examination)* get close enough, cone the hand, don't be afraid to push, I usually go through this in the car (I2); *(how do they learn)* lots of cows, eventually they work it out (I3); I try to get them to be able to close their eyes and 'see' where everything is, know with your hands where to look (I3); I talk to them about this *(doing damage)* in the car before we get to the farm. I tell them not to grab anything, be careful (I3); if we can put a cow separate, the other side of the parlour they can take time (I3); once they know what to do, if the set up permits, most students get there, sort of the basics, if there are enough cows, but then there aren't (I3); I do try to direct them.. sweep the hand from side to side (I3); it *(curled up uterus in pelvis)* is often not far in so you can tell from their hand, how far in (I3); *(EMS is the first time they examine a cow*) unless they are dairy farmer's sons.... unless they see practice with a home practice that they are friendly with (I4); you want to try and make sure they do it properly... you try and tell them how to do it right for their confidence and you don't want them to hurt the cow, you want them to take it slowly (I4); let them go first... but often you go in first so you will use that knowledge, what I have already felt, or if they go in first use the information the farmer has given you (I4); they spend a lot of time just watching the vet (I4); (*farmers*) some quite like students learning from them (I4); they are faced with the back end of a cow... they have never had to do anything like this before (I4); I try and tell them how far *(to go in)* ...(I4); (*membrane slip*) I don't do it (I4);
Problems / Deficiencies
the students just don't always get to examine enough cows during EMS (I1); vet thinks well I haven't got time to train you from scratch (I1); we can't see where they are, we really haven't got a clue where they are (I1); welfare aspect (I1); the students are extremely worried about (*brp*), which doesn't help, they don't know what they are touching (I1); (*seeing it - ref PM tracts)...* they try to feel what they see not what they touch (I1); EMS varies so much (I2); lack of time (I2); physical aspects of the cow, especially the first time (I2); they have never done it before (I2); they are going in blind (I2); they don't feel much at first (I2); (*range of pregnancies*) not in dairy practice (I2); pretty small tracts and hard to find compared *(dairy practice)* (I2); vets don't have time and farmers have other work to do (I2); too many students and not enough cows (I2); at the moment there is no alternative so they have to learn on cows (I2); it's difficult to help... at the beginning it is hard to actually teach them (I2);

Problems / Deficiencies (continued)

there isn't an alternative *(to cows)* so we have to train them this way, but perhaps we could make better use of the cows by just training the ones who want to do farm animal work ... they all have to do it at the moment (I2); some I have to stop, they can be a bit rough (I2); *(current situation for teaching and learning – is it satisfactory?)* not really, no, but there isn't much alternative (I2); *(students don't)* find it easy to identify and describe what they feel, they really can't seem to tell you (I2); they often go awfully silent (I2); EMS varies so much (I2); *(not being able to describe)* it doesn't do their confidence any good; quite a few of the third years are quite shy and they really lack confidence, that doesn't help their learning (I2); when we are on farm *(at first)* some of them stand back... unsure what to do next (I2); *(how to get their hand in)* you can't be sure every vet is going to tell them (I2); they have not been trained to do this *(a 3D picture)* and they need to know what they are looking for to find it, they don't (I3); they can't find much, well even the uterus! That's a big part of the problem (I3); *(third years)* find ovaries during EMS, mostly no (I3); universities here don't do much to train students for us and they should (I3); *(text)* you cannot teach pding like this (I3); have to think about the safety (I3); have to think about the student doing damage, grabbing things, being rough (I3); they don't know what they are doing and they can do harm (I3); some try to go places they cannot go to and they don't know they can't (I3); some are very cautious... they wont press enough to feel anything, so they aren't going to learn much (I3); for the cow's welfare I don't let them spend much time even if I have time and I often don't (I3); I have other work to do, so does the farmer (I3); *(becoming proficient)* they need enough cows to learn what to do but then there aren't always enough (I3); so many students and fewer cows (I3); in the early stage its dark in there (I3); there is no other way to teach them that is the problem (I3); they have to use these first cows to get to knowing how to feel something (I3); really ten to twenty *(cows)* or more before they are confidently picking out the uterus... (I3); teaching them is difficult if you can't see, it is definitely a problem to teach (I3); third years there is an absolute blank there, this is hopeless from both points of view, I can't see and they can't tell me (I3); they don't know the 3D image, they don't know what it feels like, the two horns. They have not be trained to do this (I3); they have no search ideas (I3); *(after sweeping to find the cervix)* I don't know where they are to tell them to go back or forward to find this uterus and they aren't telling me (I3); *(giving directions)* that is if I am there *(near enough)* to tell them; *(small curled up uterus)* it is easy to go over it especially in EMS when the vet isn't telling them, so they miss it (I3); letting these students loose for EMS, I know at the moment we do it without any training (I3); too fast to feel much and panic too, they aren't used to the sensation of putting their hand in a cow, it squeezing and the faeces being there (I4); they don't know what to do, they probably float around in the abdomen, you know not even in the pelvis, they go too far (I4); some of them don't get their hand in they don't want to push... not wanting to hurt the cow (I4); on farms where they go through the crush or the parlour you don't have much time... the farmer doesn't have much time, he's under pressure, so you can't give them much time... vets charge on time (I4); *(watching the vet)* they aren't going to learn like that (I4); if the farmer has a problem with fertility on his farm he isn't going to want students to examine his cows, some worry students will damage their cows (I4); can the farmer spare the time... takes up time when a vet could be doing something else (I4); there can be welfare issues... don't want too many students examining a cow... if you see blood on a glove you need to stop them, sometimes it's the cow and sometimes students can be a bit rough (I4); there is no other way to teach them (I4); by the time they go to practices for EMS they have forgotten the anatomy, it's been 18 months... forgotten what a uterus looks like and now they are trying to feel something they have forgotten about... anatomy it's more about seeing than feeling (I4);

Problems / Deficiencies (continued)
they are faced with the back end of a cow… they have never had to do anything like this before (I4); this lack of training is a real problem, it means the graduates aren't adequately prepared and that's a problem for the vets who employ them… farmers are less likely to want new graduates to rectal their cow (I4); vets see the initial training as the universities job (I4); they don't have the time to stand there when the student is starting to learn… it's a real problem not every vet can take this time (I4); *(university training)* give the students more access to cows but it's too expensive to have more cows… there are the welfare issues if you let lots of students examine one cow (I4); give the students more access to cows… we'd need more teaching time for this (I4); *(practitioners doing all the initial training)* some incentive… there isn't the money… we *(the university)* wouldn't have control, it wouldn't be very standardised (I4); *(feeling the uterine horns)* quite hard especially when the horns are a bit curled up, they loose it (I4).
Simulator (relating to simulator design and teaching protocol)
Anatomical models
Pelvic brim; pelvic floor; cervix; uterus; ovaries; some (*uterus*) in the pelvis and also intra-abdominal; small uterus, maybe curled one in the pelvis, also perhaps different positions; one stretched out over the brim and one of those tucked to one side; *(uterus)* a few basic positions and variations; two horns, the dip in between the two horns; groove between the horns where they're still joined; one in the abdomen…. some in the pelvis, the one that's curled up… they may miss this one… often has tone which makes it more distinct; *(to include ovaries?)* yes, they need all the anatomical structures that are there; CL; follicle; the pelvis; cervix, it's more solid *(than the uterus)*… in the midline more or less… more reliable position than the uterus; the bifurcation… quite distinct; (pregnancies) early and late; cotyledons, plaques like cobblestones, floating corks; fremitus; part of the calf; *(each structure listed was mentioned by one or more interviewee/s)*
Teaching protocol: skills required (by novices) to perform the procedure
Finding the floor and then moving their hand along the brim. If they could find the cervix too… then the uterus and ovaries (I1); the pelvic brim, cervix and uterus, identifying these with confidence (I1); recognise the basic anatomy (I1); sweep the pelvic floor and brim (I1); identifying key landmarks (*which ones)* the pelvic brim, the two tubes of the uterus (I1); how to find things (I1); becoming familiar with the uterus, feel those two bumps (I1); Tell them to cone their (I1); getting the student to describe what they were touching (I1); you'll need to teach them first (I1); another training session just before they examine cows if there is a while since the first (I1); how to work out where things are in 3D (I1); just the cervix, will probably do to begin with and the pelvic brim (I1); *(to find the uterus)* cervix to uterus first, then if they can't find it find the pelvic brim and search based on findings there (I1); first *(identify)* the cervix and from there the rest of the tract (I2); get them to find the brim (I2); sweep the brim, it would be really useful for students to be able do that; if they could tell you and with the simulator, of course, you could help them get it right (I2); teach first, then they repeat (I2); I don't think third years finding ovaries is very realistic (I2); the basics, finding the cervix, then to uterus, if not then to the pelvic brim (I2); *(for third years)* not the ovaries do that later (I2); training for some early-ish pregnancies (I2); feeling the difference in the tone, non pregnant versus pregnant; really getting to feel the uterus at this stage (*3rd year*), focus on the uterus (I2); they need to know how to put their hand in … maybe include it in your training session (I2); having an idea of the 3D arrangement, where the uterus is inside the cow (I3); having an idea of 3D arrangement,… know with your hands where to look, where it is, this is so important to be able to do it; it's key to find the uterus, is it pregnant? follow it and find the ovaries, they can't do any of this until they find the uterus (I3); initial skills are not so much pding its to do with 3D, knowing what they are looking for and how to find it (I3);

Teaching protocol: (continued)
go forward from the cervix and find the two horns (I3); find and recognise them *(cervix and uterus)* (I3); I teach them to find the cervix first, find the floor first, go to the bottom, go down and not too far in… (I3); sweep from side to side to find the cervix then follow *(the cervix)* forward, not sweeping now; stay in contact with your object (I3); that dip between the horns… it's the most important thing for them to feel (I3); *(if don't find the cervix)* going to the pelvic brim, sweep it, if I find the cervix the uterus is in the abdomen (I3); if I don't find the cervix *(while sweeping the pelvic brim)* the uterus is in the pelvis, then I go back along the floor or slightly higher (I3); *(students)* need there own search strategy (I3); train them to get their hand in that first cow (I3); need to teach them how to find the ovaries (I3); follow the uterus to find it *(ovary)* and a CL or follicle (I3); think about the way they *(CL and follicle)* feel different (I3); pregnancy diagnosis… get these during EMS right from the start (I3); go in and feel the pelvis… forward then down till they feel something, then get them to say what they feel (I4); find the pelvis first as it will always be there and its hard… give them a bit of confidence. Then… feel something within the pelvis… side to side to try and find something on the pelvic floor… then to the pelvic brim and sweep that from side to side to see if there is something going over; need to realise they have to feel things, come in contact with something and work out what it is (I4); I probably go straight to the uterus, but I tell students to find the cervix, it's more solid, they can be more sure of identifying it as the cervix rather than a random piece of uterus. Then they can find the uterus (I4); *(from the cervix)* slowly forward and going just side to side to find the uterus, then forward to the bifurcation… feel round the horns (I4); stay in contact not lift their hand off, its all about feeling (I4); *(for routine fertility work)* the ovaries are then the important part to find… follow the horn and stay close and they are near the tip (I4); get them to describe… what their fingertips are telling them (I4); *(if they can't find anything)* find the pelvis and then the pelvic brim… come back and go left to right as they do to find the uterus behind them (I4); *(if)* sweep the pelvic brim and feel evidence of some structure going over the pelvic brim.. the cervix… the uterus is in the abdomen… follow it *(the cervix)* down to find the uterus (I4); uterus might be over to the side… come back from the pelvic brim… sweeping slowly back along the floor… should find this one too (I4); being confident it's there and how to find it (I4); *(teaching pregnancy diagnosis)* definitely for going out into practice… early and late… building on the same principles they were taught in the non-pregnant find it *(the uterus)*… try and appreciate the difference in the feel of the horns, the sizes of the horns and feel the consistency of the horns, feeling over the horns… (I4); *(late pregnancy)* feel for cotyledons, first as plaques like cobblestones, then kind of the corks as they get bigger, the floating corks… fremitus… the calf… try and ballot the uterus to feel a part of the calf (I4); should feel the ovary for a corpus luteum *(same side)* (I4); *(membrane slip)* No! I don't teach them to do that (I4); *(overall)* confidence in appreciating what there is to feel… how to get there and where it might be… describe what they feel (I4); you tell them… they wont know, but then let them tell you…if you test a student who isn't very good, it might destroy their confidence… still be there to help them if they need it… more likely to remember it if they repeat it… (I4); describing what they are doing is useful for practice and helps them learn (I4).
Advantages / Disadvantages of using a simulator
Advantages: more confident and quicker (I1); provide them with training before EMS then they are going to get the opportunity to learn so much more … vet will take some time and try and train them further (I1); *(learning to describe)* very helpful. I could then help them (I2); technique and confidence to be able to say I've had some training (I2); more confidence would definitely help (I2); *(telling all students how to put their hand in during simulator training)* then there wont be some slipping through the net (I2);

Advantages / Disadvantages of using a simulator (continued)
Advantages: (if they were trained before EMS) would let them do more, I would be a bit more confident they weren't going to do damage (I3); if you could speed up that bit *(finding the uterus)* you could actually then teach them more on pding (I3); very useful if they could say *(what they are doing)*, I could help them (I3); *(having their own search strategy)* that will be very useful for EMS… they won't miss things as much (I3); vets might feel happier in letting students do more if they were trained before EMS (I4); students would be a bit faster and a bit more confident… get to do more (I4); when they go into practice it wont be like they are doing it from scratch (I4); *Disadvantages*: *(time in the curriculum)* … it could be a limiting factor (I1); obviously it is a bit different from a cow (I4); enough time (I4) *Other*: *(some diagrams as well)* that would be good (I1); if you are going to train them don't you think you should do it for all (I3);
Miscellaneous (not relating to any of above categories)
maybe we could get some tracts in the PM room and get them to palpate them through a plastic bag (I1); an anatomy refresher would be good at this stage *(just before EMS)* (I2); new graduates just get the mundane work, no fertility visits and then they get despondent with practice (I4); they still need to do it manually, there will be a limited number of scanners in the practice and say you are out seeing a sick cow that they then want you to pd well you'll have to be able to do it and there might not be a power supply (I4); the university is meant to be a teaching and training establishment so you can see why practitioners may feel it's the university's job (I4);

Appendix 3.2: Cognitive Task Analysis

Two veterinary surgeons took part in a Cognitive Task Analysis (CTA) while performing each of the component parts of bovine rectal palpation. The experts described the manual skills, the knowledge base and the factors that lead them to decide on a particular course of action. The information was compiled into pseudocode, which provided a template for the teaching protocol used during the simulator training sessions.

Task: Find and examine the non-pregnant uterus	
Steps:	
	• Ensure the working environment is safe for all personnel • Insert well lubricated gloved hand with fingers coned and then arm • Move hand forward and down
If	**Uterus is the first structure found** - skip next 2 sections, go to 'once found uterus'
If not	**Uterus not found immediately and hand in pelvis:**
	• Move hand down until make contact with pelvic floor • Locate cervix by sweeping fingers to one side along floor Find nothing:
If	• Sweep fingers to other side • Make contact with cervix, grasp between fingers and thumb and recognise as firm and as single cylinder enclosed within hand **Uterus is in pelvis**
If	• Move forward over the top of the cervix, stabilised under hand and almost immediately middle finger enters groove between uterine horns **Uterus is in abdomen**
If not	• Move further forward and down over pelvic brim and into abdomen until feel groove with middle finger
If not	**Uterus not found immediately & hand advanced into abdomen straight away:**
	• With hand just far side of pelvic brim sweep from side to side **Uterus is in pelvis**
If	• No structure found when sweep brim • Move to midline on brim, move caudally and sweeping left to right on the pelvic floor and bump into both horns of the uterus at the same time as two joined 'knuckles' • Explore horns back towards cervix moving middle finger up groove vertically and then over the top and caudally **Uterus is in abdomen**
If not	• Locate structure when sweep brim Structure identified as double bump with groove in middle
If	• Uterus is on brim Structure identified is a single cylinder and firm
If not	• Cervix is extending over brim, follow forward and down to locate uterus

Once uterus found:	
	• Identify uterus by recognising that there are 2 horns and a groove in the middle dorsally, middle finger in groove • Roll round to either side to assess relative size of horns, middle finger moving laterally across the top and round to sides, may or may not use index finger as well, thumb to one side acting as stabiliser when required, ring finger stabilises opposite side (by placing fingers around the uterus it is easier to stay in contact - if structures move) • Move forward (middle finger +/- ring finger) in groove to bifurcation - recognised as groove now running vertically and uterine horns then split • Then explore one horn by moving hand from bifurcation towards tip, middle finger (+/- ring finger) making contact with horn, moving from side to side around circumference to assess size; thumb not involved unless needed for stabilisation
If	**Horn extends laterally** • Move to cranial side of horn, fingers now vertical and move fingers laterally along horn
If	**Horn extends cranially** • Move fingers forward and down, fingers on top of horn and moving side to side as advance towards tip
If	**Horns curled under** • Move to cranial side of horns, fingers now vertical and move down following groove down, then along one horn under and back
If	**Uterus too big to reach full extent** • Attempt to move uterus back into pelvis • Retract by using all fingers spread as a rake just cranial to bifurcation
If	Unable to reach bifurcation • Move back to cervix, grab and pull backwards
	• Explore other horn N.B. One horn may be in one position e.g. curled while other horn may be in another position e.g. lateral • While exploring horns gently depress surface with middle (and ring) finger/s to appreciate wall thickness and lumen content (watery fluid = pregnancy; turgid contracting wall = oestrus; doughy and less turgid wall and no appreciable lumen content = dioestrus; doughy content and thickened wall = endometritis; viscous fluid content = pyometra)

Dealing with peristalsis	
	• Relax, cone hand, stop trying to palpate
If	Wave passes over hand • Re start palpation
If not	Wave continues to compress hand • Gently insert tips of fingers into ring of contraction • Allow hand to advance through ring to relaxed rectum • Re start palpation
If	Air ballooning rectum *(usually student following vet)* • Gently insert tips of fingers into ring at cranial extent of balloon • Encourage peristaltic wave by gently stimulating ring with fingertips
If	Air is evacuated • Re start palpation
If not	Rectum remains ballooned OR peristalsis continues • Consider terminating examination (for the student)

Task: Ovary Palpation	
Steps:	
Locate Ovary	
If	**Ovary is found straight away** – skip next section
If not	**Find ovary by exploring close to tip of horn**
	• Find uterus and follow round horn to tip (as for non-pregnant) • From tip move hand from side to side while drawing backwards in contact with pelvic floor until feel ovary between fingers and thumb as firm structure, between almond and walnut size
Palpate ovary	
	• Explore surface for cyclical features, use single digit to explore (finger or thumb depending on position of ovary when located) while other finger/s +/- thumb grasp and stabilise the ovary
Repeat for other ovary	

Appendix 3.3: Activity Implementation Chart

Table detailing the Activity Implementation Chart used during the design phase of the simulator-based teaching tool following the conversational framework (Laurillard 1993).

In column one, a series of 12 activities are listed for the teacher (T) and the student (S).

In column two, the teaching modes are listed. These could be: H-H human-human interaction; H-C human-computer interaction; and other interactions (use of other learning resources e.g. textbooks).

In column three, the details of each activity in relation to the teaching mode are describes for students being taught bovine rectal palpation (the activities that specifically relate to the proposed simulator-based training session are in bold).

Activity	**Teaching Mode**	**Learning Bovine Rectal Palpation (undergraduate)** (descriptions relating to simulator specifically are in **bold**)
1. The teacher (T) describes the concept to the student (S)	H-H H-C Other	Anatomy & physiology lectures and practicals (reproduction) **T describes bovine rectal palpation (at start of simulator session)** CAL packages (e.g. Holmes and Summerlee 1995) Text books (e.g. Noakes *et al.* 2001)
2. S describes the concept to T	H-H H-C Other	**S asks questions** during lecture, lab or **simulator session**
3. T re describes concept in view of S's description or action	H-H H-C Other	**Teacher re-iterates points** (Activity 1), **responding to S's questions in** lecture, lab or **simulator session**
4. S re describes concept in view of T's description	H-H H-C Other	**Student asks for further clarification in** lecture, lab or **simulator session (if required)**
5. T sets task	H-H H-C Other	**Teacher instructs student in procedure** **Teacher starts Level; selects another Level or menu option**
6. S performs task	H-H H-C Other	**Student describes actions; asks for guidance if necessary** **Student explores VE interacting with PHANToM; develops search strategy; identifies objects palpated**
7. T provides feedback on the task to S	H-H H-C Other	**T re directs; corrects movements (search), identifies structures** **T selects scenarios to support learning needs of S**
8. S modifies action in view of T's feedback	H-H H-C Other	**S repeats procedure or Level**
9. S reflects on action to modify description of concept	H-H H-C Other	**S reflects on performance achieved, skills developed and knowledge**
10. S adapts action in light of T's description	H-H H-C Other	**S asks questions relating to technique, T describes areas for improvement** **S explores again, if required**
11. T adapts task goal in view of S's description	H-H H-C Other	**T discusses current skill level and explains next task** **T selects same levels / another level / finishes session**
12. T reflects on action to modify description	H-H H-C Other	**T reflects on session and considers modifications to descriptions to better support learning process** **T reflects on session & considers changes to virtual models & scenarios**

Appendix 3.4: Simulation Model Parameter Values

Table detailing the basic models of the simulation used for teaching novice veterinary students to perform bovine rectal palpation.

This part of the thesis is subject to a 3 year restriction on publication from the date of publication of the main thesis (i.e. until July 2010).

Appendix 3.5: Simulator Evaluation

The form used to record the feedback from the nine veterinary surgeons during the evaluation of the simulator models and the teaching protocol.

First, in Section 1 of the evaluation, the participants were to assess the size, shape and feel (softness or firmness) of each virtual anatomical model using the following categories:

R = this is a realistic representation of the structure: a cow would feel like this

A = not quite realistic enough: this could be better but is acceptable representation

N = this is not an acceptable representation of the structure

The frequency of responses is shown together with the participants' comments and any recommendations for changes ('Action'). The results are presented graphically in Chapter 3 (Figure 3.5).

Second, in Section 2 of the evaluation, the participants were asked questions about the structure of the teaching protocol (specifically designed for novice students). They were asked about the steps that should be included to support the stages of the learning process and the order of the steps for each stage.

Section 1: Assessing the Anatomical Models

Level A

Cervix

Assessed criteria	R	A	N
Shape	7	2	
Size	3	6	
Feel	3	6	

Participant Comments

Shape	
Size	A little small; medium example; bit small; medium; disproportionate to rest of tract; average – they vary a lot; heifer; could be bigger (i-a one: size good); a bit small unless heifer; point out the range; compare the ones with different of uteri (i-a, i-p etc); want some range here.
Feel	Firmer than most; bit firm; need more difference to bone; bit hard; would be firm if small
Action	Increase diameter in some simulations and relate to real examples e.g. small = heifer, large and flatter = intra-abdominal uterus ; reduce k-spring by 0.1 = a little softer

Pelvic Floor

Assessed criteria	R	A	N
Shape	6	3	
Size	7	2	
Feel	6	3	

Participant Comments

Shape	More U shaped
Size	A little wide; possibly slightly small but OK
Feel	
Action	No change

Pelvic brim

Assessed criteria	R	A	N
Shape	6	3	
Size	6	3	
Feel	7	2	

Participant Comments

Shape	
Size	Better if could go further over; want more abdomen; want to go further
Feel	Very good, very useful landmark for working out how to proceed
Action	Use intra-abdominal simulation – can go further into abdomen

Ridge at cranial edge of pelvis **Include?** **Yes: 4** **No: 5**

Assessed criteria		R	A	N
Shape		**1**	**4**	**4**
Size		**1**	**2**	**6**
Feel		**4**	**3**	**2**
Participant Comments				
Shape	Too pointy, too high; too exaggerated			
Size	Bit big; too big; too pronounced; too big			
Feel	Too sharp; more flattened on top; not different enough from cervix; too sharp			
General	More important for calving than Pding ("calf cleaver"); don't really notice this; probably not for novices			
Action	Remove from simulated environment, may improve and include at later date.			

Level B

Intra-pelvic uterus – flat ('straight part')

Assessed criteria		R	A	N
Shape		**8**	**1**	
Size		**4**	**5**	
Feel		**5**	**4**	
Participant Comments				
Shape				
Size	OK, but cows vary so much; average OK; smallish; heifer			
Feel	Slightly firm; too firm make softer than cervix; bulling; close to oestrus; oestrus			
Action	Leave as is and explain is heifer close to oestrus (bulling)			

Intra-pelvic uterus – flat (horn) – cylinder and sphere **Yes: 6** No: 3

Assessed criteria		R	A	N
Shape		**3**	**6**	
Size		**4**	**5**	
Feel		**2**	**7**	
Participant Comments				
Shape				
Size				
Feel	Slightly firm; bulling; best if run hand round far side			
General	Want to get under and catch in hand			
Action	Use this version (horns built from cylinder and spheres not stretched sphere)			

Intra-pelvic uterus – flat (horn) – stretched sphere Yes: 3 **No: 6**

Assessed criteria	R	A	N
Shape	**2**		
Size	**1**	**1**	
Feel		**2**	

Participant Comments	
Shape	Better as don't slip off this as easily
Size	Average
Feel	A little firm
Action	Do not use this version

Intra-abdominal uterus (horns)

Diagnosis based on pelvic sweep	**i-a 9**	i-p	
Assessed criteria	R	A	N
Shape	**5**	**4**	
Size	**5**	**4**	
Feel	**5**	**4**	

Participant Comments	
Shape	Like this cervix, wider and flatter; this cervix makes a good comparison
Size	Better than other (*i-p flat*); usually bigger when in abdomen; more like a cow
Feel	Turgid = oestrus; make a bit softer; in oestrus; if over brim likely to be softer
General	Like this one
Action	Use to teach pelvic brim as has more abdomen in simulation; reduce kspring by 0.2; compare with small oestrus uterus and emphasise this is more like a cow. Explain why cervix is larger and flattened (i.e. due to weight of uterus)

Intra-pelvic uterus – curled (horns)

Diagnosis based on pelvic sweep	i-a	**i-p 9**	
Assessed criteria	R	A	N
Shape	**6**	**3**	
Size	**4**	**5**	
Feel	**9**		

Participant Comments	
Shape	
Size	Small but possible; small like young, tight ones; would be small as most are in heifers; average; heifer; OK as heifer
Feel	OK, as expect these to be firm; firm; too hard on top but OK when behind hand
General	Give students time to practice this one; take this one slowly, once you get it it's very good
Action	No changes to simulation. Emphasise typical of heifer

Ovary (partly in floor)   Yes: 9   No: 0

Assessed criteria		R	A	N
Shape		**3**	**6**	
Size		**4**	**5**	
Feel		**4**	**5**	
Participant Comments				
Shape	Very regular			
Size	A little big; big but correct for students learning; big but better for novice students to find them, more difficult ones for later years; bit big but if smaller novices might not find it so explain real maybe smaller			
Feel	A little firm;			
General	This one is better for one finger; would really be free not fixed			
Action	Use this simulation. Explain size varies			

Ovary (just above floor)   Yes: 0   No: 9

Assessed criteria	R	A	N
Shape			
Size			
Feel			
General Comments	It's difficult with the thimble; need my thumb; this doesn't work		
Action	Do not use this simulation		

CL

Assessed criteria		R	A	N
Shape		**6**	**3**	
Size		**4**	**5**	
Feel		**5**	**3**	**1**
Participant Comments				
Shape	Like the neck; flatten and squash this a bit; protrudes more than normal			
Size	Bit big; big but OK as example for students; average; bit big; good for starters; little big			
Feel	Good contrast with follicle; good contrast with follicle; not enough contrast to follicle but neck good; bit firm; more contrast with ovary; a little firm			
Action	Reduce stiffness (KSpring value) by 0.1. Explain to student is as big and pronounced as will find. Emphasise represents good contrast with follicle & appreciate the neck			

Follicle (day of ovulation)

Assessed criteria		R	A	N
Shape		**8**	**1**	
Size		**3**	**6**	
Feel		**7**	**2**	
Participant Comments				
Shape	More sunk			
Size	A little big but OK; a bit big unless literally about to ovulate; big but very good simulation overall; OK; bit big, OK for third years if explain; bit big			
Feel	Very good; need a little more distinction to ovary; even more bounce; good			
General	Depends which way you move your hand over it, left to right is best (if on R ovary and right hander)			
Action	Explain is day of ovulation size and most follicles are smaller			

<u>Pregnancy</u>

8 week

Assessed criteria		R	A	N
Shape		**7**	**2**	
Size		**4**	**4**	**1**
Feel		**5**	**4**	
Participant Comments				
Shape	Could bring horns closer together			
Size	Bit small (7&1/2), 7+ weeks; nearer 7 weeks			
Feel	Put a little more fluid for 8 weeks; maybe even softer for starters? Good			
Action	Decide to change description ("7 to 7 and a half weeks") rather than model			

10 week

Assessed criteria		R	A	N
Shape		**6**	**3**	
Size		**3**	**6**	
Feel		**8**	**1**	
Participant Comments				
Shape	Really good			
Size	Bit small; make non implanted slightly bigger; 10-ish			
Feel	Very good; can feel reduced tone and fluid; feels better than other (*8 weeks*) as bigger is easier with one finger; right a bit bigger relative to left; feels softer than 8 weeks; Good			
General	They don't all feel exactly the same size anyway (cows at the same weeks)			
Action	Be less specific with classification i.e. describe as "91/2 to 10 weeks"			

<u>Section 2: Assessing the Teaching Protocol</u> (for 3rd years prior to examining first cow)

Teaching has been divided into 'Levels' to support the learning process

Check boxes represent suggested sequential steps, explain the steps and then decide on the position (1 first, 2 second, 3 third etc.) of each in the overall order.

- **Level A – initial 3D orientation: cervix on floor of pelvis and pelvic brim**

Level Order:	*1st*	8	*2nd*		*3rd*	

No = **1** (all in Level B)

- **Level B – Finding the uterus**

Level Order:	*1st*	1	*2nd*	8	*3rd*	

  - Find uterus by following the cervix forward

Step Order:	*1st*	9	*2nd*		*3rd*	

If don't find the cervix or uterus search by finding brim **Yes 9** No 0

  - sweep pelvic brim, find cervix and go forward (**intra-abdominal uterus**)

Step Order:	*1st*		*2nd*	9	*3rd*	

  - sweep pelvic brim, no cervix, go back along floor (**intra-pelvic uterus**)

Step Order:	*1st*		*2nd*		*3rd*	9

Comments: Need to learn to how to find things; wont always find things straight away (though vets do) so need to learn a search; these seem to address the need for a logical search for students; should feel what it is like to sweep the brim, it's good to get the students to do this.

  - Include other positions of uterus (3rd years)? Yes 0 **No 9**

Other search strategies to find uterus describe: None
Comments: This is enough for 3rd years; include the bladder as they can mistake it for other structures (uterus); adding more in 3rd year would just be confusing; the little curled up uterus is commonly missed; the two bumps of the uterus are key and then they wont confuse it with the bladder; you don't need any more uterine positions for 3rd years; the positions you have are enough; add in one curled under in the abdomen for later years; the pelvic brim is helpful, students can use it to work out what to do, check for the cervix.

- **Level C - Pregnancy diagnosis Include?** **Yes 8** No 1

Level Order:	*1st*		*2nd*		*3rd*	8

Comments: Do include an obvious / easy one as it would give psychological encouragement and it's good to contrast with the non-pregnant; include as will probably do some even in first EMS;

good to learn this in a controlled environment; No – too much to take in unless do as another session; they would be safer feeling after being trained here as I'm not keen to let them do this at the moment; include some notes given out before the session, some visual aids during the session and include an approach to the cow

Teaching Session Structure

• Teacher instruct student	**Yes 9**	No 0
• Student explore on own (before instruction)	Yes 0	**No 9**
• Student explore on own (after instruction)	**Yes 9**	No 0

Discuss / Comments:
They'll need to be taught how to use the device anyway; definitely get student to describe to you what they are doing as if they could do this during EMS I think it would make it much easier for me to teach; they need to be taught because they don't know what to do and with the simulator you can tell them step by step; they should practice after being told so that they can see if they know it and the teacher could help correct any problems; it would make them think about what they are doing and feeling and build up that all important mental picture; students exploring on their own first wouldn't work that's the problem now and you want to have your hand in with them! Seeing what their up to, helps a lot! I'd use this to teach them a search pattern so they'd know what to do in the cow, then try on their own and you put them right again.

Level A – initial 3D orientation: cervix on floor of pelvis & pelvic brim

- **Protocol 1** **Yes 9** No 0
  - Down to find floor

Step Order:	*1st*	9	*2nd*		*3rd*	

  - Side to side on floor to find cervix in the midline

Step Order:	*1st*		*2nd*	9	*3rd*	

  - Forward along floor to find brim

Step Order:	*1st*		*2nd*		*3rd*	9

Comments: it's important to get them to move their hand down as it's all under them

- **Protocol 2:** Yes 0 **No 9**
  - Down to find floor
  - Side to side along floor to find cervix
  - Forward along floor to find brim
    - Sweep to find cervix (*as if i-a uterus*)
    - Sweep to find no cervix (*as if i-p uterus*)
    - Sweep hand to feel ridge on pubic symphysis Yes 1 **No 8**

Comments: could include symphysis but not 3rd years; this (Protocol 2) would confuse 3rd years; Protocol 1 is more in context to what you do; this (Protocol 2) would confuse them.

- **Protocol 3:** Yes 0 **No 9**

If 1 and 2 are not considered correct, describe other……

Level B - Finding the uterus

Flat uterus

- **Protocol 1:** Yes 0 **No 9**

  Hand straight to uterus (forward and down from just inside rectum)

- **Protocol 2:** Yes 0 **No 9**

  - Develop a search strategy to locate uterus
  - Do not train 3rd year students to explore rest of uterine horns
  - Do not train 3rd year students to find ovaries

- **Protocol 3:** **Yes 9** No 0

  - As Level A to find cervix

Step Order:	***1st***	**9**	*2nd*		*3rd*	

  - Find body by moving forward in midline as sweep left to right over cervix
  - Sweep left to right over body to familiarise with 'OO' shape

Step Order:	*1st*		***2nd***	**9**	***3rd***	**9**

  - Train 3rd year students to find rest of uterus and ovaries **Yes 9** No 0
  - Follow a horn to tip (or another method? Yes 0 **No 9**)

Step Order:	***1st***	**9**	*2nd*		*3rd*	

  - Locate an ovary, exploring close to the tip

Step Order:	*1st*		***2nd***	**9**	*3rd*	

  - Palpate a CL or follicle, appreciating the difference **Yes 6** No 3

Step Order:	*1st*		*2nd*		***3rd***	**6**

Comments: Impress on students that uterus is attached to cervix and distinguished by the two bumps (not the bladder); need two fingers for feeling ovaries, make them aware ovary not smooth – has a structure on it; don't teach ovarian structures to 3rd years; would make better use of EMS if could find ovaries; should train students to find the uterus i.e. not Protocol 1 as they wont do that (straight to uterus); feeling CL – not at this stage; students can't relate uterus to spatial 3D so wont go straight to uterus unless very obvious so need search strategy; the double bump of the uterus is very important; feeling CL etc not feasible in 3rd year; good to teach to find ovaries at this stage as will give them time to learn this; use cervix and forward first as if go pelvic brim and back may find bladder first; follow the uterus round to the ovaries and then you wont miss something in the uterine horn - like a pregnancy; probably quite often go straight to the ovaries but students wont do this and shouldn't at first, they need to examine the uterus too and learn each step.

- **Protocol 4: Other techniques**

Comments: further into cow and then come back; pull uterus back (retract) not 3rd years but useful for 4th years onwards; I tend to go forward and rake back first but probably best to get students to go forward from cervix first; we need to teach techniques, it's probably random at the moment.

If *don't find the cervix or uterus* – learn search strategy

Intra-abdominal uterus

- **Protocol 1:** **Yes 9** No 0
  - Start by sweeping pelvic brim to find cervix
  - Follow forward along cervix to find horns
- **Protocol 1A:** Yes 0 **No 9**
  - Start by sweeping pelvic brim to find cervix
  - Move down abdominal wall and sweep side to side to find horns
- **Protocol 2:** **Yes 7** No 2
  - Set up so don't / can't find uterus (not there)
  - Sweep along floor to pelvic brim, then add cervix and uterus
  - Sweep pelvic brim and find cervix (just have cervix over then add i-a?)
  - Follow forward along cervix to find horns **Yes 6** No 1
  - Move down abdominal wall, sweep side to side to find horns Yes 1 **No 6**

Comments: Getting lost is what is happening in the real cow which is why training students to develop a technique is so important.

Intra-pelvic uterus – curled

- **Protocol i-a 1:** Yes 0 **No 9**
  - Start by sweeping pelvic brim to find cervix
- **Protocol i-a 2:** **Yes 9** No 0
  - Set up so can't find uterus (not there), find pelvic brim then sweep.

Then:

- **Protocol 1:** **Yes 9** No 0
  - Sweep pelvic brim – nothing
  - Come back in midline along floor
  - Feel uterus curled behind hand
- **Protocol 2:** Yes 0 **No 9**
  - Sweep pelvic brim – nothing
  - Move hand up and much further back until nearer caudal pelvic inlet

- Move down to find cervix or uterus on floor
- Move from side to side
- Then gradually move forward as sweep from side to side to find uterus

Comments: Don't do Protocol 2 as they'll just miss it again

Pregnancy diagnosis

- Technique (**first trimester**)

o Membrane slip	Yes 0	**No 9**
o Sweep hand from side to side	**Yes 9**	No 0
o Other:		

Ballot the calf (12 weeks plus); tap it; ballot as go along horn; balloting; tap

Comments: Membrane slip: might cause abortion even if trained don't think students should be doing this; arguably safer if were trained in simulator but I still wouldn't let them do it; not safe for students to do; if you trained them they might start doing this on their own – not a good idea; too dangerous; might squeeze too hard even if trained in simulator; dangerous

- For early pregnancy diagnosis, the following are arranged in order of importance:
  1. Size (implanted versus non implanted horn)
  2. Fluid content (implanted versus non implanted horn)
  3. Wall thickness (implanted versus non implanted horn)
  4. Softness (non pregnant versus pregnant)

Other: CL same side as pregnancy; softness is not specific enough to be diagnostic; compare softness of pregnant with involuting uterus; compare with endometritis – doughy soft rather than fluid.

Appendix 4.1: 'On Farm' Instruction Sheet

General Points

- Before you start: short finger nails and rings off.
- Use plenty of lubrication.
- If you are having problems reaching the cow: ask for a crate to stand on.

Instructions before start:

- The experiment aims to assess the effect of two teaching methods:
    - Simulator training (Group A);
    - Traditional training only (Group B).
- The experiment is not assessing individual student performances *per se*.
- You are to perform bovine rectal palpation on 4 non-pregnant cows.
- **<u>The aim is to try and locate the uterus</u>**.
- You will have up to 5 minutes to examine each cow.
- You will have an ultrasound probe attached to the palm of your hand with adhesive tape for the duration of the rectal palpation.
- You will examine two of the cows first and two of the cows second i.e.
    - you will have your hand in before the other student for two cows
    - you will follow the other student for two cows.
- **<u>When you think you are palpating the uterus tell the researcher</u>** who will try to confirm this while viewing the ultrasound screen (this will not be visible to you).
- The researcher may ask you to move your hand around over the uterus to aid identification.
- Once you have located the uterus or the 5 minutes is up, the examination will terminate.
- The researcher will use a tape recorder and will describe the experiment proceedings e.g. cow ID, student group ID, unexpected events etc.
- The ultrasound trace will be recorded on a video.

To start

- Cone your hand, then push through the sphincter to insert your hand into rectum.

There will be a brief pause at the point when your hand is just through the sphincter for the researcher to start the video recording.

During the examination

- Continue to insert your hand into the rectum so that part of your arm passes through the sphincter.
- Now start to try and find the uterus.
- If the rectum is dilated with air (ballooning), inform the researcher. **Do not** remove your hand, gently push your hand forward until you feel a peristaltic wave pass over hand. The wave of peristalsis will push the air out enabling you to feel.
- If the cow strains and your hand is constricted by peristalsis **do not** take your hand out. Let the researcher know what is happening, relax, leave your hand where it is and let the wave pass over your hand - then you will be able to feel again.
- During the examination do not remove your hand from the rectum until the researcher tells you to. **However, if at any stage you wish to terminate the examination inform the researcher.**

Appendix 4.2: Time Data

The table shows the time (in seconds) taken by students in Group A (A1 to A8), simulator trained, and Group B (B1 to B8), traditional training only, to locate the uterus successfully (as verified by ultrasound). There were 18 successful identifications in Group A, one in Group B. The blank cells in the table represent the examinations where the student was unable to find the uterus within the time allowed (5 minutes) or where the identification could not be verified by ultrasound.

Cow → ↓ Student	1st	2nd	3rd	4th	Cow → ↓ Student	1st	2nd	3rd	4th
A1		155			**B1**				
A2		165	218	238	**B2**				
A3			85	45	**B3**				
A4		45	115	147	**B4**				
A5			120	57	**B5**				
A6		54	91	93	**B6**				
A7	77		68		**B7**		258		
A8		81	221		**B8**				

Appendix 5.1: Questionnaire 1

The questionnaire was used to collect information about students' experiences prior to the simulator training and to gather feedback on the training session (69 questionnaires were returned). The number of responses (for each category, for each question), are shown in **bold**.

Number of students participating in training = 94 / 97 (97%)

Questionnaire return rate = 69 / 94 (73%)

Part A: Background Information **(please tick or fill in the relevant box/es)**

1. How many cows had you rectalled before training on the haptic device:

None	1 - 5	6 - 10	11 - 25	26 - 50	> 50
14	**19**	**7**	**17**	**5**	**7**

2. If you have you rectalled cows, was this at:

Vet School	During EMS	On farms other than at vet school or during EMS
3	**48**	**17**

3. What has comprised your training for bovine rectal palpation (tick one or more):

Lectures	*In vitro* tracts (in the anatomy lab)	By vet while on farm
48	**31**	**47**

4. If you had rectalled some cows before using the haptic device, approximately how often have you found :

	Less than ⅓ of the time	Between ⅓ and ⅔ of the time	More than ⅔ of the time
The uterus	**29**	**22**	**4**
The cervix	**15**	**23**	**17**
Pelvic brim	**11**	**21**	**23**
Ovaries	**54**	**1**	

5. How confident are you at performing bovine rectal palpation at the moment?

No confidence whatsoever	Little confidence	Some confidence	Confident	Very Confident
15	**35**	**17**	**2**	**0**

Part B: Simulator Training Session
Please tick a box in response to each of the following statements.

Statement	Strongly agree	Agree	Neutral	Disagree	Strongly Disagree
Haptic training provided a useful search strategy for locating parts of the bovine reproductive tract.	**57**	**12**			
Haptic training increased knowledge of the feel of key structures e.g. the uterus	**32**	**34**	**3**		
Haptic training increased knowledge of the relative position of key structures.	**46**	**23**			
Guidance (provided by the teacher) was helpful during haptic training.	**60**	**9**			
Haptic training increased your confidence to perform bovine rectal palpation.	**43**	**24**	**1**	**1**	
Haptic training increased your confidence to perform pregnancy diagnosis.	**25**	**36**	**7**	**1**	

7. Which anatomical structures are you **confident** that you have identified:
(Please complete one or both columns as appropriate to your EMS experience).

Anatomical Structure	Before haptic training	During haptic training **Did not identify confidently**
Cervix		
Pelvic Floor		**2 / 69**
Right Ovary		**2**
Uterus(straight part, joined cylinders)		
Follicle		**5**
Pelvic brim		**3**
Corpus luteum		**7**
Left Ovary		**2**
An eight week pregnancy		**1**

8. The time allocated for the teaching session was:

Much too long	A little long	About right	A little short	Much too short
		34	**34**	**1**
Comments:				

9. The speed at which the training session was conducted was:

Much too slow	A little slow	About right	A little fast	Much too fast
		60	**9**	
Comments:				

10. The simulator training session was helpful for learning bovine rectal palpation.

Strongly agree	Agree	Neutral	Disagree	Strongly Disagree
54	**15**			
Comments: See Appendix 5.2				

11. Would you like to use the bovine rectal palpation simulator again?

62 Yes No **5** Not **2** sure

Explain....

See Appendix 5.2

12. Any other comments you would like to make? (Please write below)

See Appendix 5.2

Thank you

Appendix 5.2: Comments from Questionnaire 1

Comments from Question 10
The simulator training session was helpful for learning bovine rectal palpation.

Strongly agree	Agree	Neutral	Disagree	Strongly Disagree
54	15			

Definitely as I was able to be guided so I knew exactly where I was within the cow and what I was feeling as from previous experience I felt pretty lost.
V. good!
Without the haptic training course I don't think I would ever be really confident that I was feeling the structures I thought I was feeling.
It was useful to learn the feel of single structures but I felt the dimensions were not very realistic compared to actual cows I have rectalled. (1-5).
It was helpful to have someone able to guide and tell you what you are meant to feel and where. The main advantage was to be given a search strategy which I had not been taught previously.
As I have never attempted this in a live animal I can't be sure exactly how useful this will be. At least I should know what to look for and where it should be.
Gives you an idea visually in your head and helps you "see" where stuff is with your fingers. Anatomy helped as well (a little) but more importantly it is in your imagination.
It was very helpful that tutor knew where your hand was and could guide you to structures.
Excellent!
Seems to provide a useful stepping stone between lectures and live cows.
It was useful in establishing a method and strategy for performing rectals. May lead you into a false sense of security though because no faeces and no contractions. Needs to be developed to include older pregnancies.
I still think in life it will be very different (faeces in rectum, cow straining against you etc.) but having never rectalled before I think this very much helped me gain an impression of anatomical relationships, textures to expect and helped give a methodical way of examining the repro tract per rectum. I think I will feel a lot more confident now when I rectal my first live cow.
The session was good for being able to identify anatomical structures that were less clear prior to this session.
Very good for identifying landmarks – it's very useful for someone to tell you what you are feeling as you are feeling it. I feel that the next time I do rectals in a real cow I will be able to locate structures much more easily.
A very useful teaching medium, good to have one-on-one tuition.
Useful for learning topography of a rectal exam, and where to look next if you can't find anything.
The training was good but I think would be much more beneficial if there was a possibility of using two or more fingers for contrast/assessment of size of structures etc.
Excellent – I feel much more confident about trying it on EMS now.
Excellent – very clever way of learning!
If I hadn't used the haptic cow then I would have no idea what kind of textures to feel for in the real cow and therefore learning to rectal would take much longer.
As it's impossible for the vet to see what a student is doing inside a real cow this is the perfect means to direct them and know that both student and tutor are talking about the same structure.
During EMS it is possible to miss certain structures such as ovaries so that experience feeling these is limited. The training session gives an opportunity to identify structures with certainty.

I feel I will be more able to make use of any time I may spend doing rectal palpation on EMS as I have an idea of what to look for.
It is very useful to have it all fully explained to you. Also as your position in the cow can be monitored all the time they can help you – tell you where to go and what exactly you are feeling.
I found this session extremely useful and enabled me to find structures that I hadn't felt – showed me how to look for them.
Very useful, but it does take some getting used to. Strange just feeling with your fingers not your whole hand.
Vet willing but v difficult to explain feel of structures in words. Now feel much more confident in explaining where I might be so vet more able to help in future and I can get some practice!
This session ahs certainly greatly increased my confidence and I look forward to putting it to the test next EMS period.
Structures all felt a bit solid. Think soft tissue structures are more squishy and less defined in amongst all the other structures when you are actually inside a cow.
Very useful, perhaps should be brought in earlier so as to catch early EMS.
It was very useful having someone guiding you who could see where you were, because even though vets try and guide you it's not always easy (during EMS).
I found the haptic training session very useful, and it gave me much more confidence with the cows I've rectalled since! Thank you!
In an incredible way it gets your touch receptors reconnected to your brain. I think the more you used it the better it would be. It would be great to use it alongside a real cow of similar pregnancy stage, age, size etc. so you could be guided by computer then practice in the real cow.
I found the haptic cow v. useful with the feel and texture of areas of the tract, pelvis etc.
The haptic cow training session was very useful. Additional sessions throughout the remaining two years would be useful – suggestion that these sessions constitute unknown scenarios i.e. student actual diagnoses therefore allowing evaluation of performance by student / tutor
Feel more confident now when going out to PD.
Having confirmation that I was touching the structures that I thought I was, was extremely useful.
Definitely very helpful. Would feel more confident when performing rectal examination on a real cow!
However I have limited experience to compare it to the real thing!
An excellent learning tool and should be developed as much as possible
VERY USEFUL!
After having used the simulator I feel more confident about doing a rectal exam on cows. Now knowing what the structures should feel like.
It would have been useful to get more experience and spend more time feeling ovaries. Also possibly carruncles, membrane slip if possible or fremitus?
Very useful for learning to perform palpation in a systematic way.
This would be really useful for students before starting clinical EMS as how to begin the process and carrying it out logically is useful to know before the real thing.
Very good and a very good patient instructor who gives you confidence.
Very useful for getting to know basic landmarks and using the sense of touch.

Comments from Question 11
Would you like to use the simulator again?
Yes = 62, No = 5, Not sure = 2

The comments from those who wanted to use the simulator again:
It might be useful to go back to the haptic cow after doing some rectals in cows.
For repetition to ensure the feelings and locations stay in my mind.
Definitely!
Possibly to keep practicing intermittently.
Because it allows time to reinforce the touch sensation in a controlled environment where you know what you are feeling.
I think it would be useful to use the simulator again after I have rectalled some actual cows to be able to apply what I have learnt and discuss any problems I had in real cows.
It would be good to use to keep refreshing your memory as it is easy to forget during terms between holidays.
Repetition always helps me to learn.
Not sure – would like to go and rectal cows now then possibly come back and use it again depending how I get on.
I would like to practice on live cows as well because doing a live rectalling is quite different from the "mechanical" cow – sight, smell, sound peristalsis. If scenarios in the BRPS get more challenging (i.e. set questions that you'd ask yourself if you found such and such a thingy where) I reckon it would help to reinforce what we learn in reproduction lectures as well.
Helpful in building confidence.
Would be good to repeat before farm animal EMS.
To gain confidence in decisions.
Having not rectalled before the more practice the better.
I found it very useful and a relaxed learning environment – wasn't under any pressure from farmer, cow, vet etc. Could really think about where everything was and what it felt like.
It would be useful to use it again before going out on farms to PD cows just as a review.
I think its something that you can't really do too much.
Not sure – depends how well I get on during xmas EMS.
Would be good to use again once I have rectalled some more cows during EMS to confirm what am feeling in live cows.
It is very good practice as it correlates well with my knowledge of EMS.
If I do get the opportunity to do some on EMS and I have problems – then it would help to go over things on the simulator.
I would like to use it again closer to an EMS placement so it is fresh in my mind before rectalling a real cow.
One go is enough to get used to the device and get a good idea what it's all about. It would be nice if I could have a few goes without having to be talked through what I am feeling.
I was aware that time was short and practise can only improve my rectalling skills.
I think it would be useful to try to identify the unusual positions of structures e.g. ovaries and uterine horns if this could be available.
Will be useful to practice with especially after doing a real rectal palpation so that can remind yourself what it feels like.
Extremely beneficial.
Possibly after going rectalling some real cows again it may be good to come back to compare and straighten things out in your head!?
Having got used to the machine I feel would get a lot more out of it. But overall it was a very useful exercise.
It would be very useful immediately prior to farm EMS.

Confident with cervix, uterus and pelvic brim but I felt I needed a little imagination to be confident feeling follicle or CL, so with a little more practice may become more confident with this.
To confirm search strategies which are useful. To be more familiar with the machine feeling and how the haptic device works.
Practise, practise, practise.
Having had minimal experience, I found it extremely useful.
It would be very useful to do before doing EMS on a mixed practice.
Practice makes perfect! More confidence!
I'd like to familiarise myself better with it.
I would like to try what I learnt in real cows and then reinforce these again with the haptic cow.
Any practice is good! It would be useful to run through it all again, get it fixed in my head.
But without instruction i.e. have a scenario programmed in and then tell the instructor my interpretation of it.
Would like to feel more situations and perhaps revise Pding and the feel of follicles and corpus luteum.
Before I go on EMS to large animal practice or the Cochno farm.
Would be useful before going on EMS.
The more practice the better!
Although after using it once I would rather try it on some real cows to see if I could still feel the structures.
Just to go over everything again to be more confident
To increase my confidence about going on EMS and being able to actually identify things, to use the simulator again would be great!!
It would be useful to have a little bit longer to really familiarise yourself with the structures and maybe have a refresher session later this year or next.
I would like to spend more time feeling ovarian structures.
Because it was very helpful and gives you more confidence when having to do it in front of a vet or farmer as you have some idea of what you are doing. It puts you a step ahead of people who haven't done it.
More practice would further increase confidence at this technique.
Gives confidence to try it in EMS. Would be good to feel different stages of pregnancy.

The comments from those who did not want to use the simulator again (5 students):
(the number in brackets, after each comment, is the number of cows each student had examined before simulator training)
Would like to apply what I've learned in real cows (>50).
I feel its benefits would be greatest before having done a large number of cows in practice and then you need to deal with faeces etc (>50).
It was useful but obviously practice on real cows is more important. Having said that a refresher course before EMS would be good in an ideal situation. Having the handout for revision is very useful (1 – 5).
Not at the moment, but if I struggle at rectal palpation during EMS I may wish to give it another go (11 – 25).
Think I have gained all I can from it. Need some live cows now (11 – 25).

Comments for Q12
Any other comments?

I had no knowledge of the technique before this session. I now feel confident to try a rectal examination in a real cow and to locate and palpate the important structures.
Short but useful session. Think it will help in actual cows as you are never sure that what you are feeling is actually what you think it is. This way by being able to identify certain landmarks you'll be able to tell that you are at least in the right area rather than searching around a huge area!!
I feel the haptic cow is useful because on the farm in EMS I always feel the pressure of time, the vet has to get on with the PDing and you don't really get the time to be taught properly. It helps that the teacher can see what you're doing.
Much easier than real cows (hence good for inexperienced such as myself). It felt easier because there was no rectal wall to feel through as well – easier to discern between different structures and textures.
Extremely helpful and really increases confidence.
What about fat or thin cows and the different affects on being able to rectal. What about other bits of anatomy, other than the repro-tract.
Thanks very much I found it very useful and definitely helped me.
Before the practical I know U have felt lots of different structures but only when explained how they should feel. I know my confidence and also a strategy for when U can't feel anything as to what to do.
Very helpful to have some time to appreciate basics of rectal examination especially on individual basis. I think it really helps to have at least tried a rectal exam on a real cow first, so you can translate what you feel in haptic cow back to real cow.
More finger units, understandably expensive but would complete experience.
It did help. Thanx.
I'd like to try the simulator adjacent to a live animal to (with similar tract/stage etc.) just to verify that what I was feeling in the simulator was indeed what I was feeling in the cow.
In vitro tracts are absolutely useless.
For the available time the session was very informative.
The haptic cow is an excellent teaching device.
The more life-like the better it will be. Excellent overall.
Excellent program – would be especially useful for lower years who have not started clinical EMS to give them some confidence and understanding of the technique.
Maybe good if there was some visual element incorporated e.g. scanning screen picture as would be able to relate more to what you are feeling at the time.

Appendix 5.3: Questionnaire 2

The questionnaire was used to gather feedback on the training session after the students had undertaken the next extramural studies on farms with veterinary surgeons (50 questionnaires were returned). The number of responses (for each category, for each question), are shown in **bold**.

1. How many cows have you rectalled <u>**since**</u> the simulator training session: **(tick relevant box/es)**

None	1 - 5	6 - 10	11 - 25	26 - 50	> 50
	4	**7**	**15**	**18**	**6**

2. How long was it between your simulator training and the next time you rectalled a cow:

Next day	Between 2 & 7 days	Between 1 wk and 1 month	Between 1 & 3 months	Between 3 & 6 months	More than 6 months
	1	**6**	**32**	**11**	

3. <u>**Since**</u> simulator training where have you examined cows (tick one or more):

Vet School	At Lanark	During EMS	On farms other than at vet school, Lanark or during EMS
2	**4**	**47**	**6**

4. <u>**After**</u> **the simulator training** when examining cows approximately how often have you found:

	Less than ⅓ of the time	Between ⅓ and ⅔ of the time	More than ⅔ of the time
The uterus	**2**	**16**	**32**
The cervix	**5**	**11**	**34**
Pelvic brim	**3**	**2**	**45**
Ovaries	**24**	**21**	**5**

5. How confident are you at performing bovine rectal palpation **now**?

No confidence whatsoever	Little confidence	Some confidence	Confident	Very Confident
	7	**33**	**9**	**1**

6. Could you rate the effect that simulator training had on your confidence:

Greatly decreased confidence	Slightly decreased confidence	No effect	Slightly increased confidence	Greatly increased confidence
		2	**41**	**7**

Effect of Simulator Training

7. From your experience examining real cows **<u>after</u> simulator training** could you classify your response to the following statements:

Statement	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
A. Simulator training had improved your ability to orientate inside the cow	**15**	**33**	**1**		**1**
B. Simulator training had improved your ability to **find** the uterus when examining real cows	**9**	**35**	**4**	**2**	
C. Simulator training had improved your ability to **identify** the uterus (i.e. you were able to recognise the uterus when you palpated it) when examining real cows	**9**	**30**	**9**	**2**	
D. Simulator training had increased your speed finding structures when examining real cows	**4**	**21**	**20**	**4**	**1**
E. Simulator training had improved your ability to locate the ovaries when examining real cows	**4**	**18**	**15**	**10**	**3**
F. Simulator training had increased your overall confidence to perform rectal palpation	**11**	**28**	**9**	**2**	
G. Simulator training had increased your overall confidence to perform pregnancy diagnosis	**3**	**18**	**20**	**8**	**1**

8. Which anatomical structures are you now **confident** you can identify when examining the real cow:

Anatomical Structure	Yes	No
Cervix		**3 / 50**
Pelvic Floor		**0**
Ovary		**29**
Uterus (straight part, joined cylinders)		**4**
Follicle		**40**
Pelvic brim		**2**
Corpus luteum		**34**
An early pregnancy (e.g. between 7 & 10 weeks)		**34**
A more advanced pregnancy (e.g. between 4 & 9 months)		**10**

9. The handout notes were helpful.

Strongly agree	Agree	Neutral	Disagree	Strongly disagree
7	**40**	**3**		

10. Having examined cows since the simulator training session could you categorise you response to the following statement:

'The simulator training session was helpful for learning bovine rectal palpation'

Strongly agree	Agree	Neutral	Disagree	Strongly disagree
16	**29**	**5**		
Comments: See Appendix 5.4				

11. After the initial simulator training session have you had a chance to use the Bovine Rectal Palpation Simulator again? Yes **6** No **44**

Would you still like to/like to again? Yes **48** No **2** Not sure **0**

12. Any other comments you would like to make? (Please write **below and / or overleaf**)

See Appendix 5.4

Thank you

Appendix 5.4: Comments from Questionnaire 2

Feedback after examining cows <u>after</u> first training session and after the next EMS
50 questionnaires returned

Question 10. The haptic training was helpful for learning bovine rectal palpation

It helps but out in the field with a busy vet and farmer it can sometimes be a bit rushed but some vet / farmer combinations did give me time with each cow.
Yes, although it doesn't prepare you for the actual rectal examination conditions i.e. peristaltic waves etc. And gives no idea of the delicacy or moveability of the rectum or uterus and uterine horns.
Was helpful in familiarisation with structures present in pelvis but was quite different once had hand in a cow!
Not so much pressure involved.
I believe I was better at pd than I would otherwise have been but the real cow pushes your hand out and each uterus is in a different position making it difficult to locate the uterus and ovaries in many cases.
I think it felt quite different but I felt that I could approach the situation in a systematic way with a list of check points to work through so felt less intimidated and under pressure.
As it was 10 weeks from doing haptic cow until EMS I had forgotten a lot and it was not as useful as I had hoped.
It was very helpful being able to picture the positioning of everything inside the cow, but everything is mobile and full of faeces. I found it more difficult in real life.
Really helped me orientate and ask stupid q's that are too silly to ask the EMS vet.
It gave you an idea what structures you were feeling.
I found the haptic cow to be VERY helpful. It is one thing saying to someone what you can feel, it's another having someone confirming/correcting what you think you are feeling – Thank you.
It gave me a bit of confidence but in EMS you are pushed for time and they often use the scanner.
Still not too sure about ovaries though and if you were using two or more fingers it might be easier.
I think it is really useful thing for people who have had a limited past experience of rectalling. My answers aren't meant to indicate the cow is not good (>50 after, SD orientation, D identify uterus, D speed, SA ovaries, N rest), only I've done quite a lot of rectalling before/after - the practice for inexperienced people is I think a good thing. The notes were a good thing – good information.
Think people who haven't done much rectalling may be led into a false sense of security – no contractions, no faeces, no other structures in the way! Think this should be explained to students.
The haptic cow was great and really helped but in a farm situation (real cows) I found a lot more difficult.
Gave confidence to have a go.
It gave you an idea what structures you were feeling
I found after doing the haptic cow session that I was a lot more confident and couldn't wait to rectal a real cow. But when I did I couldn't find structures as easily as I thought I would and it was very different. I was disappointed by this and my confidence has decreased due to this.
Useful in developing a search routine/ technique but I did not feel that it actually felt very much like a real cow but a very good introduction to rectal exams.
Search strategy was useful. Palpation of other structures that were in way in real cow was very different to haptic cow.

Question 12. Any other comments

Not only does haptic training help my confidence with rectal palpation but also gives me a strategic approach when performing palpation in small animals as well.
Need real practice to put skills learned to use!
It helps but out in the field with a busy vet and farmer it can sometimes be a bit rushed but some vet / farmer combinations did give me time with each cow.
The haptic cow was helpful for its search strategy before actual rectal examination. To have some experience beforehand was very useful. It gave me something to start from rather than not having a clue!
Things felt fine on the haptic cow but when I was rectalling after this I still wasn't sure about some structures
Obviously it is much harder to palpate the live animal as each is individually different, how fat they are, location of the uterus etc. but the haptic cow is good for identifying landmarks.
Perhaps you could explain to EMS how you teach us?
Previously to haptic, I would wave my hand around wildly inside the cow and nod my head quietly when the vet questioned what structures I was feeling – now I know what to look for and what it feels like, even if I don't always find it first time around and I'm more confident explaining where I might be to the vet. Thanks.
I found rectalling a real cow quite difficult as they tense up so it was quite difficult to feel!
I found the haptic cow very good but disappointed with the association with the real cows.
Not used to uterus feeling different at different stages of pregnancy e.g. 4 -5 months compared with non pregnant (qualifying answer category 'neutral')
Ovaries – confusing these with other structures
In EMS I didn't have time to look
Pregnancy – some very far forward into abdomen – more reach!
I'm confident now (if given enough time)

Appendix 5.5: Second Training Session Form

The form given out to students prior to the second training session with the aim of gathering information that would be used to customise the session to the individual student's learning needs.

....

A second training session will be offered to students who wish to use the simulator again. This session will be customised for each individual student, will last about 20 minutes and will take place on Tuesday or Wednesday afternoons this term.

- Please read the entire list below **before** making your selections.
- The aim of the training session is to concentrate on areas that you consider would be most helpful.
- As many as possible of your selections will be covered within the time limit.

Please select from the list below **Matric No. (email) ....**

Please **prioritise your choices** by placing a number in the boxes:

- if locating the non-pregnant uterus is your **main priority** put **1** in the box
- if identifying normal ovarian structures is your **next priority** put **2** in the box and so on
- if you do **not** want to cover a particular procedure e.g. "identifying abnormal ovarian structures" – **leave the box blank**

☐ Repeat the first training session

☐ Locating the non-pregnant uterus in different positions

☐ Locating ovaries

☐ Identifying normal ovarian structures (e.g. corpus luteum, follicle)

☐ Identifying abnormal ovarian structures (cysts, anoestrus)

☐ Pregnancy diagnosis (early i.e. 7 – 10 weeks)

☐ Pregnancy diagnosis (more advanced stages)

Part of the training could be run in a manner where you are given a typical 'on farm' situation and asked to solve a problem e.g.
Farmer: "This cow was served 7 weeks ago but she might have been bulling last week"
Would you like this approach to be part of your training session?

☐ Yes ☐ No

Appendix 5.6: Questionnaire 3

The questionnaire was used to gather feedback after the second simulator training session (43 questionnaires were returned). The number of responses (for each category, for each question), are shown in **bold**.

Number of students participating in training = 54 / 97 (56%)

Questionnaire return rate = 43 / 54 (80%)

1. Could you respond to the following statements:

Statement	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
a. **This** training session increased your overall confidence to perform bovine rectal palpation.	**27**	**16**			
b. **This** training session increased your overall confidence to perform pregnancy diagnosis.	**18**	**25**			

2. **If** you chose to practice some **"on farm scenarios"** during the training session e.g. where you were given some history and made a diagnosis based on what you palpated, could you rate whether you found this **<u>way of learning</u>** bovine rectal palpation beneficial?

Definitely beneficial	Beneficial	Neutral	Not beneficial	Definitely not beneficial
34	**9**			
Comments: See Appendix 5.7				

3. Would you like to use the simulator again?

Yes **40** No **2** Not Sure **1**

4. What other clinical scenarios (bovine or other species) do you think would benefit from being taught with the haptic simulator?
See Appendix 5.7

Any other comments you would like to make?
See Appendix 5.7

Thank you

Appendix 5.7: Comments from Questionnaire 3

Q2. If you chose to practice some "**on farm scenarios**" during the training session e.g. where you were given some history and made a diagnosis based on what you palpated, could you rate whether you found this **way of learning** bovine rectal palpation beneficial?

Definitely Beneficial	Beneficial	Neutral	Not Beneficial	Def Not Beneficial
34	9	0	0	0

On farm scenarios created the 'stress' that a new vet will feel in finding out what is going on in the farmer's cows
The session encouraged practical application of material from the CIC course – excellent!
I feel this is the very best way to learn while using the haptic cow
Helps you think about what you would do in certain situations
This made me think, rather than just sticking my hand in and 'saying what I could feel!'
Really good – helps you think about the real in practice situation and made the whole learning experience real.
It's more real and you're faced with more real issues – like pressures from the farmer!
I found these "on farm scenarios" really useful since you have to think of the history as well as what you can feel
V. beneficial as this is what you will get when in practice, better to practice now than when in the real world!
Makes situation more real and makes you think about things as you would have to on a farm
'On farm' cases useful as you can to think about what you are doing when feeling the structures
It was nice to integrate knowledge of pharmacology with practice at palpation – a good opportunity to bring all my knowledge together. It is also nice to be talked through the structures you are feeling and be asked about the significance. I don't think I'm collating all the information I should. It was nice for someone to emphasise what I should be doing, what not to overlook or miss.
Good preparation for being asked questions by the vet/farmer while seeing practice, helped me to think about things as I would have to in practice
I thought this part of the session was excellent. It helps in understanding what you are feeling and when in the oestrus cycle you would feel it. It's a really good way of learning
It would undoubtedly help with confidence to practice identifying pregnant or not and stage when mistakes can be discussed immediately to correct the diagnosis demonstrating with no adverse consequences – we really need this!
My lack of experience in knowing what questions to ask for the history of each scenario was the problem; it was a very useful way of learning
Very helpful 'cos will be like this in real life
It's easy enough to rectal a cow and say "yes I've rectalled a cow" but it is completely different to understand your findings having carried out rectals and know how to deal with your findings e.g. endometritis, follicular cyst. Therefore I think the "farm scenarios" are completely, absolutely and totally valuable and worthwhile!
It was very useful as it helped you think in a clinical way, what you would do in the situation and what the consequences of your decisions and actions would be. It helped as it made you think more carefully about what you palpated and couldn't just guess at what to do!
Made me think more laterally, in a more problem solving way, more like in practice
This was really good as made you think the whole scenario through – use of drugs etc was really helpful

This is as would be in practice so very useful aid
I find information much more easily retained through problem based learning
More realistic – especially since farmer uses different terms from vets may use. Initially would be helpful to be told where to look, but it's good practice for us to reach our own conclusions about the diagnosis – I enjoyed the role playing
Helped to put clinical knowledge and lecture info into "palpable" context!
Much better to make you think yourself rather than just being told

Q4. What other clinical scenarios (bovine or other species) do you think would benefit from being taught with the haptic simulator?
Equine reproduction (4)
Equine PDs (8)
Equine colic (15)
Equine rectals (9)
Bovine intestinal problems (1)
Bovine uterine torsion (2)
Dystocia (1)
Vaginal examination (1)
Small animal abdominal palpation (2)
Canine prostate (1)
General comments: more pregnancies; add in ultrasound; more abnormal bovine reproductive scenarios; more scenarios

Any other comments
It's all experience – the more the better, so thank you for this second opportunity
I find these sessions extremely beneficial – thank you!
Very helpful overall – helps you be systematic and think about what you're looking for
Feels realistic enough, just slightly easier than the real thing!
Everything I thought was very helpful, it's just that some parts are harder than others, but it was definitely beneficial! Cheers!
It was very helpful and S. Baillie doesn't make you feel silly!
I found this training session even more helpful than the last. I'd never felt anoestrus ovary before so this was useful. The afternoon after I did this training I PDed 4 cows at a farm where I work part-time and felt much more confident with what I was feeling
Very useful, would be better with >1 finger
Found this session v. informative and a basis for PDing. I am looking forward to trying the aspects of this session in a real cow
Would feel much happier doing bovine rectals in practice now and feel the haptic cow is a good basis for learning during EMS
I find the haptic training extremely useful – it's just a shame students can't be offered more sessions on a regular basis as part of the farm animal course
Found it very useful overall for learning the general technique of searching for various structures
Wonderful simulation, every vet school should have one!
Having done some rectalling with vets on farms since my last haptic cow session it has been very helpful to receive this instruction where Sarah can see exactly what I am feeling. Also on farms there was often not enough time to allow me to feel ovaries
Very useful, I'd still like to see another machine for contrast between thumb and finger for size – expensive I know but useful
Very, very useful having real life on farm simulations to relate what you are feeling to what the "farmer" is telling you! Thank you!
Very impressed with the technology – a fantastic learning aid

Appendix 6.1: Training Session Instruction Sheet

Students were given an instruction sheet before training which explained the structure of the session and explained about using the keys

STRUCTURE OF THE TRAINING SESSION

A. Initial Training

1. This allows you to become familiar with the simulated environment
2. The simulation is very simple – just inside a box with a cylinder lying on the floor
3. The procedure is:
    a) First the machine moves your hand around while you listen to audio instructions
    b) Then you can explore on your own, and press the 'Help' key to identify structures
    c) Press the 'End' key when you have finished

B. Learning Bovine Rectal Palpation

1. There are simulations to represent: the pelvic area of the cow, the cervix, and two representations of the uterus: one curled up in the pelvis and the other extending into the caudal abdomen
2. There are 5 lessons
    a) Finding the pelvic landmarks
    b) Finding the cervix
    c) Finding the uterus in the pelvis
    d) Finding the uterus in the abdomen
    e) What to do when you get lost…
3. As in the initial training:
    a) First the machine moves your hand around while you listen to audio instructions
    b) You will progress through the 5 lessons while under this form of instruction
    c) Then you can explore on your own and alternate between the two uterine simulations
    d) At the end, there is an audio debriefing

KEYS

START – Press when you are ready to start
You will then hear audio instructions and the machine will move your hand around
After this you can explore on your own

FREE – Press to start exploring on your own
This key is also used (for the bovine simulation) to change the simulation:
i) uterus is in the pelvis (intra-pelvic) ***or***
ii) uterus is in the abdomen (intra-abdominal)

While exploring:
HELP – Press and the structure you are touching will be identified

END – Press when you have finished
An audio debriefing will play; then the program ends

RED BUTTON – If you want to stop the machine at any time – press the red button

Appendix 6.2: Questionnaire

The questionnaire used to gather feedback from students about simulator training with the automated version.

Eight students took part in the training session and each completed the following questionnaire:

'Part A: Using the simulator' was completed immediately after the training session

'Part B: How useful was the simulator for learning skills for examining cows?' was completed immediately after the farm visit.

'Part C: Additional questions' was completed immediately after the farm visit.

Please tick or put a cross in a box in response to each of the following statements.
Please read each statement carefully before answering…

Part A: Using the simulator					
Statement	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
1. The training environment (haptic device, key presses, etc) was easy to use	6	2			
2. The device moving my hand around was confusing			1	2	5
3. The amount of audio instruction was about right	2	6			
4. I had no difficulty working through the training using the key presses	7	1			
5. The audio would have been better with a human voice rather than a simulated voice	2	2	3		1
6. A mixture of simulated voice and real human voice would be the best option			6	2	
7. The preliminary 5 minute training was unnecessary			2	4	2
8. If I could have also seen my hand movements inside the 'cow' on the computer monitor that would have been better		1		6	1
9. Having the chance to explore on my own as part of the training was useful	6	2			
10. When exploring on my own I found the Help key valuable	2	3	2		1*
11. I used the Help key:	Never	Once	Several times		Many times
* same student for Q10 and 11	1*		6		1

Part B: How useful was the simulator for learning skills for examining cows?					
Statement	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
1. During the training, I got a good impression of the directions I need to use to search for structures in the cow	**5**	**2**	**1**		
2. During the training, I got a good impression of the shape of the anatomical structures	**4**	**3**	**1**		
3. During the training, I got a good impression of the feel of the anatomical structures	**2**	**4**	**2**		
4. As a result of the training, I had a good understanding of how to find the uterus in the cow	**4**	**4**			
5. As a result of the training, I had a good understanding of how I would recognise the uterus in the cow	**5**	**3**			
6. As a result of the training, I understand the importance of 'sweeping the pelvic brim' when I get lost examining the real cow	**5**	**3**			

Part C: Additional Questions					
Statement	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
1. I think the simulator would be used if available in a clinical skills lab (e.g. before farm animal EMS)	**8**				

2. Any ideas, thoughts about the simulator e.g. any improvements you would like to see; any extra simulations that should be included; any changes you would make…

Comments:

(see Appendix 6.3)

General comments:

(see Appendix 6.3)

(your thoughts & ideas are much appreciated!)

Thank you for your time during the simulator validation experiment and for completing the questionnaire.

Appendix 6.3: Comments from Questionnaire

Simulator Training (automated version)

Improvements:
The ceiling was a bit confusing as it was not mentioned or named (when press Help)
Could you include other simulations of the uterus particularly the harder ones i.e. smaller uterus, off to one side, etc?
The comparison of the simulator to the real cow might be better at the start not the end
Include some asymmetric simulations (uterus displaces R/L of midline)
Possibly one to show the rumen, kidney and bladder as these were landmarks that added confusion
Ultrasound pictures
I would have found it easier if I'd been told during the simulation how far to go into the real cow.

General comments:
I found the 'Help' button useful to check that I was right as I didn't want to learn the wrong thing.
Thought it was very good overall, and very useful to have done this before rectals
The simulator was fantastic, I had never done anything like this on a real cow before but after using the simulator I felt like I knew what to feel for.
An excellent resource that should be part of the course before EMS
It was very, very helpful
I found it so helpful for palpating landmarks and finding the uterus which will be really helpful in the future. I would have found it so much more difficult without.
Really useful to know what a typical uterus feels like and be confident that you know what you are feeling.
I felt that I had a good idea of how to find the uterus and recognise the pelvic landmarks etc.

Appendix 6.4: Time Data

The table shows the time (in seconds) taken by students in Group C (C1 to C8), simulator trained (automated version), and Group D (D1 to D8), traditional training only, to locate the uterus successfully (as verified by ultrasound). There were 12 successful identifications in Group C, 2 in Group D. The blank cells in the table represent the examinations where the student was unable to find the uterus within the time allowed (5 minutes) or where the identification could not be verified by ultrasound.

Cow → ↓ Student	1st	2nd	3rd	4th	Cow → ↓ Student	1st	2nd	3rd	4th
C1	140	95			**D1**				
C2		184			**D2**				
C3		220		80	**D3**			121	
C4	198		47		**D4**				
C5			270	62	**D5**				282
C6			212		**D6**				
C7			48	56	**D7**				
C8					**D8**				

Appendix 7.1: Comments about Hand Use

Comments entered by veterinary surgeons on the questionnaire used to gather information about hand use when performing rectal palpation of cows or horses (78 questionnaires returned)

Right-handed: 64 / 78
Right-handers using left hand (19 / 64)
Originally told to use left hand although vets in practice encouraged me to use the other hand too
Left is more sensitive
We were taught to palpate with left so could write with right
I was made to but I think it would have been more natural to use my dominant hand
I was just told to
Told to do so
I was told to use the left as it was more sensitive and now I'm lost if I use my right
Seemed more comfortable and the right was free to do other things
Initially I chose the L as I didn't want to break my right arm, I think my left is more sensitive now
Not sure, just told to I think
Taught to
Leaves right hand free for AI rod and I think the left is more sensitive?
There was this belief at college that the left was better but I don't know why?
I was forced to as a student (so my right hand was free to write – not that I ever have!) and now it would feel unnatural to use the right
Lecturer taught us to use the left hand
Left is more sensitive
Taught to use the left hand
Better sensitivity with left
I learned to use the left at college and now find the right difficult
A lecturer at college told us to and so did the vet I saw practice with
Started with my left hand, no problems so no reason to change

Right-handers using right hand (37 / 64)
Taught to use left but I then injured fingers on the left hand and changed to the right
Told to use right
Right hand stronger and I find right easier
Right is more 'sensitive' or 'aware' of 3D, although left more sensitive to T, I think
I could feel more with my right hand
Just because I'm right-handed
More dextrous with right hand, better a little, fiddly tasks
Just because I'm right handed, though I occasionally use the left hand to feel the right ovary
I found it easier with the right
I was told to use both but I felt I was better with the right
I just decided after trying both that I got on better with the right
I found it easier
It just seems more natural
'cos right handed
I do everything else with it
Because the scanner is more often on the left
I get on better with my right
Told cattle left, as more sensitive, horses right, as approach from left side but I ended up using the right most of the time
I got on better with my right although my Dad (a vet) told me to use the left. In his day you didn't wear gloves so you wanted your right hand to be clean to shake hands (which a vet always did with a client in his day!)
Use right hand for everything, it's easier
Just copied the vet when I was seeing practice
I can only do it with the right hand, it is difficult to do with the left

Because I'm right handed, I think my right is more likely to be right, I mean correct!
Got used to it this way, seemed right as I'm right handed
I was told to use the left but I found I was better with the right
I'm better at manipulating with the right Stronger
Wish I could use the left but I just can't!
More confident about what I'm feeling with the right hand
My left shoulder subluxates so I wouldn't want to risk it
Taught to use the right hand
I'm fitter with my right and can do things better
I was told to use my left but it got tired very easily so I changed to my right and prefer it
It's easier and the right hand doesn't get as tired
Stronger, more sensitive and more confident
I'm totally uncoordinated with my left hand, no contest!
No reason given (1)

Right-handers using both (either) hands (8 / 64)
Use left when AI (with right) or if can't get right in (too wide). Otherwise I use either
I use the left when I'm scanning as the right works the buttons and keys, but it feels more natural with the right and I think it's better
I swap hands depending on what I'm doing during the rectal exam
Either, just depends on the day!
Depends where you're PDing
If I get cramp in one I use the other
I started with my right but got injured and had to learn with my left. I now use both which is quite handy if I get tired (lots of PDs) or the cows are on the wrong side of the parlour
No reason stated (1)

Left-handed: 10 / 78
Left-handers using left hand (8 / 10)
I find it more sensitive and easier
More strength and better feel More dextrous
Told to more natural to use my dominant hand and more certain of what I'm feeling
More pregnancies on the right which is easier to feel with the left hand
I glove up both though I mostly use the L, I sometimes find the R is better at pulling up the uterus
It's easier and doesn't get tired
No reason stated (1)

Left-handers using both (1 / 10)
Convenient and I think my right is more sensitive?

Left-handers using right (1 / 10)
My right arm is stronger (as I play tennis right handed) and I think it's more sensitive though right handers at college were told to use the left hand

Ambidextrous: 4 / 78
Using right hand (3)
I just got used to using my right hand, although I could use my left if necessary
I write with my L hand but use my R for a lots else & my natural instinct was to use my R for this
Use both hands but was taught right hand
Both hands (1)
Which one is cold at the time! I'm comfortable with either

Appendix 7.2: Edinburgh Handedness Inventory

Edinburgh Handedness Inventory

Please **indicate your preferences in the use of hands** in the following activities by putting tick/s in the appropriate column for each task.

Place **one tick** in the 'Left' or 'Right' column unless:
a) The preference is so strong that **you would never try to use the other hand**, unless absolutely forced to. In these cases, **put 2 ticks** in one column ('Left' or 'Right').
b) If in any case you are **really indifferent** put and a **tick in both columns** ('Left' and 'Right')
c) If you have **no experience** of the object or task, **leave a blank**

Some of the activities listed below require the use of both hands. In these cases the part of the task, or object, for which hand preference is wanted is indicated in brackets.

Task	Left	Right
1. Writing	☐ ☐	☐ ☐
2. Drawing	☐ ☐	☐ ☐
3. Throwing (*e.g. a ball*)	☐ ☐	☐ ☐
4. Scissors	☐ ☐	☐ ☐
5. Toothbrush	☐ ☐	☐ ☐
6. Knife (*without fork*)	☐ ☐	☐ ☐
7. Spoon	☐ ☐	☐ ☐
8. Broom (*upper hand*)	☐ ☐	☐ ☐
9. Striking Match (*holding the match*)	☐ ☐	☐ ☐
10. Opening box (*hand on the lid*)	☐ ☐	☐ ☐
TOTAL (*ticks in both columns*)		

Form based on the categories and guidelines of Oldfield (1970). The dominant hand is identified from the column with the higher total score.

Appendix 7.3: Experiment Instruction Sheet

Instruction sheet given to participants at the beginning of the handedness experiments.

Skills for pregnancy diagnosis

The real task involves **assessing the relative size and fluid content (or softness) of the two pregnant horns of the uterus**. Experiments are being conducted where participants compare:

- o Two objects of different **softness**
- o Two objects of different **size**
- o You will perform **one of these** tasks **with one hand and then the other**

The real task is unsighted and therefore you will only examine the objects using touch (i.e. palpation).

The Training

Before **each** section of the experiment you will undertake a short training session. Please feel free to ask the researcher questions at this point.

Design

- Compare the size of 2 adjacent objects, one situated on the left and one on the right
  - One object is the **standard** and remains the same size throughout each experiment
  - The other object, **the comparison is larger,** this object changes as the experiment proceeds.
  - You are to **identify the larger** cylinder (**larger = wider and higher**)
- Initially there is a considerable difference between the comparison and the standard objects. As the test proceeds the comparison object will get closer to the standard i.e. the difference gets less.
- The aim of the experiment is to find the point at which human perception can no longer discriminate between the two objects. We are trying to find the point at which the objects appear to match i.e. you can't tell them apart. Therefore, there **will be** a point at which you find it difficult to discriminate - this is what we are measuring.
- Take as much time as you need to make your decision (*within reason*).
- **The experiment requires you to make a decision, to choose the object on the left or the right,** even when it is difficult to differentiate (*as the two objects are never going to be exactly the same*). This is called a 'forced-choice' test.

You are to perform each test with one hand and then the other as we are looking to see if one hand is better than the other at these tasks. There will be a rest period between the two parts of the experiment.

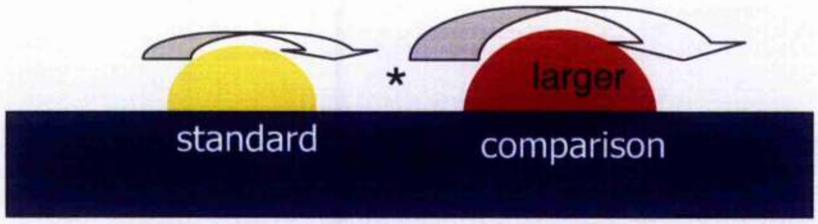
Notes:

- o The comparison and standard objects will be randomly presented on the left and right
- o The same comparison may be presented to you several times
- o At the point at which you are having difficulty accurately differentiating between the two objects:
  - Tests will be performed around this point a number of times
  - At this point, these repeat tests may take quite a while

If you wish to stop or rest at any time let the researcher know. Thank you

Further explanation for each experiment:
Participants were shown one or the other of the two following sections, depending on which experiment they were undertaking.

Size Experiment - decide which cylinder is larger

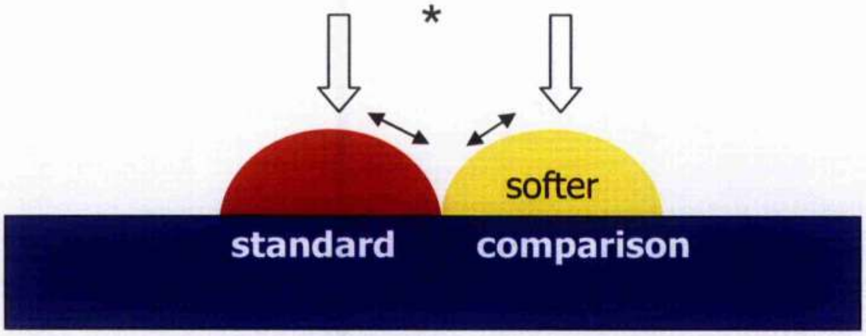


Steps:

- o Palpate and compare the two cylinders and **decide which is larger**
- o Press the key which corresponds to your choice **L or R**
- o The simulation then updates (changes) and the next test is presented
- o In between each test rest on the platform in the middle between the two cylinders *

OR

Softness Experiment - decide which cylinder is softer



Steps:

- o Palpate and compare the two cylinders and **decide which is softer (L or R)**
- o Press the key which corresponds to your choice **L or R**
- o The simulation then updates (changes) and the next test is presented
- o In between each test move your hand off the platform and rest *

Appendix 7.4: Results for the Size Experiment

Table A7.4.1. The results of the thirty-six participants showing, for each participant, the:

- Edinburgh Handedness Inventory (EHI) score
- Difference threshold (DT) for each hand (DTL and DTR), the average of the last eight reversals (expressed as the difference in the diameter of the standard and comparison cylinders in mm)
- Last eight reversals from the staircase (the size of the comparison cylinder, diameter in mm)

Participant 1		Participant 2		Participant 3		Participant 4	
EHI L = 0, R = 12		EHI L = 0, R = 20		EHI L = 1, R = 17		EHI L = 0, R = 20	
DTL(1st)	DTR(2nd)	DTR(1st)	DTL(2nd)	DTL(1st)	DTR(2nd)	DTR(1st)	DTL(2nd)
2.81	4.78	4.59	4.34	3.00	4.28	2.38	5.16
Last 8 reversals		Last 8 reversals		Last 8 reversals		Last 8 reversals	
33.25	35	34.25	34.25	33.25	34.25	33	35.75
32.75	34.75	33.75	33.75	33	33.75	32.5	35
33	35.25	34.75	34.5	33.25	34.25	32.75	35.25
32.75	35	34.5	34.25	32.75	34	32	35
33.25	35.25	35	34.5	33	35.25	32.25	35.25
32.5	34.25	34.75	34.25	32.5	34	31.75	35
32.75	34.5	35	35	33.25	34.5	32.5	35.25
32.25	34.25	34.75	34.25	33	34.25	32.25	34.75

Participant 5		Participant 6		Participant 7		Participant 8	
EHI L = 3, R = 17		EHI L = 0, R = 15		EHI L = 5, R = 15		EHI L = 0, R = 16	
DTL(1st)	DTR(2nd)	DTR(1st)	DTL(2nd)	DTL(1st)	DTR(2nd)	DTR(1st)	DTL(2nd)
2.16	1.72	4.56	9.41	4.88	1.78	1.78	3.22
Last 8 reversals		Last 8 reversals		Last 8 reversals		Last 8 reversals	
32.5	32	34.25	39.25	35.5	31.75	32.25	33.25
32	31.75	33.5	39	35	31.25	31.75	33
32.25	32	34.25	39.5	35.75	31.75	32	33.25
32	31.5	34	39.25	34.5	31.5	31.5	33
32.25	32	35	39.75	34.75	32	31.75	33.5
31.75	31.25	34.75	39.5	34.25	31.75	31.5	33.25
32.5	32	35.5	39.75	34.75	32.25	32	33.5
32	31.25	35.25	39.25	34.5	32	31.5	33

Participant 9		Participant 10		Participant 11		Participant 12	
EHI L = 0, R = 13		EHI L = 0, R = 19		EHI L = 6, R = 14		EHI L = 5, R = 15	
DTL(1st)	DTR(2nd)	DTR(1st)	DTL(2nd)	DTL(1st)	DTR(2nd)	DTR(1st)	DTL(2nd)
1.56	4.53	4.28	7.75	3.09	2.41	6.34	6.22
Last 8 reversals		Last 8 reversals		Last 8 reversals		Last 8 reversals	
32.75	35.25	35.75	38.25	33.75	33.75	37	36.25
31.5	34.75	35.25	37.25	33.5	32.25	36.5	36
31.75	35	35.5	37.75	33.75	32.5	36.75	36.5
31.25	34.5	33.5	37.5	33	32.25	36	36.25
31.5	34.75	34	37.75	33.25	32.5	36.25	36.5
31	34	33	37.5	32.5	31.75	36	36
31.5	34.25	33.75	38.25	32.75	32.25	36.25	36.25
31.25	33.75	33.5	37.75	32.25	32	36	36

Participant 13		Participant 14		Participant 15		Participant 16	
EHI L = 0, R = 20		EHI L = 5, R = 15		EHI L = 1, R = 19		EHI L = 2, R = 18	
DTL(1st)	DTR(2nd)	DTR(1st)	DTL(2nd)	DTL(1st)	DTR(2nd)	DTR(1st)	DTL(2nd)
2.31	2.63	6.44	4.59	5.00	4.72	9.38	7.94
Last 8 reversals		Last 8 reversals		Last 8 reversals		Last 8 reversals	
32.5	32.25	36.75	34.75	34.5	34.75	40.75	39.75
32.25	32	36	34.5	34.25	34.25	40	39
32.5	33	37	34.75	35	35.25	40.25	39.25
32	32.5	36.5	34.5	34.75	35	39	38.5
32.75	33	37.75	34.75	35.5	35.5	39.25	38.75
32.25	32.75	35.75	34.5	35.25	34	38.5	36
32.5	33	36	34.75	35.5	34.75	38.75	36.25
31.75	32.5	35.75	34.25	35.25	34.25	38.5	36

Participant 17		Participant 18		Participant 19		Participant 20	
EHI L = 4, R = 10		EHI L = 1, R = 19		EHI L = 5, R = 15		EHI L = 3, R = 17	
DTL(1st)	DTR(2nd)	DTR(1st)	DTL(2nd)	DTL(1st)	DTR(2nd)	DTR(1st)	DTL(2nd)
2.44	2.81	4.19	3.09	9.00	4.94	3.56	6.16
Last 8 reversals		Last 8 reversals		Last 8 reversals		Last 8 reversals	
32.75	32.75	34.25	33	38.75	34.25	33.75	36.25
32.25	32	34	32.75	38.25	34	33.5	36
32.5	33.5	34.5	33.25	39.5	34.75	33.75	36.5
32.25	32.75	33.5	33	39	34.5	33.5	36.25
32.75	33	34	33.25	39.25	35.25	34.25	36.5
32.25	32.25	33.5	33	39	35	33.25	36.25
32.5	33.5	35	33.5	39.25	36	33.5	36.75
32.25	32.75	34.75	33	39	35.75	33	34.75

Participant 21		Participant 22		Participant 23		Participant 24	
EHI L = 2, R = 14		EHI L = 0, R = 17		EHI L = 3, R = 17		EHI L = 1, R = 17	
DTL(1st)	DTR(2nd)	DTR(1st)	DTL(2nd)	DTL(1st)	DTR(2nd)	DTR(1st)	DTL(2nd)
2.47	3.06	2.06	2.81	3.59	3.84	3.28	2.84
Last 8 reversals		Last 8 reversals		Last 8 reversals		Last 8 reversals	
32.75	32.75	33.75	32.75	33.5	33.5	32.75	32.75
32.25	32.5	33	32.5	33.25	33.25	32.5	32.5
32.5	33.25	33.25	33	33.75	34.25	33.75	32.75
32.25	33	31.5	32.75	33.5	34	32.75	32.5
32.5	33.5	31.75	33	34	34.25	33.5	33.25
32.25	33.25	31	32.75	33.5	33.75	33.25	32.75
32.75	33.5	31.25	33	33.75	34.5	34	33.25
32.5	32.75	31	32.75	33.5	33.25	33.75	33

Participant 25		Participant 26		Participant 27		Participant 28	
EHI L = 4, R = 16		EHI L = 2, R = 15		EHI L = 0, R = 13		EHI L = 0, R = 20	
DTL(1st)	DTR(2nd)	DTR(1st)	DTL(2nd)	DTL(1st)	DTR(2nd)	DTR(1st)	DTL(2nd)
3.56	5.22	2.81	2.34	5.91	3.03	3.91	3.41
Last 8 reversals		Last 8 reversals		Last 8 reversals		Last 8 reversals	
32.75	36	33	32.5	36	33	34.75	33.25
32.5	35	32.5	32.25	35.75	32.75	34	33
33.5	35.25	32.75	33	36.25	33.5	34.25	33.5
33.25	35	32.5	32.75	36	33	33.75	33
34.75	35.25	32.75	33.75	36.5	33.25	34	33.75
33.5	35	32.5	31.5	35.75	32.5	33.75	33.5
34.25	35.25	33.5	31.75	36	33.25	34	33.75
34	35	33	31.25	35	33	32.75	33.5

Participant 29		Participant 30		Participant 31		Participant 32	
EHI L = 6, R = 14		EHI L = 2, R = 18		EHI L = 1, R = 15		EHI L = 4, R = 16	
DTL(1st)	DTR(2nd)	DTR(1st)	DTL(2nd)	DTL(1st)	DTR(2nd)	DTR(1st)	DTL(2nd)
4.56	5.56	6.97	6.88	8.69	4.47	2.97	2.88
Last 8 reversals		Last 8 reversals		Last 8 reversals		Last 8 reversals	
35	36.25	36.75	37.5	38.75	34.75	33.25	32.75
34.75	35.75	35.75	37.25	38.5	34.5	33	32.5
35	36.25	36.5	37.5	38.75	35.25	33.5	33.25
34.75	34.75	36.25	36.75	38.5	34.5	33.25	32.5
35	35.25	37.75	37	38.75	34.75	33.5	32.75
33.75	35	37.5	36.75	38.5	33.75	32.5	32.5
34.25	35.75	37.75	37	39	34.25	32.75	33.5
34	35.5	37.5	35.25	38.75	34	32	33.25

Participant 33		Participant 34		Participant 35		Participant 36	
EHI L = 0, R = 19		EHI L = 7, R = 12		EHI L = 3, R = 14		EHI L = 1, R = 14	
DTL(1st)	DTR(2nd)	DTR(1st)	DTL(2nd)	DTL(1st)	DTR(2nd)	DTR(1st)	DTL(2nd)
6.23	3.25	2.50	2.50	5.25	3.50	2.59	3.34
Last 8 reversals		Last 8 reversals		Last 8 reversals		Last 8 reversals	
37	33.5	32.5	32.75	35.25	33.75	32.75	33
36	33.25	32.25	32.25	35	33	32.5	32
36.25	33.5	32.5	32.5	35.25	33.5	32.75	34.5
36	33.25	32	31.5	35	33.25	32.5	32.75
36.5	33.75	33	32.5	35.75	34	32.75	33.75
36	33	32.5	32.25	35.25	33.5	32.5	33.25
36.5	33.25	32.75	33.5	35.5	33.75	33	34
35.5	32.5	32.5	32.75	35	33.25	32	33.5

Participant	DT Left	DT Right	DT 1st	DT 2nd	L - R
1	4.78	2.81	4.78	2.81	1.97
2	4.34	4.59	4.59	4.34	-0.25
3	3	4.28	3	4.28	-1.28
4	5.16	2.38	2.38	5.16	2.78
5	2.16	1.72	2.16	1.72	0.44
6	9.41	4.56	4.56	9.41	4.85
7	4.88	1.78	4.88	1.78	3.1
8	3.22	1.78	1.78	3.22	1.44
9	1.56	4.53	1.56	4.53	-2.97
10	7.75	4.28	4.28	7.75	3.47
11	3.09	2.41	3.09	2.41	0.68
12	6.22	6.34	6.34	6.22	-0.12
13	2.31	2.63	2.31	2.63	-0.32
14	4.59	6.44	6.44	4.59	-1.85
15	5	4.72	5	4.72	0.28
16	7.94	9.38	9.38	7.94	-1.44
17	2.44	2.81	2.44	2.81	-0.37
18	3.09	4.19	4.19	3.09	-1.1
19	9	4.94	9	4.94	4.06
20	6.16	3.56	3.56	6.16	2.6
21	2.47	3.06	2.47	3.06	-0.59
22	2.81	2.06	2.06	2.81	0.75
23	3.59	3.84	3.59	3.84	-0.25
24	2.84	3.28	3.28	2.84	-0.44
25	3.56	5.22	3.56	5.22	-1.66
26	2.34	2.81	2.81	2.34	-0.47
27	5.91	3.03	5.91	3.03	2.88
28	3.41	3.91	3.91	3.41	-0.5
29	4.56	5.56	4.56	5.56	-1
30	6.88	6.97	6.97	6.88	-0.09
31	8.69	4.47	8.69	4.47	4.22
32	2.88	2.97	2.97	2.88	-0.09
33	6.23	3.25	6.23	3.25	2.98
34	2.5	2.5	2.5	2.5	0
35	5.25	3.5	5.25	3.5	1.75
36	3.34	2.59	2.59	3.34	0.75

Table A7.4.2. The difference threshold (DT) values for the thirty-six participants in the size experiment. For each participant the threshold values (the difference in millimetres between the standard and comparison objects) are recorded for the: left hand, right hand, hand going first, and hand going second. The final column shows the difference between the threshold values for the left and right hands (value for left minus value for right hand). Eighteen participants were better with the left hand and seventeen were better with the right hand, one had equal performance with both hands.

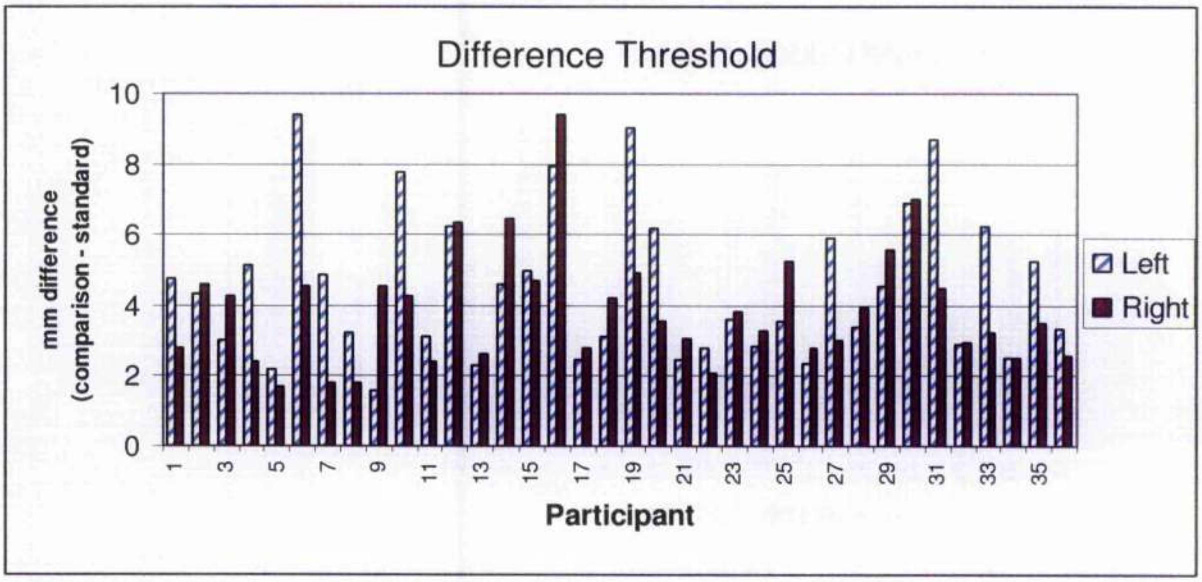


Figure A7.4.1. A graph showing the values for the difference threshold or least detectable difference in millimetres between the standard object (a half cylinder, 30mm diameter) and the comparison object (40mm diameter initially). Thirty-six participants performed the task with the left (hashed blue bars) and right hands (solid crimson bars).

Appendix 7.5: Results for the Softness Experiment

Table A7.5.1. The results of the thirty-six participants showing, for each participant, the:

- Edinburgh Handedness Inventory (EHI) score
- The difference threshold (DT) for each hand (DTL and DTR), the average of the last eight reversals (expressed as the difference in N/m between the KSpring of the standard cylinder (0.3N/m) and the comparison cylinder)
- Last eight reversals from the staircase (the KSpring of the comparison cylinder)

Participant 1		Participant 2		Participant 3		Participant 4	
EHI L = 0, R = 16		EHI L = 2, R = 14		EHI L = 0, R = 20		EHI L = 1, R = 17	
DTL(1st)	DTR(2nd)	DTR(1st)	DTL(2nd)	DTL(1st)	DTR(2nd)	DTR(1st)	DTL(2nd)
0.0094	0.0262	0.0525	0.0559	0.0278	0.0353	0.0750	0.0706
Last 8 reversals		Last 8 reversals		Last 8 reversals		Last 8 reversals	
0.2975	0.2675	0.2475	0.2425	0.2675	0.2625	0.2200	0.2275
0.2900	0.2700	0.2500	0.2450	0.2700	0.2650	0.2225	0.2250
0.2925	0.2675	0.2425	0.2425	0.2675	0.2625	0.2200	0.2325
0.2900	0.2725	0.2475	0.2475	0.2750	0.2650	0.2275	0.2275
0.2925	0.2700	0.2450	0.2425	0.2725	0.2625	0.2250	0.2325
0.2875	0.2825	0.2500	0.2450	0.2775	0.2675	0.2300	0.2300
0.2900	0.2775	0.2475	0.2425	0.2725	0.2650	0.2250	0.2325
0.2850	0.2825	0.2500	0.2450	0.2750	0.2675	0.2300	0.2275

Participant 5		Participant 6		Participant 7		Participant 8	
EHI L = 2, R = 16		EHI L = 1, R = 13		EHI L = 2, R = 15		EHI L = 1, R = 15	
DTL(1st)	DTR(2nd)	DTR(1st)	DTL(2nd)	DTL(1st)	DTR(2nd)	DTR(1st)	DTL(2nd)
0.0694	0.0578	0.0247	0.0334	0.0578	0.0559	0.1034	0.0941
Last 8 reversals		Last 8 reversals		Last 8 reversals		Last 8 reversals	
0.2300	0.2375	0.2725	0.2675	0.2475	0.2425	0.2000	0.2050
0.2325	0.2400	0.2700	0.2650	0.2500	0.2400	0.2025	0.2075
0.2300	0.2375	0.2775	0.2700	0.2425	0.2450	0.2000	0.2025
0.2375	0.2450	0.2750	0.2650	0.2450	0.2400	0.2025	0.2075
0.2300	0.2425	0.2775	0.2700	0.2375	0.2475	0.1900	0.1975
0.2325	0.2475	0.2725	0.2650	0.2400	0.2450	0.1925	0.2100
0.2250	0.2425	0.2800	0.2675	0.2325	0.2475	0.1900	0.2075
0.2275	0.2450	0.2775	0.2625	0.2425	0.2450	0.1950	0.2100

Participant 9		Participant 10		Participant 11		Participant 12	
EHI L = 2, R = 14		EHI L = 2, R = 14		EHI L = 1, R = 19		EHI L = 3, R = 17	
DTL(1st)	DTR(2nd)	DTR(1st)	DTL(2nd)	DTL(1st)	DTR(2nd)	DTR(1st)	DTL(2nd)
0.0406	0.0306	0.0203	0.0294	0.0747	0.0397	0.0528	0.0275
Last 8 reversals		Last 8 reversals		Last 8 reversals		Last 8 reversals	
0.2575	0.2675	0.2750	0.2650	0.2275	0.2575	0.2400	0.2775
0.2550	0.2700	0.2775	0.2675	0.2250	0.2600	0.2425	0.2725
0.2650	0.2675	0.2750	0.2650	0.2275	0.2575	0.2400	0.2750
0.2625	0.2700	0.2850	0.2775	0.2225	0.2625	0.2500	0.2725
0.2675	0.2675	0.2800	0.2725	0.2250	0.2600	0.2475	0.2775
0.2550	0.2750	0.2875	0.2750	0.2225	0.2625	0.2550	0.2675
0.2575	0.2675	0.2775	0.2700	0.2275	0.2600	0.2500	0.2775
0.2550	0.2700	0.2800	0.2725	0.2250	0.2625	0.2525	0.2600

Participant 13		Participant 14		Participant 15		Participant 16	
EHI L = 3, R = 17		EHI L = 5, R = 15		EHI L = 5, R = 14		EHI L = 0, R = 15	
DTL(1st)	DTR(2nd)	DTR(1st)	DTL(2nd)	DTL(1st)	DTR(2nd)	DTR(1st)	DTL(2nd)
0.0556	0.0684	0.0619	0.0412	0.0450	0.0266	0.0325	0.0331
Last 8 reversals		Last 8 reversals		Last 8 reversals		Last 8 reversals	
0.2425	0.2500	0.2375	0.2600	0.2500	0.2650	0.2675	0.2600
0.2400	0.2225	0.2400	0.2625	0.2525	0.2675	0.2650	0.2625
0.2425	0.2275	0.2425	0.2600	0.2500	0.2650	0.2675	0.2600
0.2400	0.2250	0.2375	0.2625	0.2575	0.2775	0.2650	0.2700
0.2475	0.2325	0.2425	0.2575	0.2550	0.2725	0.2675	0.2675
0.2450	0.2300	0.2325	0.2600	0.2575	0.2825	0.2650	0.2725
0.2500	0.2350	0.2375	0.2525	0.2550	0.2775	0.2725	0.2700
0.2475	0.2300	0.2350	0.2550	0.2625	0.2800	0.2700	0.2725

Participant 17		Participant 18		Participant 19		Participant 20	
EHI L = 3, R = 16		EHI L = 4, R = 13		EHI L = 1, R = 15		EHI L = 0, R = 18	
DTL(1st)	DTR(2nd)	DTR(1st)	DTL(2nd)	DTL(1st)	DTR(2nd)	DTR(1st)	DTL(2nd)
0.0328	0.0269	0.0244	0.0594	0.0312	0.0606	0.0406	0.0437
Last 8 reversals		Last 8 reversals		Last 8 reversals		Last 8 reversals	
0.2700	0.2625	0.2825	0.2450	0.2675	0.2400	0.2625	0.2550
0.2725	0.2600	0.2700	0.2475	0.2700	0.2350	0.2600	0.2575
0.2650	0.2775	0.2750	0.2375	0.2675	0.2375	0.2675	0.2550
0.2675	0.2750	0.2725	0.2400	0.2700	0.2350	0.2525	0.2575
0.2650	0.2775	0.2775	0.2375	0.2675	0.2425	0.2600	0.2550
0.2675	0.2750	0.2750	0.2400	0.2700	0.2400	0.2575	0.2575
0.2625	0.2800	0.2775	0.2375	0.2650	0.2450	0.2600	0.2525
0.2675	0.2775	0.2750	0.2400	0.2725	0.2400	0.2550	0.2600

Participant 21		Participant 22		Participant 23		Participant 24	
EHI L = 4, R = 13		EHI L = 5, R = 15		EHI L = 2, R = 18		EHI L = 6, R = 14	
DTL(1st)	DTR(2nd)	DTR(1st)	DTL(2nd)	DTR(1st)	DTL(2nd)	DTL(1st)	DTR(2nd)
0.1000	0.0937	0.0809	0.0450	0.1184	0.1356	0.0950	0.0556
Last 8 reversals		Last 8 reversals		Last 8 reversals		Last 8 reversals	
0.2000	0.2100	0.2200	0.2500	0.1900	0.1675	0.2050	0.2425
0.2025	0.2125	0.2225	0.2525	0.1925	0.1600	0.2075	0.2400
0.1975	0.2050	0.2150	0.2500	0.1825	0.1625	0.2025	0.2425
0.2050	0.2075	0.2175	0.2550	0.1850	0.1600	0.2050	0.2400
0.1975	0.2050	0.2150	0.2525	0.1750	0.1675	0.2025	0.2525
0.2000	0.2075	0.2200	0.2600	0.1800	0.1650	0.2050	0.2450
0.1975	0.2000	0.2175	0.2575	0.1700	0.1675	0.2025	0.2475
0.2000	0.2025	0.2250	0.2625	0.1775	0.1650	0.2100	0.2450

Participant 25		Participant 26		Participant 27		Participant 28	
EHI L = 3, R = 15		EHI L = 0, R = 20		EHI L = 2, R = 17		EHI L = 0, R = 17	
DTR(1st)	DTL(2nd)	DTL(1st)	DTR(2nd)	DTL(1st)	DTR(2nd)	DTR(1st)	DTL(2nd)
0.0312	0.0400	0.0434	0.0831	0.0381	0.0300	0.0887	0.0631
Last 8 reversals		Last 8 reversals		Last 8 reversals		Last 8 reversals	
0.2700	0.2600	0.2600	0.2150	0.2725	0.2725	0.2175	0.2400
0.2725	0.2625	0.2550	0.2175	0.2650	0.2675	0.2050	0.2425
0.2675	0.2600	0.2600	0.2075	0.2725	0.2700	0.2125	0.2375
0.2725	0.2625	0.2575	0.2175	0.2550	0.2675	0.2100	0.2400
0.2675	0.2575	0.2650	0.2150	0.2575	0.2725	0.2125	0.2325
0.2700	0.2600	0.2500	0.2225	0.2550	0.2700	0.2075	0.2350
0.2625	0.2575	0.2550	0.2175	0.2600	0.2725	0.2150	0.2325
0.2675	0.2600	0.2500	0.2225	0.2575	0.2675	0.2100	0.2350

Participant 29		Participant 30		Participant 31		Participant 32	
EHI L = 0, R = 18		EHI L = 3, R = 17		EHI L = 3, R = 17		EHI L = 2, R = 18	
DTL(1st)	DTR(2nd)	DTR(1st)	DTL(2nd)	DTL(1st)	DTR(2nd)	DTR(1st)	DTL(2nd)
0.0441	0.0581	0.0678	0.1209	0.0919	0.0541	0.0281	0.0497
Last 8 reversals		Last 8 reversals		Last 8 reversals		Last 8 reversals	
0.2525	0.2375	0.2425	0.1775	0.2075	0.2400	0.2725	0.2525
0.2550	0.2400	0.2325	0.1800	0.2100	0.2425	0.2700	0.2475
0.2525	0.2375	0.2350	0.1775	0.2075	0.2400	0.2775	0.2525
0.2575	0.2450	0.2275	0.1800	0.2100	0.2500	0.2750	0.2500
0.2500	0.2400	0.2325	0.1775	0.2025	0.2475	0.2775	0.2525
0.2600	0.2475	0.2300	0.1800	0.2100	0.2500	0.2700	0.2500
0.2575	0.2425	0.2325	0.1775	0.2075	0.2475	0.2725	0.2525
0.2625	0.2450	0.2250	0.1825	0.2100	0.2500	0.2600	0.2450

Participant 33		Participant 34		Participant 35		Participant 36	
EHI L = 3, R = 17		EHI L = 2, R = 15		EHI L = 2, R = 13		EHI L = 3, R = 14	
DTL(1st)	DTR(2nd)	DTL(1st)	DTR(2nd)	DTR(1st)	DTL(2nd)	DTR(1st)	DTL(2nd)
0.0450	0.0622	0.0597	0.0300	0.0325	0.0269	0.0612	0.0737
Last 8 reversals		Last 8 reversals		Last 8 reversals		Last 8 reversals	
0.2650	0.2425	0.2425	0.2675	0.2675	0.2675	0.2450	0.2225
0.2675	0.2450	0.2400	0.2625	0.2650	0.2700	0.2475	0.2250
0.2475	0.2350	0.2425	0.2750	0.2675	0.2675	0.2375	0.2225
0.2525	0.2400	0.2350	0.2700	0.2650	0.2750	0.2400	0.2300
0.2450	0.2350	0.2400	0.2725	0.2700	0.2725	0.2350	0.2250
0.2550	0.2375	0.2375	0.2700	0.2675	0.2825	0.2375	0.2275
0.2525	0.2325	0.2450	0.2725	0.2700	0.2725	0.2325	0.2225
0.2550	0.2350	0.2400	0.2700	0.2675	0.2775	0.2350	0.2350

Participant	DT Left	DT Right	DT 1st	DT 2nd	L - R
1	0.0094	0.0262	0.0094	0.0262	-0.0168
2	0.0559	0.0525	0.0525	0.0559	0.0034
3	0.0278	0.0353	0.0278	0.0353	-0.0075
4	0.0706	0.0750	0.0750	0.0706	-0.0044
5	0.0694	0.0578	0.0694	0.0578	0.0116
6	0.0334	0.0247	0.0247	0.0334	0.0087
7	0.0578	0.0559	0.0578	0.0559	0.0019
8	0.0941	0.1034	0.1034	0.0941	-0.0093
9	0.0406	0.0306	0.0406	0.0306	0.0100
10	0.0294	0.0203	0.0203	0.0294	0.0091
11	0.0747	0.0397	0.0747	0.0397	0.0350
12	0.0275	0.0528	0.0528	0.0275	-0.0253
13	0.0556	0.0684	0.0556	0.0684	-0.0128
14	0.0412	0.0619	0.0619	0.0412	-0.0207
15	0.0450	0.0266	0.0450	0.0266	0.0184
16	0.0331	0.0325	0.0325	0.0331	0.0006
17	0.0328	0.0269	0.0328	0.0269	0.0059
18	0.0594	0.0244	0.0244	0.0594	0.0350
19	0.0312	0.0606	0.0312	0.0606	-0.0294
20	0.0437	0.0406	0.0406	0.0437	0.0031
21	0.1000	0.0937	0.1000	0.0937	0.0063
22	0.0450	0.0809	0.0809	0.0450	-0.0359
23	0.1356	0.1184	0.1184	0.1356	0.0172
24	0.0950	0.0556	0.0950	0.0556	0.0394
25	0.0400	0.0312	0.0312	0.0400	0.0088
26	0.0434	0.0831	0.0434	0.0831	-0.0397
27	0.0381	0.0300	0.0381	0.0300	0.0081
28	0.0631	0.0887	0.0887	0.0631	-0.0256
29	0.0441	0.0581	0.0441	0.0581	-0.0140
30	0.1209	0.0678	0.0678	0.1209	0.0531
31	0.0919	0.0541	0.0919	0.0541	0.0378
32	0.0497	0.0281	0.0281	0.0497	0.0216
33	0.0450	0.0622	0.0450	0.0622	-0.0172
34	0.0597	0.0300	0.0597	0.0300	0.0297
35	0.0269	0.0325	0.0325	0.0269	-0.0056
36	0.0737	0.0612	0.0612	0.0737	0.0125

Table A7.5.2. The difference threshold (DT) values for the thirty-six participants in the softness experiment. For each participant the threshold values (expressed as the difference between the KSpring value of the comparison and the standard objects) are recorded for the: left hand, right hand, hand going first, and hand going second. The final column shows the difference between the values for the left and right hands (value for left minus value for right hand). Fourteen participants were better with the left hand and twenty-two were better with the right hand.

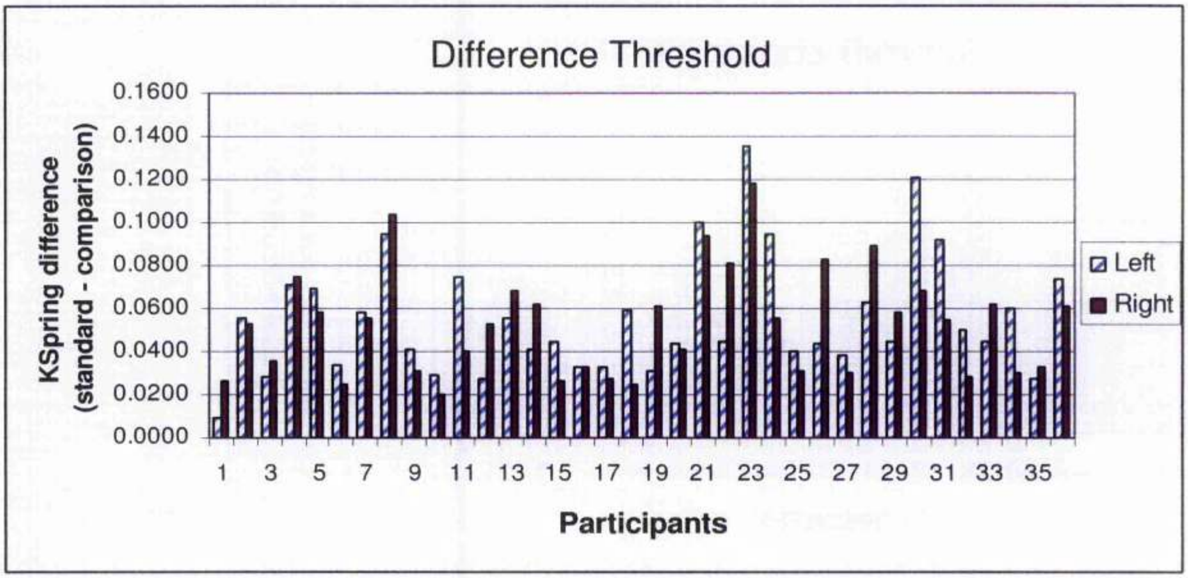


Figure A7.5.1. A graph showing the values for the difference threshold or least detectable difference in KSpring values between the standard object (KSpring 0.3000N/m) and the comparison object (KSpring initially 0.1800N/m). Thirty-six participants performed the task with the left (hashed blue bars) and right hands (solid crimson bars).

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