A STUDY ON CHOICE AND REACTION TIME

A Thesis submitted for the Degree of Doctor of Philosophy in the College of

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By

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DEDICATION

TO MY PARENTS

DECLARATION

I herby declare that this thesis embodies the results of my own work, that the work, of which it is a record, has been done by myself, that it is not been submitted in any previous application for a higher degree. All sources of information have been acknowledged by means of references.

Paola Rizzi

SUMMARY

Every day we have to make choices, to solve small and big life problems, and we behave accordingly. The experience becomes crucial and determinant in sport situation. The research intends to propose an analysis, at a first level, of the main factors involved in choice and action. The direction and the conditions proposed by the study could be a framework for future research and for further developments in sport.

Selection among options, choice, focal action and the time of reaction are the centre of the investigation. The main parameters are choice and reaction time. Choice describes the process of weighting and picking the more suitable alternative. Reaction time is the time of preparation and execution, the time during selection, choice, and the performing of the focal action, which ends at the recording of the data.

Reaction time period and choice events were analysed separately. Choice, in particular, was related to a positive prediction, that is to a correct answer. Among the variables involved in the experimental situation, choice, reward, delay and cues were chosen. The main aim was to find the change in reaction time, when a correct response could be predicted.

A special Reaction Time Device was built up, tailored on the specific needs of the experiments. The period between a visual “go” signal and a target touching by an arm, the focal action, was the time of reaction. The feedback given by the Device informed the subject on the correct or not correct choice. A basic protocol was defined, and the experimental plan, built up by 4 steps, related to specific aims, was fixed.

The first step had an introductory role. It tested simple and choice conditions. Random sequences and random delays were presented. Choice reaction time was examined when dominant, non-dominant and either arm were performing. The final evaluations allow detecting correct and incorrect answer factors, and the effect of different delays, as first reference of these components. The data register no difference in reaction time between dominant and non dominant arm performed during choice.

The second step involved reward factor. The aim was to compare reaction time without and with a possibility of reward. The results showed that at those conditions, no significant reaction time difference was registered.

The third step examined the delay factor and tested the reaction time when a variable or a fixed foreperiod was presented, before the "go" signal. It was concluded that there is no significant difference in time of reaction between a constant and a changeable delay.

The contractions of the subject's focal and postural adjustment representative muscles were simultaneously recorded during the tests through EMG, to check the preparation phase and, eventually, a possible change in muscle contractions during the selection of the alternatives. The results confirmed that choice is a high level process and that, at least at those conditions, muscles are involved only at the last, final stage, after selection.

The former 3-step experiments had the role of premise to test the weight of some relevant variables. The centre of decision-making process is guessing, is anticipating the event. It implies the presence of clues, which can be identified, recognised and can lead the person to predict the next answer. This was the main motive of the fourth step. Three of the four sequences had a pattern, made up by 3 numbers, presented 4 times in the same sequence. The reaction time results included very short and very long values, far from the normal

distribution. They were transformed in Log (- 350), to get coefficients suitable to be processed through parametric tests.

The numbers suggested that after the first experiences of the pattern, some subjects, having the feedback at each trial, identified and recognised the regularity and tended to be more correct at the last presentation. Some of them took a longer time to come to a choice, some were quicker. Two among 3 patterns were detected easier. In one of the 3 special sequences, the percentage of pattern correct answers was 48%, beyond the probability limit. It means that nearly half of the answers were positive and nearly half of the people guessed the pattern.

There was a clear difference in percentage of correct answers between the random sequence, which remained within the probability percentage, 33%, and 2 of the 3 sequences. In addition the percentage of patterned correct answer was higher than the total percentage of positive responses, inside the same sequence. Nevertheless in statistical terms the p values were not significant.

The 2 factors tested during the investigation, reaction time and choice, showed that, at the specific conditions of the experiments, there is no clear reciprocal correspondence. Unlike the studies in the field, correct answers were not directly related to lower reaction times, as expected, in patterned trials. Sometimes the subjects took more time to make their choice.

Short and long reactions, within the same subject and among quick and slow volunteers, balanced the data. The results were not significant, nevertheless the differences were evident and in the right direction.

The conclusion was that in a choice situation, when guessing was encouraged by cues to get correct response, the number of patterned correct trials tended to increase, in particular at the last repetition of the pattern.

The analysis on reaction time could not confirm the expected relationship between pattern correct trials, a sign of guessed cue, and a decreasing time of reaction.

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CHAPTER 1

GENERAL INTRODUCTION AND LITERATURE REVIEW

1.1 INTRODUCTION

Much of human behaviour is the result of foreseeing what is likely to happen, adjusting ourselves to our environment, solving problems and choosing among different alternatives in order to pursue our own goals. These actions rely on feedback mechanisms and predictive strategies (Lam et al., 2006). An effective behaviour is a quick, adequate response. The first attribute, "quick", is directly linked to delays in neural and muscle system; the second, "adequate", refers to the quality of satisfying the requirements coming from the situation and goals. It involves the right answer, which confirms the prediction, emerging from the hypothesis about the future event. The relevant point, under discussion in this thesis is to distinguish the "pure" mechanical response and the neural activity, which, in the experimental context, is not reflexive; it is the time of option selection and choice.

Primary needs guide animal behaviour in the environment; most of the time they have to be fast to reach their targets. Humans have to balance speed and economy. Sometimes the situation asks for quick reactions, sometimes choosing is required before the action, sometimes movement has to be controlled and slow.

I mention here a related specific situation, the sport experience, which is the final destination of this first level investigation. During a sporting performance, i.e. a tennis

match, the athlete has to be effective and quick. It means that he/she has to perform according to the correct technique, to the best strategy in the given circumstances, has to move fast, but his/her energy has to last till the end of the match, and has to be successful.

This pushes to anticipate other people's behaviour, in particular the one coming, for instance, from the opponent player and to look for the most effective (correct) answer in situation of choice. The aim is to be ready at the right time and eventually, to make him/her stop or change the strategy.

If we examine every choice circumstance, we realise that the critical point is not the action, but the time of preparation, the selection of options and the choice. The behaviour is their direct effect. The action, the time "after" the choice, tells us if we predicted correctly or not. In the first case we have achieved our aim.

The topic affects people in many situations. The research described in this thesis lies entirely inside this framework and intends to address the basic points of the field, reaction time, the stage "before": option selection, choice and focal action prior to target reaching, and its connection with muscle contractions.

Different perspectives and different disciplines have investigated decision-making. Here it is proposed to present a synthesis of the studies, the identification of the scientific area, its main features relevant for the study. This review will introduce the aims and directions of the investigation.

The research will be centred on the time taken to choose and to respond to a visual trigger. The emphasis is not on pure reaction to a perceived input: the main investigation will be the right choice made among alternatives.

The second research motive involves the measurement of the time taken from a given starting point, a visual stimulus, to the achievement of the goal, a touching target. Two sections make up the research plan:

- an introduction, to measure reaction times at basic experimental conditions: dominant and non dominant arm, no-choice and choice situations. In addition it will be examined the connection with specific variables: delay, the time between alarm and go signal, and reward
- a central part, which takes account of the conclusions from the previous steps and analyses the variable cue, to encourage guessing and the right response. Repeated patterns inside a sequence are presented.

This chapter presents first an introduction to the decision making concept, the basic field, and then single topics are analysed: central processing, accumulation of sensory evidence, brain nuclei integration, which lead to preparation, planning, focal action, feedback, feed forward and reaction time.

Specific relevant issues are examined:

- right-left arm preference
- delay from different positions, sitting and standing
- reward
- patterned sequence

1.2 DECISION MAKING

Decision making is “a dynamic process of choosing, evaluating an outcome and adjusting future behaviour accordingly” (Cohen and Ranganath, 2005). Wang (2008) proposes that it is a process of picking out an opinion or an action among a set of two or more alternatives. This author specifies that the process implies a behaviour which is not just an immediate response, the result of a reflex; it involves selection, choice and actions goal-directed. Expected consequent outcomes are assessed and taken into account. In its essence a decision is to make the right choice, according to the aims, under the uncertainty about the long-term consequences of the action.

We perceive many stimuli coming from the outside. Their processing entails sensory system codification of the input, brain nuclei activation, integration of neural representations and efferent pathways involvement to come to action planning and execution. The action processing may be flexible and adaptive. Future outcome and reward are taken into account (Opris and Bruce, 2005).

Yarkoni et al. (2005) identified specific qualities of the process; in particular the authors discussed the continuous dynamic change of the situations. A person has to update and readjust the data from the environment in order to make valid predictions, choose properly and achieve the aims.

1.3 CENTRAL PROCESSING

We decide what is relevant in the external world, at any moment, we point voluntary selective attention at specific relevant objects, their relationships, and then we make a series of choices in order to achieve our goal. Activity of the nervous system prepares for the action. Accumulation of sensory evidence and integration of sensory signals are steps dealing with afferent inputs and brain activity. The converging final point is the choice, linked to planning and the stages of preparation.

The topic is organised in separate issues: accumulation of sensory evidence, brain nuclei integration and inhibition.

1.3.1 ACCUMULATION OF SENSORY EVIDENCE

A choice, at its basis, implies the ability to detect and filter out, through neural circuitries, irrelevant information within a stimulus set (Bunge et al., 2002). Rules are part of the context. The instructions in particular require acquisition, long-term storage, retrieval, maintenance, implementation and imply flexibility to suit different situations. The information is compared with subject's expected reward and prior experience. These factors lead to the selection of a response.

Sensory perception is the first stage of the neural process. Visual stimuli are used in this project. From the retina the visual input is processed by the Lateral Geniculate Nuclei, Primary Visual Area (VI), in the Cortex, by the Secondary, Tertiary and Higher Level Visual Areas in the Parietal and Temporal Lobes. There are two main streams of activity,

the ventral and dorsal stream. The information path through the ventral stream involves the Inferior Temporal Cortex, for visual motion and location of static stimuli (Himmelbach et al., 2007). There is a connection with Amygdala, cells of midbrain Ventral Tegmental Area, Pars Compacta of Substantia Nigra, Nucleus Accumbens, Anterior Cingulated, Prefrontal Cortex and Mediodorsal Nucleus of Thalamus for stimulus-reward associations.

The information from the dorsal stream activates area V5, the middle temporal, into the Posterior Parietal Cortex, for stimuli moving in one direction and spatial location of visual target. The signals merge to Prefrontal Cortex for spatial and temporal coordination of the action (Krauzlis et al., 2004).

1.3.2 BRAIN NUCLEI INTEGRATION

The external signal, coded in visual input, is processed. The stage includes: representation of the stimulus template, remembering the cue, that is working memory activity, the retrieval of the associations among them, knowing or remembering the rules. Accumulation of sensory evidence, storage of information in working memory and interpreting relevant perceptual information are the result of activity coming from Lateral Intra-Parietal neurons, in the Parietal Cortex, and Dorsolateral Prefrontal Cortex.

Activity of the Prefrontal Cortex, Anterior Cingulate Cortex, Posterior Parietal Cortex, Posterior Cingulate Cortex and Basal Ganglia was found during the phase of integration of actions, outcomes of these actions and reward value about future events (Sharot et al., 2004).

Knowledge from prior experience with an expected Reward is processed in the nuclei connected to the Basal Ganglia-Thalamo-Cortical Loops. Reward-related information is processed by the Striatum, the input unit of the Basal Ganglia, and by the Caudate Nucleus, part of the Dorsal Striatum (Delgado et al., 2005).

Dopaminergic neurons in the midbrain are involved in integration of cognitive and motivational information. They increase firing to unexpected Rewards and to stimuli which predict a Reward. The signals guide to the acquisition of goals. Goals are desired end state. The neurons allocated in the dorsal portion of the Striatum, a component of multiple Cortico-Striatal Loop, become more active when an action is correlated to an outcome. Here there are links to prediction, feedback and learning (Dehaene and Changeux, 2000).

1.3.3 INHIBITION

Facing strong alternatives, the organism has the need to cope with the interfererence and to activate timely the selected response (Miller and Cohen, 2001). This is done through inhibition, which is an active process suppressing an excitatory action (Burle et al., 2004), or an inappropriate response linked to stimulus-response mapping, or it is connected to task setting, when the context changes, when memories interfere during retrieval (Aron et al., 2004).

The process occurs at the stage of response programming or execution, it is the result of reciprocal interaction at the level of Motor Cortex (Praamstra and Seiss, 2005). The spinal circuitry and corticospinal projections on motoneurones are involved to ensure co-

ordination between agonist and antagonist muscles, active on the same joint (Porter and Lemon, 1993). It is cause of slower response times as consequence of an increase of Working Memory load (Bunge et al., 2001 and 2004).

The activation of one response corresponds to the inhibition of the competing response. One response is selected after alternating cycles of activation and inhibition (Sclaghen and Eimer, 2002, Eimer, 1999).

When the signals are recognized, the process becomes voluntary (Logan and Cowan, 1984). It is controlled at central level, in the Prefrontal Cortex, by executive control mechanisms (Band and van Boxtel, 1999).

1.4 SELECTION AND CHOICE

Selection of behavioural response is the step before the choice, when options are kept open (Schall, 1999 and 2001). The choice is a "picking out" of one from a group of similar things, the alternatives. The correct response is activated in compatible conditions.

The evaluation process gradually accumulates evidence by a response priming process, (Coles et al., 1985). The "relative salience" of the competitors is linked to the "weight" attributed, which gives "appropriate dominance" to one of them (Redgrave et al., 1999a). The greater is the conflict, the longer is the latency of the correct response.

Activation of one among the competing channels, gives as *a* result an overt response when the first of them reaches a threshold level (Burle et al., 2002 and Gratton et al., 1988).

Kornblum and Lee (1995) studied the field and proposed a “compatibility effect", the facilitative process, the fast reaction time, as result of the matching between a stimulus and an identified, already mapped, response set. The option can be compatible, with the same response as the target, incompatible with a different response or neutral, when linked to no response. An incompatible situation is preceded by an activation of the incorrect response. Slow reaction times depend on interfering process (Hasbroucq et al., 1997 and 2001). The magnitude of the priming effect is determined by the perceptual strength of stimuli (Schlaghecken and Eimer, 2002). Stimulus-response mapping *sets* are no more adequate, when the context changes. The most effective option has to be selected (Aron et al., 2004).

Stopping irrelevant options improves the signal and conveys the input to activation of the action that is needed. Selection includes “assessing the cues, evaluating the spatial representation of probabilities, making a decision between competing options, weighting the possible outcomes” (Ernst et al., 2004). Inhibitory control and error processing are part of executive functions.

Interference or interactions between different information pathways become signs of conflict, when infrequent responses are required (Braver et al., 2001). Habitual or frequent responses have a high level of readiness, they show a strong stimulus-response mapping. The effect is a powerful immediate response. When a low frequency alternative is chosen, the response is the result of a competition. The Anterior Cingulate Cortex is the brain area critically involved in response conflict, such as low frequencies response, inhibition and errors.

Stimulus-response mapping is a sign of central processing. Motor execution, the next stage, involves neural structures at peripheral level. In random events people tend to look for patterns (Elliott et al., 1997), which are confirmed or not by the result of the choice. Lam et al. (2006) suggested that adjustment among options is the consequence of predictive strategies, a series of actions for reacting to the stimulus.

1.5 PREPARATION

Voluntary movements can be decomposed into two basic processes: motor preparation, involving planning and programming, and then motor execution. It has been suggested that the lateral zone of cerebellum is primarily involved in motor preparation, while the intermediate zone is closely related to execution (Cui et al., 2000). Ebner (1998) found that the cerebellum during movement is involved in processing some information: direction, speed of limb movement and eye movement functions. These are key points for feed forward signals connected to internal models (Miall et al., 1998).

Preparatory processes, the first covert step of voluntary motor acts, are directly linked to our need to anticipate future events, to reduce our uncertainty about them, and to improve our reaction in similar future situations (Requin et al., 1991). This leads to an optimal adjustment between perceiving and replying (Brunia and van Boxel, 2000).

Several factors may influence premotor processes:

- stimulus intensity

- action complexity

- speed-accuracy balance, the interaction of speed of movement and the desired accuracy

- number of response alternatives

- event uncertainty.

Stimulus intensity deals with attention and the relevance of the perceived stimulus. Its effect depends on the goals of the action. An intense stimulus will be easily identified and will urge the subject to act (Miller et al., 1999). Often the action is a chain of different steps. Action complexity may involve different parts of the body and their significant or secondary role during the different stages of the action (Smulders et al., 1995).

Speed-accuracy balance is linked to the need to be quick and precise. If the behaviour is complex, anticipation takes more time. Because of this, the action has the chance to be precise. When the request is to be fast, the action tends to loose accuracy. The two extremes are: quick and inaccurate and slow and accurate. The person has to find a balance between them according to the situation and the goal-directed action (Osmann et al., 2000).

The number of available options is one of the sources of event uncertainty. When it is important to make the right prediction, the result is slower reaction time (Osmann et al., 1995).

Neural structures are pre-activated in order to increase the upcoming information processing and organise the action. Brunia (1999), Brunia and van Boxel (2000) proposed that this is due to an increase of the state of alertness and a focused attention on perceptual input and motor output. They proposed that a subject anticipates the behaviour selecting the information at local level through a growing excitation of the

relevant structures and an inhibition of the irrelevant ones. The process is short, lasting few milliseconds, and it is fatigue-sensitive.

Two aspects were identified: event preparation and temporal preparation. Event preparation is aimed to a reduction of uncertainty and to an adjustment to the range of possible answers. Temporal preparation points at the readiness of the subject and the synchronisation to the response signal. Tandonnet et al. (2003) studied the anticipation time inside reaction time and warning signal experience. The perceived stimulus gives information on the characteristics of the coming event and *its* the timing.

The subject can be ready for the specific event, at the right time. The state of readiness affects the excitability of peripheral and central motor structures through a progressive inhibition of the spinal structures and an increment of neuronal central excitability (Birbaumer et al., 1990).

There is a debate about the effect of temporal preparation. Muller-Gethmann et al. (2003) proposed an enhancement of early processes, like stimulus evaluation, feature extraction, stimulus identification and response selection. Macar and Bonnet (1987) studied the reaction to a precue signal and suggested that the Central Nervous System tends to link the two events, expecting the second, the go signal, because it follows the first one, the warning signal, after a definite delay. The subjects try to guess the time of the signal and to make the starting of the second signal coincident with their readiness (Niemi and Naatanen 1981). The uncertainty depends on the distribution of the foreperiod duration.

Hasbroucq et al (1997) observed an acceleration of the decrement in cortico-spinal excitability at the end of the foreperiod. The authors concluded that temporal preparation

involves the inhibition of cortico-spinal excitability and the increase of sensitivity of the cortico-spinal tract (signal-to-noise ratio) to the chosen command.

1.5.1 PLANNING AND PROGRAMMING

After a perceptual phase, there is a motor processing stage, which shows activity in Superior Colliculus for target selection and movement specification, Frontal Eye Field and Intra-Parietal Area to select the movement before the beginning of the action. (Schall, 1999). Brunia (1999) suggests that preparation to respond consists of motor programs at low level and planning at higher level. The plan is a broad scheme of action, taking account of temporal order and dimensions related to the trials of the task (Quintana and Fuster, 1999). Benvenuti et al. (1997) proposed synergies as components of motor programs. They are stereotyped patterns, which follow a definite order. Keele (1968) defines the motor program as a set of muscle commands for a specific goal, which is structured before a sequence of movement begins. It is organised according to identity, ordered in a chain of commands, linked to the muscles, the terminal nodes. Klapp (1995 and 1996) proposed a two-process model. The first level deals with the organisation of the internal features of the single elements of the movement. The second is linked to sequencing the response elements into the right order, before the execution. Verwey (1993, 1996 and 1999) proposed a motor buffer stage, before the sequencing stage. During the phase of identification of the specific task code, the subject, in the first step, selects in Long-Term Memory the proper task representation and remembers its elements, activating Working Memory. The length of the sequence is defined, constructing motor structures or loading chunks, fixing spatial-temporal properties. Inside the buffer stage

there is a second step, motor programming. Kinematic variables for the control of the structure are involved: force, speed, limb movement. This preceding step implements the action execution.

1.6 REACTION TIME

Reaction Time is the interval between the presentation of the trigger signal and the time of the end of the action, when its measure is taken. Planning and programming are the support for the focal action. In experimental conditions, the behaviour involves the arm touching of one of the pads. It implies that there is a stimulus and a reply of the person after its perception. Two major aspects have to be underlined: the difference between simple and choice Reaction Time and the connection with task complexity.

The duration of reaction times differs in simple and choice conditions. Schluter et al. (2001) compared the two situations. Simple Reaction Time refers to one target. The simple reaction-time task has one stimulus and just only one response. In this condition the authors found contralateral activations in the Sensorimotor Cortex. Right hand showed involvement of Median Parietal Cortex, left hand was connected to right Premotor Cortex activity, Right Cingulate Sulcus, ventral Supplementary Motor Cortex (SMA) and Insula, right and left.

Vidal et al. (1991), Coull et al. (2000) and Hackley (2003, 2006) discussed the effect of warning signals on reaction time. In the case of constant delay, they found no reaction time difference between short and long foreperiods. In random conditions, long and unexpected very short delays are linked to slower reactions. As the foreperiod increases,

in fixed conditions, reaction time lengthens, because the accuracy on detecting time decreases. The time between signal and action was used as a basic measure in studies on reaction time and reflexes, right-left arm differences and different positions of targets.

The main features linked to choice reaction time are described by the studies of Baranski and Petrusic (2003). The list includes accuracy and speed of responding, discriminative performance, judgmental confidence, target comparisons and context induction comparisons.

Choice reaction time involves activation of more brain areas. Left Ventral Frontal Cortex and Intraparietal Sulcus stimulate both right and left hand movement. Right Dorsal Prefrontal Cortex and Intraparietal Sulcus activate left hand movements. The picking up of one alternative requires more time to accomplish the task, because it implies discrimination among stimuli and action selection. The studies on choice reaction time analyse sensory organisation, which perceives external information, brain integration for detecting differences, identifying objects, evidence accumulation in favour of one option among many, and response execution, the final step.

Ortiz et al. (1993) proposed that in experiments where subjects have to choose between two targets, the response is affected by the kind of discriminative processes. They reported a two-stage integration process of stimulus-evaluation and response execution. The response is the consequence of two variables: first the adjustment, required for achieving the threshold level, in order to come to the reaction, and second the adopted strategy. They found the same two-stage process when subjects chose between 3 targets. This is the condition of the current investigation. The authors proposed a distinction

between slow and fast responders. Times of reaction are proportioned to the basic speed of the subjects.

When the subject knows, through feedback, if the choice they made was correct or incorrect, he/she enhances the association between a particular response and the specific cue presented. For example: response 1 is (only) successful (correct) in the presence of cue A (Passingham et al., 2000). Reaction time values are proportioned to the difficulty of the motor programming, and a sign of task complexity.

The response period is divided into two different sections: pre-motor time, and motor time. Pre-motor time is the delay between the "go" signal and the "first discernable" change in the focal movement activity, and motor time, the time between focal activity initiation and the target achievement, when data are collected. The discrimination will be relevant during the discussion of the EMG figures and the interpretation of reaction time data.

The time of the reaction depends also on the compatibility-incompatibility condition during the selection phase. Umilta' and Nicoletti (1990) concluded that incompatible responses require more time by central information processing, so reaction needs more time. In fact the stimulus code has to be translated into a code suitable for a proper response.

Allain et al. (2009) investigated time adjustments before and after errors and concluded that subjects take more time after an incorrect answer to prevent the occurrence of a new wrong response. This implies that the error has been detected, inhibited and corrected as part of online executive control.

When one response is activated, there is no conflict. They defined the concept of conflict as “the sum of the products of the activations of the possible responses weighted by the negative connection strengths between them”. In the context after an error there is a reduction in response priming. The result is a slower, but accurate response (Botvinick et al., 2001). The word accurate refers to lower error rate. Short or long reactions are signs of the time spent for choosing among the alternatives. A short time tells that the subject predicts without uncertainty the next result, and the action follows immediately. A long time of reaction is a sign of the weighting the options (Rabbitt, 1966). The final choice and the behaviour “cut”, literally, bring to an end, the decision path. After some trials, a strategy applied to pad touching might be recognised.

1.7 THE ACTION

Deecke (1996) studied the attributes of the action and concluded that there are two different categories of movement: the ones internally initiated (self-initiated), and the ones externally initiated, trigged by events from outside. He defined the latter ones as re-actions. Re-actions are the focus of the discussion and they are examined from different perspectives.

The action is the consequence, the final result of a complex path, which includes issues like balance, anticipatory postural adjustment and focal action. The organism re-action implies somatosensory feedback, automatic postural adjustments following external perturbations, and focal movement. These activities require organisation of muscle synergy for postural stabilisation, balance between postural and focal components, adjusted for supporting the action, and temporal relationship among the components.

1.7.1 BALANCE

The body is able to execute the movement when mechanical conditions of static and dynamic equilibrium are met, in other words, when postural contractions sustain the main action.

Posture has two main functions. The first one is antigravity control, linked to the ability of the kinematic chain of movements to sustain the body weight against gravity forces and ground reaction forces. The second function is related to sustain the moving segments during a focal action and to control equilibrium (Massion et al., 2004). The result is an interaction between external and internal forces.

The notion of equilibrium lies inside the concept of posture. Balance has an antigravity function, as the centre of antigravity projection has to remain inside the supporting surface, as in the basic standing position. Equilibrium is the result of the matching of the torques and segment motions. It is organised before or after the effects of postural disturbance. The result is postural stabilisation, starting, before the focal movement, with a sway in the opposite direction of the segment used for the focal movement and the sway immediately after (Cordo and Nasher, 1982).

The reaction implies somatosensory feedback, automatic postural adjustments following external perturbations, and focal movement. These activities require the organisation of muscle synergy for postural stabilisation, balance activity between postural and focal components, adjusted for supporting the action, and the temporal relationship between these components.

1.7.1.1 BALANCE FROM SITTING POSITION

There are differences between sitting and standing postures. These differences change the organisation of anticipatory postural adjustments. Postural activity involves all the body. In particular it has to be underlined the involvement of upper and lower limbs.

In sitting position the support is large, it is easy to maintain the Centre of Mass within the base of support, and the lower part of the body is sustained (Aruin and Shiratori, 2003). The upper limb muscles are mainly involved in phasic non-postural activities, for example reaching something or key-boarding (Hasbroucq et al., 1997). Teyssedre et al. (2000) studied anticipatory patterns linked to preferred and non-preferred arm movements from the sitting position. The differences were in latency and muscular excitation. They found that anticipatory postural adjustments started earlier for movement of the preferred arm. This was connected to the higher velocity of the preferred arm. For a similar performance additional postural muscles are activated during non-preferred arm movements.

1.7.1.2 BALANCE FROM STANDING POSITION

From a standing position, feet in a step stance, trunk and leg muscles are activated before the arms. Leg muscles cannot go ahead, until there is enough steadiness to compensate the effects of the upcoming action (Massion, 1992).

The person interacts with surface and with gravitational force, in order to maintain a geometric relationship among several joints and muscle groups and the equilibrium

coming from all the forces. It can be organised as a reaction to the effects of postural disturbances, in anticipation of, or after them.

The role of leg movements is supporting the body, adjusting it to any change in the support conditions, like the shift of the Centre of Gravity (Massion, 1992). Balance disruption activates leg muscles to establish a steadier situation of centre of gravity and pelvis. Massion (1994) and Slijper et al. (2002) examined voluntary movements performed by a standing person, the result of external forces, interaction torques, changes in the body geometry and postural equilibrium. The reaction to the forces leads to changes in postural contractions before, during, and after the motion has to come to a stable balance (Cordo and Nashner, 1982).

1.7.2 ANTICIPATORY POSTURAL ADJUSTMENTS

Anticipatory postural adjustments build up the conditions for maintaining the chain of multiple muscle contractions, the focal movement. Cordo and Nashner (1982) defined anticipatory postural adjustments as the activation of rapid postural contractions related to voluntary movements, which disturb postural equilibrium. They are linked to biomechanical factors, like inertia of the moving segment (Aruin and Latash, 1995), initial and final position of the body (Aruin et al., 1998) and velocity of voluntary movements (Lee et al., 1987). Van der Fits et al. (1998) analysed the relationship between postural adjustments and different body positions. They proposed three parameters for the basic organisation of these contractions: spatial, temporal and quantitative. In particular about the timing of postural activation, for instance in

conditions of fast movements, postural adjustment contractions start prior to focal movement initiation. Slijper et al. (2002) analysed them as adaptations to changes in the background activity of postural muscles, linked to associated shifts of the centre of pressure. Lestienne and Gurfinkel (1988) observed that the postural system implies a central organisation and an internal model of the body, included the geometry of the body and its dynamics, the body scheme.

The synthesis between the body multi-component system and the continuous communication with the external world leads to an adjusted behaviour and to effective goal-directed-actions. The related neural network is located at the level of the brain stem and spinal cord. The Supplementary Motor Area and the Basal Ganglia, in the hemisphere contralateral to the postural activity, control the process; the focal action is the result of the activity of the Primary Motor Cortex of the other hemisphere (Brown and Frank, 1987).

Brooks (1986) studied the central organisation of the coordination between posture and movement and came to the conclusion that there are two levels of processing: one refers to movement planning and programming and involves the association areas, the Basal Ganglia and the Neocerebellum, the second level deals with movement execution and involves the pathway from the Motor Cortex to the periphery.

Horak and Nashner (1986) proposed the concept of strategy. It is related to the occurrence of various postural reactions, and depends on the initial support conditions. It is a high hierarchical level process, which leads to plan a goal directed movement choosing one way among different paths. A strategy is realised by a pattern, a synergy, a series of muscle activation.

Postural activity involves the whole body, lower and upper limbs play an important role. Among the first group, lower limbs, Soleus muscle has mainly a postural action, involving the antigravity control of muscles. The upper limb muscles are mainly involved in phasic non-postural activities, for example reaching something or playing a piano keyboard (Hasbroucq et al., 1997).

1.8 FOCAL ACTION

Focal movement is the execution of a voluntary action. “It is a transmission of re-active forces between individual and the environment and results consequently in changes in the centre of gravity” (Cordo and Nashner, 1982).

The action, the result of cognition, motivation, working memory load, activation and inhibition, is a signal of peripheral motor execution (Hasbroucq et al., 2001), of afferent, central and efferent processes, the consequence of planning; it is directly linked to a motor program, a set of neural commands for a specific goal (Benvenuti et al., 1997).

The majority of movements deals with upper and low limbs. Arms perform accurate movements for reaching, grasping and touching objects. According to Kato and Asami (1998) upper limb movements depend mainly on central information processing. Bouisset and Zattara (1987) suggest that a role for arm movements is to maintain the connection between body segments during the action and the balance at the same time. During the acquisition of a skill, action becomes more accurate, because of practice, and becomes fast, so the subject can rely less on feedback control. It means that there is a shift in control strategy.

Legs have the function of support, balance and moving the body, through steps. Lower limb activity is related to central information processing and peripheral motor control.

1.9 FEEDBACK

Feedback is "the information about the progression toward a goal" (Voltz et al., 2005). The advice about success or failure of the prediction in choice Reaction Time has emotional connotation. Right or wrong responses are positive or negative reinforcements, a support for attention, for working memory activity, and in particular for up-dating memory content. The consequence is a variation on the time of reaction.

The feedback can be negative or positive. Negative feedback calls for a behavioural or strategic change. Subjects tend to slow down on trials subsequent to errors (Rabbitt, 1966). Response latency after negative feedback is the consequence of the subject paying attention, as he does not intend to repeat the mistake (Laming, 1979). It is related to the need to resolve interference from the prior trial (Monsell et al. 2003, Smith et al., 1998). Positive feedback confirms the choice; it is a "keep at it" signal, a support to the idea "go on, you are using the right strategy".

The subject tends to develop a preference for one option over time and probably will use the reward, the positive response, to improve the performance of the following trials (Pew, 1974). Feedback is a guide to monitor the performance, and a help for the subjects to adjust their approach to the task. It provides an assessment of performance in a guessing task. After the first choice, feedback afferent pathways inform the neural system if the behaviour met the goal (positive feedback) or if there is a difference (error detection), which needs an adjustment or a change of strategy (negative feedback).

The steps of the path will be: feedback (positive or negative) from the focal action just performed, re-adjustment of the pattern or the model extracted by the situation, new choice inside this pattern, preparation and finally focal movement. This is the core of my research and the topic will be discussed later on in detail.

1.10 FEEDFORWARD

A feed forward process is related to the action effect, from two perspectives: the accurate movement of the organism and the achieving of the goal. The conditions of my investigation are more directly connected to the second aspect.

The need for checking the goal directed action leads to control the information. The consequence is a possible change, during the action, because of errors (Shadmehr and Mussa-Ivaldi, 1994). These errors push the nervous system to update the internal model and adjust the motor output to the new demands of the task (Kawato and Wolpert, 1998). The modified motor command will be compared to the original model, which is recognised as movement error. This is called after effect.

Feedback information coming from sensory receptors during the action leads to the achievement of the goals and to the management of the action through adjustments. It affects afferent inputs, which in turn affect*s* efferent outputs. The tool is open loop feed forward commands and its function is to maintain equilibrium under central control and posture under peripheral control, to contain balance and posture disturbances (Massion, 2004). The body stabilisation involves head, trunk, limbs and legs.

1.11 RIGHT-LEFT HAND PREFERENCE

Many studies have analysed right/left arm preference. Carson et al. (1995) studied right and left hand action during reaction time. Given that right hand is recognised as dominant in most of cases, they proposed that there is a left hand advantage for speed preparation, due to a better dealing with spatial parameters and a more effective organisation of movement. The right hand performs better for movements lasting for shorter time. The left hand shows a temporal advantage in movement initiation. Contralateral movements, directed to internal targets, were slower than ipsilateral movements to external targets (Carson, 1990). It implies that, if the subject, in experimental conditions, is performing with the right hand, reaction time will be shorter when he/she will choose pad number 2 or 3 (in the middle or on the right), and will be slower when he/she will touch pad number 1(on the left). Carson (1989) found that, before the beginning of a rapid movement, left hand advantage is the result of right hemisphere involvement in attention mechanisms, integration and feed forward of information in connection to the position and orientation of a target. This effect is more evident for ipsilateral targets. Von Donkelaar and Franks (1991) studied response accuracy. They found that the right hand performs better. Mieschke et al. (2001) concluded that this could be a consequence of making more effective small adaptations to the trajectory before the arm approaches the target.

The time of the action of right and left hands is the same when accurate instructions are given. The precue situation promotes the programming in advance. The left speed advantage for pre-initiation movements might be removed when feedback is proprioceptive . This is what will be tested during the experiment. According to Schluter

et al. (2001) in choice reaction time left hand movements are less automated. There is activation in the contralateral premotor, ventral prefrontal and anterior Cingulated Cortex, for the left, and not the right, dominant, hand.

1.12 DELAY

The time between "alert" and "go" signals is called foreperiod or delay. The first signal triggers a "waiting readiness", a posture reaction, so the subject will be ready for the next event at the right time (Tandonnet et al., 2003).

Two mechanisms are related to foreperiod effects:

- the warning signals with short period durations

- expectations with longer periods.

It is relevant to identify if delay enhances the speed of processing of early perceptual stages or the processing of late, motor, stages.

Muller-Gethmann et al. (2003) proposed that temporal preparation enhances the readiness of early processes of the motor system. Sensory processes, feature extraction, stimulus identification, stimulus evaluation and response selection are facilitated. According to Hasbroucq et al. (1997) this effect involves also the inhibition of cortico-spinal excitability, increases the signal-to-noise ratio and the sensitivity to the voluntary order of the cortico-spinal tract. The foreperiod enhances the anticipation processes, giving a warning signal about the upcoming stimulus and helping to synchronise them to the signal (Niemi and Naatanen, 1981). The authors found that when delay is kept constant

within a block of trials, reaction times are usually shorter. When it varies randomly from trial to trial, reaction times are longer.

Beside these effects, the constant delay conditions produce a sharp decrease of reaction time after short foreperiod durations, within the range of 0-150 msec. (Bertelson and Tisseyre, 1968), because the "alarm" signal produces immediate arousal (Ulrich and Mattes, 1996). In choice reaction time, when the delay is fixed, the subject perceives this time during the first trials and prepares the action in advance, because he/she can quantify the time and to be ready at the starting of the "go" signal. Long foreperiods, in fixed delay conditions, produce more temporal uncertainty, which leads to longer reactions. This is due to an increasing difficulty in estimating the time at which the response signal will occur (Klemmer, 1956, 1957, and Requin et al., 1991).

In random delay conditions, the timing of the response cannot be predicted, the subject must face a range of delay times, from very short to long. According to Laming (1979), if the foreperiod is overestimated, the stimulus comes before the entire reaction process, and the response is delayed. If it is underestimated, the stimulus comes later, the reaction process is switched on too soon, and this will modify the time of the response.

The time of reaction will be affected both by the uncertainty of the preparation time and by the feedback, positive or negative, given to the former choice.

The precue time conveys the information, activates the preparation phase involving several cortical areas: the Parietal Cortex (related to the direction of the to-be-completed response movement), the Supplementary Motor Area (related to the length of time of the forthcoming movement), and the Primary Motor Cortex (related to the response force).

A progressive inhibition of the spinal structures and a progressive increment of central excitability lead to implement time preparation. Weak activation remains below a hypothetical inhibition threshold, overt behaviour may follow strong partial response activation, or it can be actively inhibited. Reaction time depends also on the delay time of the preceding trial. When the former foreperiod was longer than the current foreperiod, reaction time tends to be slower (Los and Van den Heuvel, 2001).

1.13 REWARD

Reward is positive information about the effectiveness of the achievement of a goal. The positive feedback works like a reinforcement of the strategy used before. Negative feedback pushes to a closer control of the situation and to a change of strategy (Savine and Braver, 2010). When positive feedback results give proper advantages, reward is emotionally loaded and operates as an effective motivational factor, influencing human performance. The experience stimulates learning, representation and planning of the action. According to Ramnani and Miall (2003), expectation of reward affects feature extraction in cortical association areas, attention, cue identification, visual input decoding, working memory activity and application of previously detected rules. Certain types of events can improve retention, consolidation, when they occur continuously. The reinforcement increases arousal and influences memory process.

Schultz (1998) proposed that some objects or events have particularly significant effect on welfare or survival. The motivational value can be positive, rewarding, or negative, punishing. The first situation, like in stimulus-reward association, leads to approach it, to

an increasing frequency and intensity of behaviour, to learn it and to prevent extinction, by maintaining the learned behaviour.

Reward is an incentive, gives a positive emotional state and becomes a goal of behaviour after associations between responses and outcomes (Dickinson and Ballein, 1994). Aversive stimuli are negative reinforcers, result in withdrawal responses, and tend to maintain avoidance behaviour at the next presentation. The internal emotional impact is negative. The association between stimuli and their particular outcomes helps to identify objects and discriminate them from less valuable objects (Adam et al. 2010). The experience allows giving a value, in advance, to future events. This builds up the conditions for selection, for choosing among alternatives, for preparation, and increases the likelihood of approaching or avoiding them, helps to integrate knowledge from different sources, to think of various ways of reaction, evaluating different strategies, to speed up the performance and to reduce reaction time.

The reward behaviour is the effect of a complex organism neurophysiological activity (Ridderinkhof et al., 2004). The most relevant factors are dopamine neurons, which release the neurotransmitter from axonal varicosities in the Striatum (Caudate Nucleus, Putamen, and Ventral Striatum including Nucleus Accumbens) and in Frontal Cortex. Cell bodies of dopamine neurons are found mainly in midbrain (A8), Dorsal and Lateral Substantia Nigra, (A9), Pars Compacta of Substantia Nigra, (A10), Ventral Tegmental Area medial to Substantia Nigra and in Amygdala. Dopamine reaction depends on event unpredictability. It affects attention:

- through adaptive responses during learning episodes

- through effective stimuli (the ones which have become valid predictors because of repeated and contingent pairing with rewards, the ones which elicit generalising responses, the novel ones, or the particularly salient stimuli, not necessarily related to specific rewards)

- through error signal predictions.

1.14 PATTERN

Bunge et al. (2001) studied the process of keeping information. They suggested that keeping relevant information in mind, not taking account of irrelevant data, comes from active maintenance of goal appropriate information. It involves attentional control system, storage of visual spatial and verbal information, and executive control.

Attention plays a critical role in signal selection. What is specified as relevant will be assumed as part of a system, associating categorised stimuli. This leads to extract regularities. Executive control is related to information stored on-line for a short period, choice among strategies, to achieve the goal, execution and maintenance of the strategy, inhibition of the strategy in case of a change in task demands. According to Matsumoto and Tanaka (2004), three processes are relevant in goal achieving:

- action selection based on goal expectation and memory of action-outcome contingency

- action evaluation based on immediate outcome

- discrimination of the early steps from the final step towards the goal

The executive functions (cognitive control) include task monitoring, error detection, and "compensatory" behavioural alteration (Garavan et al., 2002). One of its basic components is the ability to use on-line appropriate task rules or prescribed guides for action, that is the capacity to retrieve, maintain and use the relevant rules (Crone et al., 2006). The final result is the plan.

Processes involving single decision-making trials (related to action selection, anticipation, and experience of outcome) and the ones, which must be kept across many or all trials (connected to maintenance of task instructions, evaluation of different response strategies and multiple outcomes) are activated by specific neural paths (Yarkoni et al., 2005).

Opris and Bruce (2005) suggest that, during the process of decision making, sensory data are transformed into simple discrete categories. They propose that: "the brain uses specialised neural circuits, analyses and interprets the sensory information using the knowledge from previous experience, weights the expected outcomes (they call it utility) and selects the option that maximises the expected utility". Keele et al. (2003) proposed that skill acquisition requires the development of abstract associations. Associations are made even in presence of random events. In that case working memory is activated. It relies on the active maintenance of goal-relevant information and depends on:

- the level of awareness of options

- the level of awareness during choice process

- the anticipation phase

Repetition indicates priming, when a change in behavioural response is shown, as consequence of a stimulus followed by re-exposure. Tasks connected to familiar visual objects involve facilitation of perceptual identification, the formation of a more direct association between the stimulus and the given answer. The response will be cued by the repetition of the stimulus (Horner and Henson, 2008).

A pattern is a regular and repeated arrangement of numbers inside a sequence. The subjects have to notice and identify it, in other words, they have to learn the new information, recognise it, when it is re-proposed, and choose it at the option selection time. The process is directly connected to stimulus-response mapping, managed by central processing during premotor time. Targets are defined through categories and this leads to associations among them. The process is the result of repeated occurrence of one stimulus after another. Sequence learning implies that the response features (Willingham et al., 2000) and the sequence of motor responses (Nattkemper and Prinz, 1994) are detected. An abstract representation links the elements in a sequence (Dominey et al., 1998). This implies two dimensions: type of judgement (numerical/spatial) and judgement to response mapping (compatible/incompatible) (Keele et al., 1998). Nattkemper and Ziessler (2001), Ziessler et al. (2004), Dominey et al., (1998) and Willingham et al. (2000) studied the field; in particular they were focused on the way the brain makes associations and retains them in memory. Crone et al. (2006) analysed the capacity to retrieve, maintain and use the relevant rules. Horner and Henson (2008) proposed a study on tasks connected to familiar visual objects. The experience involves facilitation of perceptual identification, the formation of a more direct association between the stimulus and the given answer. The response will be cued by the repetition of

the stimulus. When an internal model is acquired it is possible to compare the predicted and the desired state of the action (Heuer et al., 2001). “The effective intention to process particular stimuli in a particular way is called a task set” (Rogers and Monsell, 1995). The result is the configuration and the reconfiguration of the task set. Inside the trigger conditions for task set reconfigurations, implicit and explicit cues are distinguished. Implicit cues are inherent to the serial order of a predictable sequence of tasks (Allport et al., 1994). Advance preparation of task set does not require external precues. It can be based on knowledge about the regularities of a sequence of trials. After identification of a pattern from the subject, the re-proposal of the first figure stimulates recognition of the scheme and increases data organisation. Acuna (2002) analysed the way of responding and concluded that correct answers may occur by applying pre-determined logical steps sequentially, as a scheme, by building and operating upon mental representations or by a combination of methods. As learning progresses, reaction time increases, when high repetition rates interfere with recall of the correct answer. Predictions, which seem not reliable, prevent the grouping.

Many authors have studied cerebellum function related to sensory processing and timing. A subject can recognise the order in which the stimuli are presented, the sensory information related to one stimulus must remain active in the working memory and “compared” with the next ones. Braitenberg et al. (1997) proposed that sequence detection is a cerebellar function of motor control. The cerebellum sends excitatory inputs to the cerebral cortex “linked to the predictability of the stimulus sequence” (Molinari et al. 1997), and to expectancy of sensory signal.

According to Bellebaum and Daum (2007), fronto-cerebellar circuits are implicated in generation of internal models. In particular the cerebellum, receiving inputs from the Cerebral Cortex nuclei, is in the position to predict the sensory consequences of movement. Prediction and consequences of the action are the relevant points of a plan. They will result in labelling actions (Blakemore and Frith, 2003).

Sequence representation is activated from upstream sources in the Supplementary Motor Cortex and Parietal Cortex. It involves cortical networks: Premotor Cortex, anterior regions of Prefrontal Cortex, posterior cortical regions of the Temporal and Occipital Lobes. Prefrontal Cortex and Temporal Lobes are linked to executive control and context-dependent learning (Eichenbaum, 2000). Pascual-Leone et al. (1999) studied the end of the learning period, when reaction times are "stabilised" and subjects can recall the ordered sequence already presented. The authors found that at the beginning of the learning stage there is an increasing of cortical activity; it decreases to the baseline at the end of the stage.

Nissen and Bullemer (1987) suggested that a decrease in reaction time is a signal of recognition and knowledge acquisition.

1.2 AIM OF THE STUDY

The scientific studies on the main issues of reaction time, option selection and choice, describe the features of the field and introduce the research. The investigation is centred on the selection among alternatives and the choosing experience, at different conditions. The purpose intends to find regularities and trends of behaviours using as parameters time of reaction and correct choice. Time of reaction is analysed:

- when the chosen answer was correct or incorrect, or the previous answer was correct or incorrect
- when the correct choice is the result of chance or when it is predictable due to the precues.

The Experimental Hypothesis predicts that, in choice and cue conditions, trials from a recognised pattern give faster and more correct responses than random trials.

The plan is developed through steps, which test specific variables connected to partial aims and build up the conditions to obtain the final achievement.

CHAPTER 2

GENERAL METHODS

2.1 GENERAL METHODS

The chapter presents the way in which the study was built up and realised: general methods, volunteers, Ethics Committee review, authorisation and instrumentation.

The investigation is the result of an experimental design and a planned way, step by step, to test the aims and to come to the final conclusions.

Some key concepts were crucial in this work: choice situation, correct answer and time of reaction. The most effective choice has to be correct and quick in achieving the goal. A response can be positive by chance or by cue guessing. This was the direction of the research plan. The third quality, rapid reaction, is directly linked to the right answer. To be fast and incorrect is useless, to be slow and correct can be positive, but sometimes is not productive, especially when we face, in the real life, a situation of competition.

A four step path was designed to achieve the aim. The first step proposed to fix the basic parameters on reaction time: no choice and choice condition, focal action of dominant and non dominant arm. The data were also the first reference on delay variable, on correct and incorrect answer reaction times. These specific topics were analysed in later experiments. The second step was aimed on testing reaction time without and with reward. The third step pointed at the effect of delay on reaction time. The fourth step tested the relationship between cues, correct answer and time of reaction.

2.2 VOLUNTEERS

67 volunteers were involved in the experiments described in this thesis, 33 were men and 34 women. 21 volunteers took part in the experiments described in Chapter 3, 13 were the subjects at University of Padova, in Italy, and these took part in the experiments described in Chapter 4. 12 and 21 volunteers performed in experiments presented in Chapter 5 and in Chapter 6 respectively. They were University students of Padova or Glasgow University and staff of Glasgow University. The age range was 20 to 60 years. All were healthy.

2.3 ETHICS COMMITTEE REVIEW AND AUTHORISATION

All experiments involved human volunteers. The protocols were reviewed and approved by the Ethics Committee of University of Glasgow and Corso di Laurea di Scienze Motorie, University of Padova. All volunteers were fully informed of the nature of the experiments and signed a consent form. Details of the application are contained in Appendix I, page 160.

2.4 INSTRUMENTATION

Two main instruments were used: a device to deliver stimuli and to measure reaction times, the reaction time device; a computer interface system recorded all events. A system for recording surface electromyogram (EMG) was used in experiment 4 and examined in chapter 5, Methods and Materials, page 81.

2.4.1 REACTION TIMER DEVICE

This device was designed and constructed by Nosrat Mirzai, the Head of the BioElectronics Unit of Glasgow University. The specifications were created by the author and her supervisor.

The features of Reaction Timer are:

- it delivers stimuli in the form of illuminating an LED at one of three positions.

- the position is chosen in advance by the experimenter.

- the stimulus is preceded by a warning light.

- there is a delay between the warning light and the signal to start the movement.

- this delay was between 1 and 9 seconds and was determined in a pseudorandom sequence by the device.

The volunteer touches a pad switch to signal his or her response.

The device automatically records the time of the warning light, the time of the go signal and the time of the response.

The experimenter determines in advance the position of the target light i.e. the correct response.

After each trial the volunteers receive feedback from the device about the correctness of their response. If it is correct, a green light behind the touched pad, in the horizontal part of the device, will be switched on. If it is incorrect two lights will appear simultaneously: a red light behind the chosen pad and a green light behind the right pad.

All the results from an experimental session are transferred to a computer as a text file via an RS232 interface link.

Experimental set up is slightly different in each experiment. Specific details are given in each chapter. The basic layout is shown in figure 2.1.

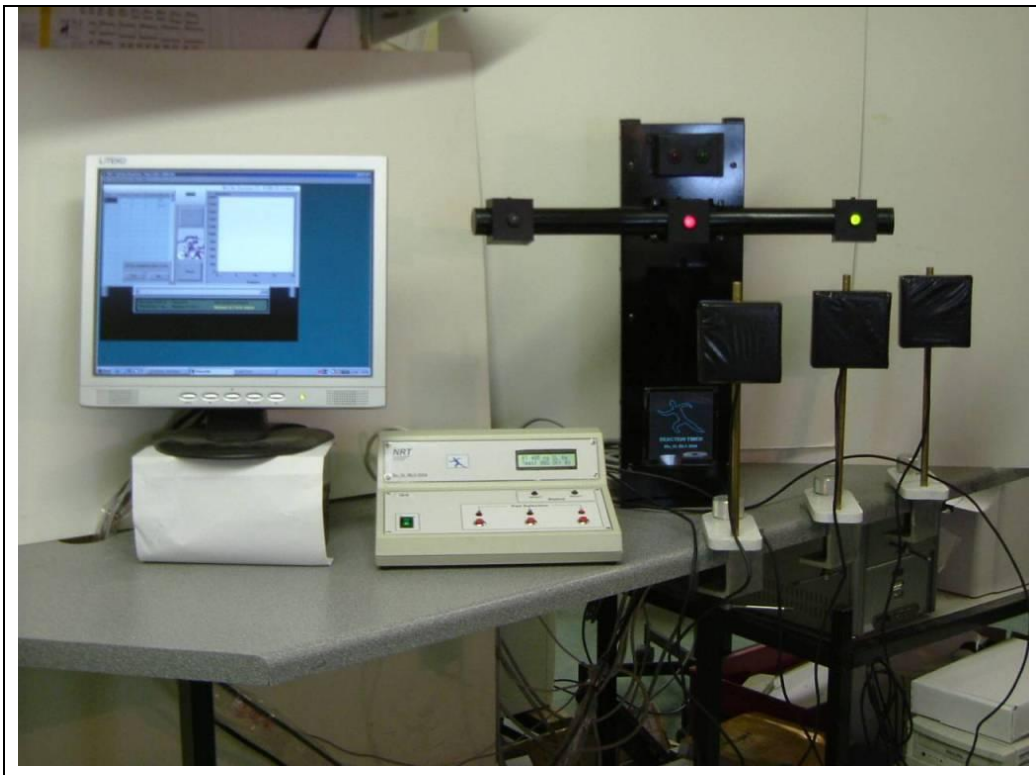


Figure 2.1
This photograph shows the basic set up of the experiment: the computer screen showing the text file of data transferred from the reaction timer, the command box in the middle of the picture, the three pads or switches on the far right and behind them there is the device, the bar with the LEDs indicating at the top the alarm and get ready signal, in the horizontal part, the green light of the correct choice, behind the correspondent pad, and the red light of the wrong target position.

The arm holding the target lights seen in figure 2.1 sits on a rectangular metal base from which a sort of cross rises. The vertical post is 40cm and the horizontal bar is 35 cm across. The lights signalling ‘get ready’ and ‘go’ are located near the top of the vertical post. The 3 target lights are located on the horizontal bar.

There are 3 pads positioned ahead of this structure and in front of the subject. Each pad is clamped securely on the table edge. Its position is adjusted according to the subject's height or trunk position. Pad 1 is on the left of the subject, pad 3 on the right and pad 2 in the middle. It is simpler to mention here the pad numbers and not the arm used to touch the pad. In some experiments the volunteer was seated and the pads were positioned to be level with shoulder and the volunteer reaches one of them straight forward. In other experiments the subject stood and the pads were in a relatively lower position compared to the shoulder, but still easy to reach. The distance between the central pad and others is 30 cm. Each pad is connected with the reaction timer box. The box was kept hidden from the volunteer and in a position where it could be managed by the experimenter.

The command box has 3 switches; they control which target light will be illuminated. A fourth switch initiates the test and after delays the get ready and go lights are illuminated by the device. The experimenter follows a script to determine the sequence of lights (left, right and middle). This script could contain random sequences or patterned sequences depending on the experiment. Table 2.1 shows an example of typical summary data. The first column shows the sequence number of the trial, the second column shows the duration of the delay between 'get ready' and 'go' lights being illuminated, column 3 shows the cumulative number of correct answers (i.e. where the volunteer selects the target chosen by the experimenter), column 4 shows the cumulative number of incorrect answers (volunteer chooses a target other than the one selected by the experimenter), and lastly column 5 shows the reaction time for that trial.

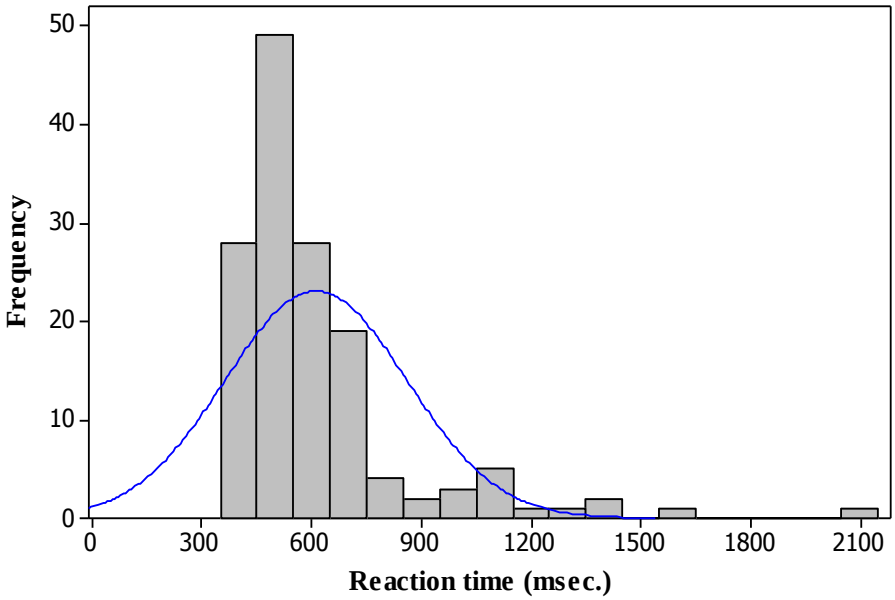
Summary of the data from the Reaction Time Device				
Trial number	**Delay (seconds)**	**Correct response**	**Incorrect response**	**Reaction Time (milliseconds)**
1	5	1	0	784
2	1	1	1	1466
3	1	1	2	756
4	2	2	2	758
5	1	2	3	708
6	1	3	3	900
7	7	3	4	668
8	1	3	5	970
9	1	4	5	769
10	3	5	5	731
11	2	5	6	776
12	9	5	7	836
13	8	6	7	703
14	5	6	8	682
15	6	6	9	699
16	9	6	10	647
17	1	6	11	1280
18	1	6	12	910
19	6	6	13	674
20	5	7	13	789

Table 2.1
This table shows specimen data downloaded from the reaction time device. The columns link reaction time with *the cumulative number* of correct and incorrect answers, the delay applied at that trial and the sequence of trials

2.5 STATISTICS

The raw data were stored initially as text files sent from the reaction timer to a computer. Typically, these data were transferred to Excel and Minitab version 15 files. Minitab was used for statistical analyses. Usually, the volunteer performed two or four sequences of twenty responses each. This number was based on advice given by Dr Aitchison of the Department of Statistics, Glasgow University. Dr Aitchison suggested that the minimum number of 8 trials is adequate to generalize the data. The decision to adopt 20, as the

standard number, allowed the rejection of some measurements in each set, when there is a malfunction of the equipment or in case of poor attention by the people involved. It was concluded that it was better to have too much data rather than to risk finishing with too little. The number chosen still allowed the experiment to be completed in a short time before the volunteer fatigued. In some experiments the reaction data was edited to remove very long times. These were usually identified as problems with volunteers lacking attentional focus or looking away from the get ready/go lights at a critical moment. In addition, there were infrequent failures of switches, the contact was not recorded, usually because the touch was too light. The experimenter signed this during the experiment in her notes. A cut off of 800 msec. was used in some experiments presented in Chapters 3 and 4. This was based on inspection of all the data. The cut off eliminated the points in a long tail of reaction times. The distribution of the raw data for one experiment is shown in figure 2.2. There are no very short reaction times to be eliminated. It was not possible to establish an absolute cut of point where genuine reactions stop. The choice of 800 msec. simply is a reasonable, practical way forward. In later experiments, where the reaction times were longer, because of complex choice situations, there was no cut off. Details of editing are given in the appropriate chapter. The editing process typically rejected about 10% of the reaction times. In the last set of experiments all data were included in a mathematical and a statistical model. This was done to follow the advice of Dr Nair, Mathematics Department, Glasgow University and Dr. Bondarenko, Department of Biostatistics, University of Michigan, Ann Arbor, USA. Figure 2.2 A shows an example of reaction time distribution.

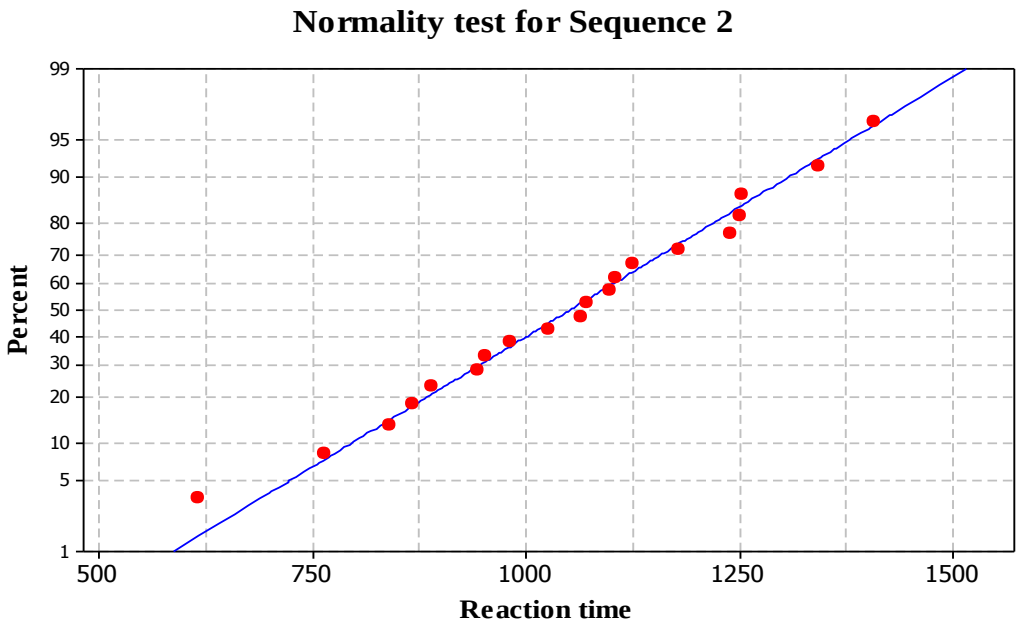


A

Figure 2.2 A

The histogram showing the distribution of reaction times recorded in 13 volunteers.

In general, the normality of the data was investigated using a Ryan Joiner test. When these confirmed the normality of the data, ANOVAs and t tests were used. The significance level was set at $p< 0.05$. The data sets of the number of correct and incorrect answers were stored and edited in a similar manner. Their frequency was investigated using Chi square tests. The significance level was at 0.05. Figure 2.2 B presents the percentage of the reaction time distribution in a Normality test and figure 2.2 C shows an example of results of a Chi square test.



B

Fig. 2.2 B

The figure shows the results of the Normality test for one sequence.

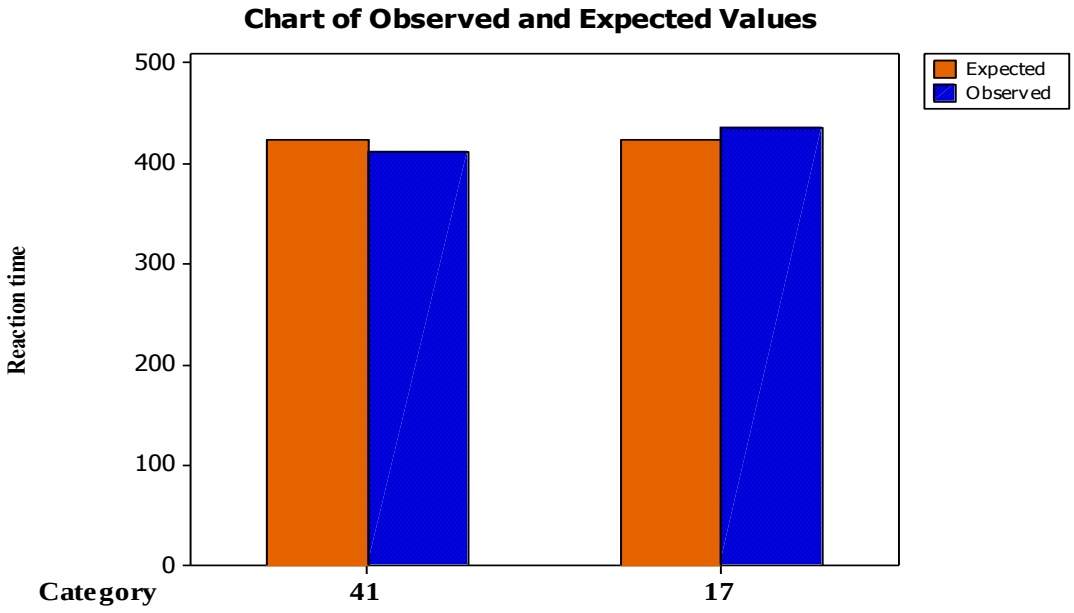


Fig. 2.2 C

The figure shows an example of Observed and Expected values in a Chi square test.

CHAPTER 3

FIRST EXPERIMENTS TO MEASURE REACTION TIMES IN DOMINANT AND NON-DOMINANT ARMS

3.1 INTRODUCTION

The concepts discussed in the Literature Review form the scientific base for the overall research project. The experiments described in this chapter tested the reaction time device and the responses of the volunteers in relatively simple conditions. The first section measures no choice reaction times, i.e. when only one target is presented and the volunteer is instructed to use the nearest arm or the preferred arm. Later experiments use three targets and the same volunteer will be able to select which arm to use to make his/her response.

Having tested the basic reaction time relationships, the second section of the experiment selects and fixes the conditions under investigation: choice situation, focal action performed by dominant arm, random delay, and two 20 trial sequences. The number of trials for each sequence allows a first level of computation of the data, as a first reference about the main values and about specific relationships, connected, for example, to the effect on reaction time of the previous correct or incorrect answer. The single topics will be analyzed later on in specific experiments.

3.2 AIMS

The overall aim was to use the reaction time measurements to provide information about the option selection phase by the volunteer. This was discussed in detail in chapter 1. The following aims were established:

- to measure reaction times in a series of volunteers in a simple situation where the volunteer is directed to respond to one target position
- to measure reaction times in the same volunteers in a more complex situation where the volunteer responds with one arm to a series of targets
- to measure reaction times in the same volunteers when the choice includes which arm to move and a series of targets is available
- to investigate how the duration of delay between get ready and go signals affects the reaction time
- to identify an experimental protocol for future experiments on reaction time, choice and delay
- to investigate if reaction times are different for correct and incorrect responses during the choice experiments

The results of these experiments will be used to establish a testing protocol for all future experiments described in later chapters.

3.3 METHODS

The basic experimental condition is described in chapter 2. In the first no choice study, only 1 target is used and the volunteers sit before the target. The distance separating them is the length of the subject's arm plus 10 cm and the target is positioned to be at the level of his/her shoulder. In each run the volunteer made 8 responses. There was a randomised delay of 1-9 seconds between the 'get ready' and 'go' signals. These delays were generated automatically by the software in the device. The randomisation of the order of the *trials* is shown in Appendix III, Table 3.1, page 180.

In later experiments three targets were used. They were positioned 30 cm left and right of the central target. The reaction timer generated random delays as before. The sequence of targets for the volunteer was randomised. Details of the randomisation process are given in Appendix III, Table 3.2, page 181

In this situation 12 trials each time were used to measure the choice reaction time in 2 conditions: dominant and either arm. After each action the volunteer will be informed if the prediction was right or wrong. He/she gets feedback by the device, through green and red lights, as explained in Chapter 2.

In the second section two 20 trial sequences were tested. The series are random. The volunteers touched the targets using their dominant arm.

The number of data for each person is now adequate for further data processing on the reaction time of positive or negative responses.

3.4 VOLUNTEERS

Each meeting began with subject being welcomed by the experimenter, informed on the basic goals of the experiment, and receiving a briefing on the procedures of the experiment. He/she was asked to read and sign a consent form.

All experiments were conducted in a quiet laboratory with a minimum of distractions.

21 undergraduate and postgraduate students volunteered. They were aged between 17 to 50 years. Six men and 6 women took part in the measurements of reaction times in no choice and choice experiment, in which the volunteers could use dominant and either arm to respond. A further 9 volunteers, 5 men and 4 women took part in experiments where only their dominant arm in choice situation was used.

The advice was given to stop at any time, if the subjects wished. The experimenter was ready to answer any volunteer's question. There was an initial short training session for the volunteer to let him/her become familiar with the device and the behaviour**.**

3.5 STATISTICS

The data on the first experiments, on simple choice and on the relationship between no choice and choice reaction time, were processed using t test, comparing the two means. The statistical analysis of delay and correct, incorrect answer variables needed a different procedure. One way ANOVA was used to compare the values of the dependent variables: the nine conditions of the delay, from 1 to 9 seconds, and the two conditions of the response, correct and incorrect.

3.6 REACTION TIME RESULTS

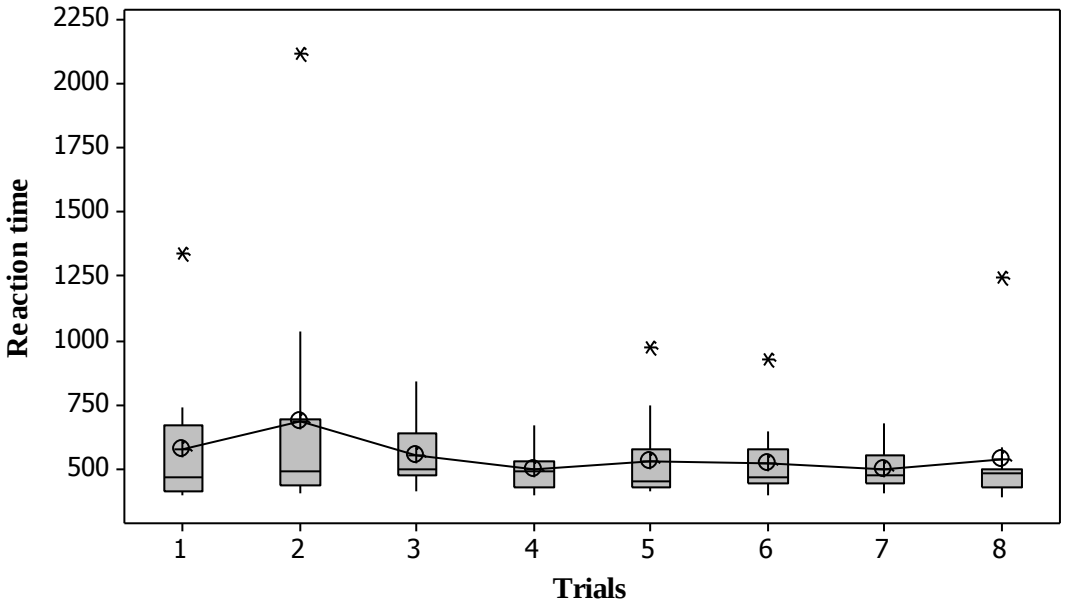
Table 3.3 shows the reaction times measured in 8 trials, in no choice condition, by 12 volunteers. In these experiments the volunteer was directed to the central target first, later on to the external and internal pad. The pad 2 data show the range of reaction times measured. The shortest reaction time is 394 msec. and this is well within the range found in previous publications. Some volunteer shows very long reaction times. These are highlighted in the table. They are beyond the cut off time of 800 msec. proposed in chapter 2.

Pad 2 data										
Subject	**Trial number and reaction time (msec.)**									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Mean**	**Mean with deletion**
S1	744	619	664	671	746	587	570	587	648	648
S2	636	601	514	599	456	548	466	494	539	539
S3	433	475	**844**	472	424	474	438	**1245**	601	**453**
S5	686	505	506	507	597	452	605	477	542	542
S6	**1338**	**1035**	478	479	528	409	470	494	654	**476**
S7	404	410	487	513	420	**923**	421	394	496	**436**
S8	452	**2117**	739	399	448	468	409	485	690	**486**
S9	396	466	420	431	438	446	492	410	437	437
S10	485	723	580	520	**970**	484	505	485	594	594
S11	443	406	418	435	453	651	462	486	469	469
S12	514	475	472	538	466	468	682	501	514	514
S13	397	433	486	430	411	403	481	401	430	430

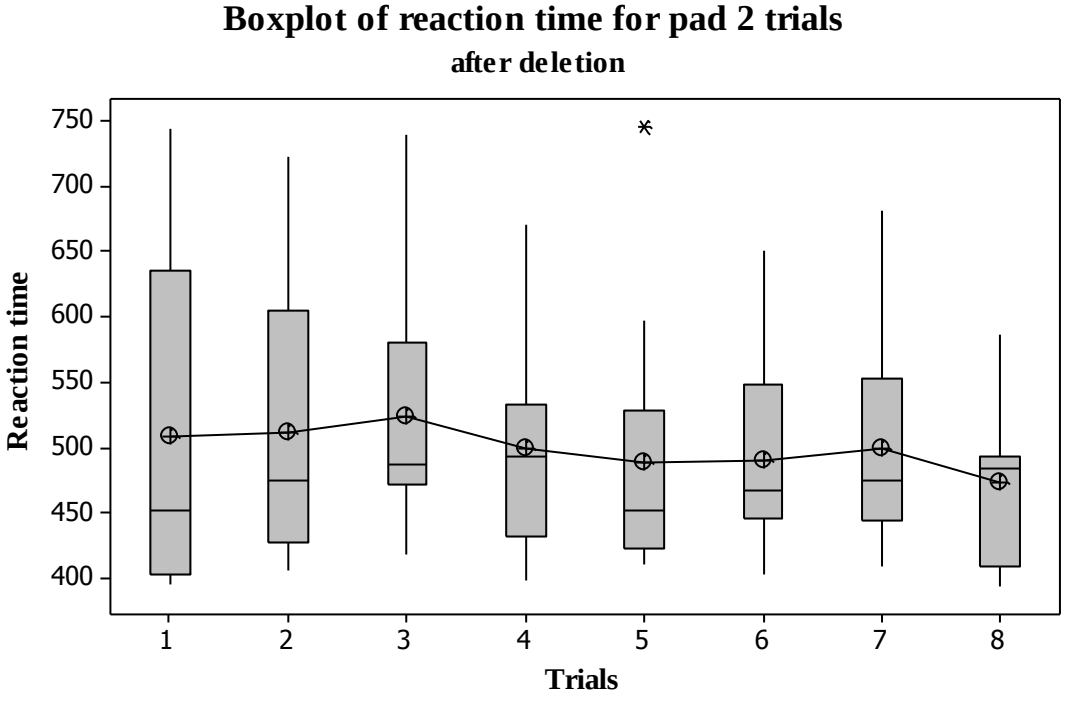
Table 3.3
This presents the data of pad 2 for 12 subjects and the mean for each subject, without and with deletion. Six numbers are 800 msec. longer. They are not included in the mean and not computed. The table shows these numbers in bold.

The case for rejection of these long values is made below. The long times do not represent typical behaviour in no choice condition and the inclusion of high and unusual numbers upsets the calculations of the means. For example, volunteer 7 has seven reaction times between 394 msec. and 513 msec. and one very long reaction time more than twice the duration of the other seven.

This can be clearly seen in figure 3.1. The boxplots of the data before and after deletion show how much the long reaction times, clearly a mistake in no choice experiments, affect the means and, at the end, the final results.



A



B

Fig. 3.1 A and B
The figure presents the boxplots of the data for each trial before and after deletion.

The same no choice experiment was repeated directing the volunteers to only the left target, pad 1, using the left arm, and only the right target, pad 3, using the right arm.

All the data are synthesized by Figure 3.2 A and B. The histogram in panel A shows the distribution of all reaction times measured in this no choice experiment without deletion. Most of the results are inside a small range of reaction times. The trend is far from a normal curve distribution. The histogram of panel B presents the data after deletion; the most frequent results are between 400 and 500 msec. It shows, on the right of the figure, a descending slope of the high reaction time values and on the left just few elements; the first two suggest that few people had very quick reaction times.

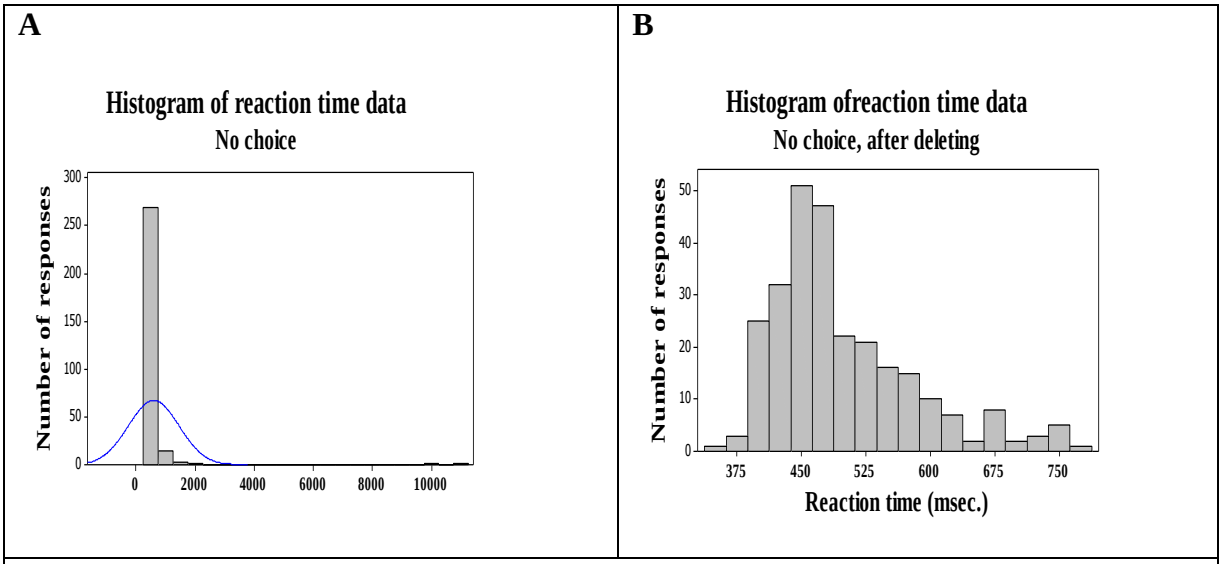


Figure 3.2 A and B
The histogram in panel A shows the distribution of the reaction time data from pad 1, 2 and 3, from all the subjects in no choice condition. The histogram in panel B shows the spread of the same data after deleting the values above 800 msec.

The data in figure 3.2 were tested for normality using Ryan Joiner plots. These are shown in figure 3.3. The whole data set are shown in panel A and it is again clear that the very long reaction times lie far from a normal distribution. The mean is 551 msec., standard deviation 232 and the p value < 0.010. The data set after deletion is shown in figure 3.3

B. The distribution is now much closer to normal but there are rather too few very short and very long reaction times. The mean is 501 msec., standard deviation 63 and the p value < 0.010.

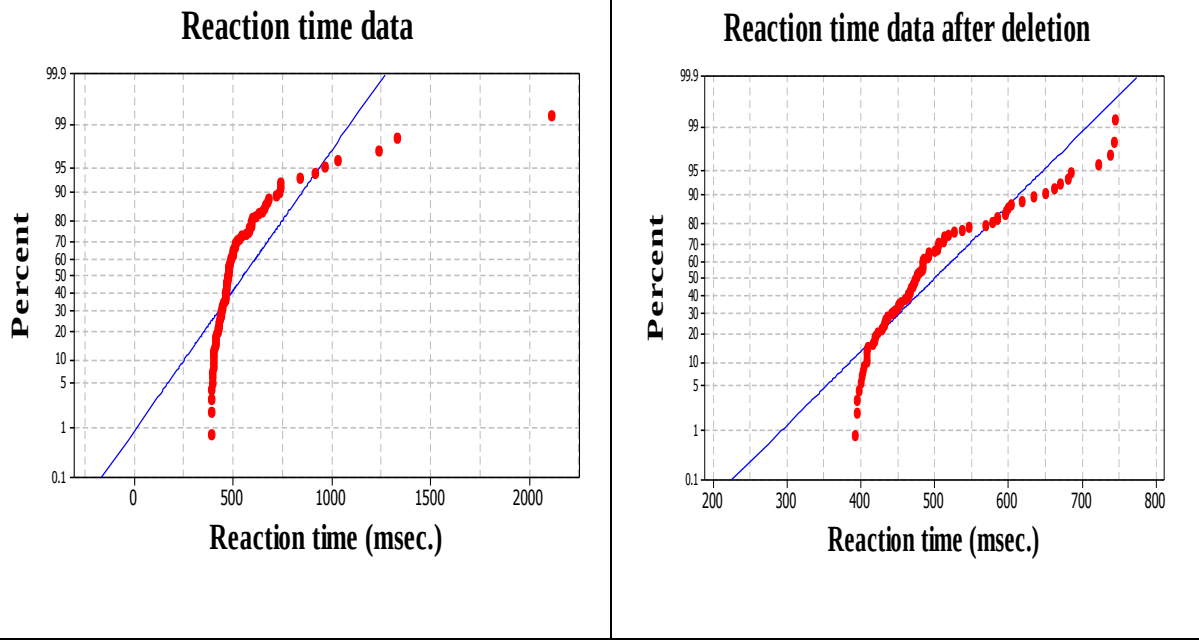


Figure 3.3 A and B
The graph in panel A shows the deviation of the set of data from normal distribution.. Standard deviation confirms their dispersion. Panel B presents a reduced deviation from normal values, if compared to the previous image.

As presented in Table 3.4 A, the mean reaction times, calculated after deleting the values greater than 800 msec., were 502 msec. ± sd 53 msec. for pad 1, 506 msec. ± sd 80 msec. for pad 2 and 496 msec. ± sd 57 for pad 3. The target position did not significantly affect the time of reaction.

Means of reaction time data for the 3 pads in no choice condition						
Sub.	**Pad 1**	**StDev**	**Pad 2**	**StDev**	**Pad 3**	**StDev**
1	619	51	648	70	598	35
2	480	48	539	67	495	48
3	405	48	509	149	431	36
5	632	81	542	79	544	77
6	465	30	476	39	520	85
7	459	41	436	46	439	35
8	467	38	474	112	454	40
9	510	84	448	30	454	58
10	600	102	589	177	543	87
11	453	43	478	78	492	41
12	488	52	500	83	517	96
13	448	16	435	35	466	42
Mean	**502**		**506**		**496**	

Table 3.4 A

The table shows the means and standard deviations of the data for pad 1, 2 and 3 for each subject.

Table 3.4 A shows the results of subjects who have right or left dominant arms. Tables 3.4 B and 3.4 C propose a comparison between the data of these 2 groups of people, touching pad 1, 2 and 3. The left dominant people of the group are quicker than right dominant subjects. It is not possible to generalize this suggestion, because 3 subjects are too few to find a valid relationship. The reaction time differences among the 3 pads for each right/left category are again not significant.

Reaction time data of right hand subjects			
Subject	**Pad 1**	**Pad 2**	**Pad 3**
1	619	648	598
2	480	539	495
3	405	509	431
5	632	542	544
6	465	476	520
9	510	448	454
10	600	589	543
11	453	478	492
13	448	435	466
Mean	**512**	**518**	**505**

Table 3.4 B
The table presents the reaction times of the right hand subjects.

Reaction time data of left hand subjects			
Subject	**Pad 1**	**Pad 2**	**Pad 3**
7	459	436	439
8	467	474	454
12	488	500	517
Mean	**477**	**470**	**470**

Table 3.4 C
The table presents the reaction times of the left hand subjects.

In a second series of experiments choice situation is tested. The target position is touched by the dominant arm or by the arm near to the pad. Each volunteer has to respond to one of three target positions using the dominant arm in a series and either arm in another one. In the first case the volunteer lifts the dominant arm to the shoulder level during the delay time, and touches the target after the "go" signal, when reaction time is measured. In the second case the arms are down at the body side and the action of arm lifting and target touching is performed by one of the two limbs after the "go" signal. In the two sequences the focal actions starts at different times. The expected different values will help to choose the most appropriate behaviour for the next experiments.

The pad position was left, central and right as before. In these experiments the volunteer in the first sequence made 12 responses with their dominant arms and in the second sequence 12 with either arm. The mean data, edited as before to eliminate very long reaction times, are presented in table 3.5 A. The means have the same value, 540 msec., standard deviation means are 61 for dominant arm and 72 for either arm sequences. Paired t-test gives a p value of 0.978.

Means of reaction time data for dominant and either arm in choice condition				
Subject	**Dom Arm**	**StDev**	**Either Arm**	**StDev**
1	651	38	702	60
2	546	55	552	54
3	428	33	425	133
5	646	79	624	57
6	550	88	517	67
7	432	49	434	62
8	502	54	488	57
9	494	52	456	50
10	637	64	681	74
11	582	96	555	76
12	504	73	539	91
13	504	54	502	89
Mean	**540**		**540**	

Table 3.5A
The table shows the means and standard deviation of the subjects in choice condition, when they touch the target with the dominant arm or with either arm

The same results are shown in the boxplots in figure 3.4.

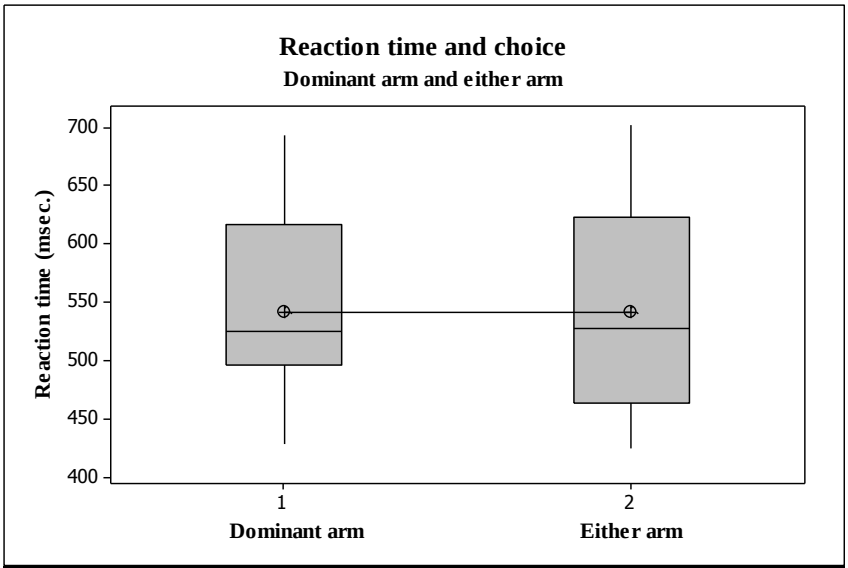


Figure 3.4
The figure shows the relationship between reaction time and choice in dominant arm and either arm conditions.

Table 3.5 B and C show the reaction time of right and left hand subjects when the same volunteers touch the switches using only the dominant arm or the nearest arm to the chosen pad. The time difference between the 2 groups is maintained, left arm people are quicker. Again a proper comparison between the 2 categories of people is not valid, because the results of only 3 subjects cannot be generalized.

Reaction time data of right hand subjects for dominant and either arm		
Subject	**Dominant**	**Either arm**
1	651	702
2	546	552
3	428	425
5	646	624
6	550	517
9	494	456
10	637	681
11	582	555
13	504	502
Mean	**560**	**557**

Table 3.5 B
The table presents the reaction times of the right hand subjects.

Reaction time data of left hand subjects for dominant and either arm		
Subject	**Dominant**	**Either arm**
7	432	434
8	502	488
12	504	539
Mean	**479**	**487**

Table 3.5 C
The table presents the reaction times of the left hand subjects using dominant and either arm.

Table 3.6 shows the mean reaction time when the volunteer has to choose between the 3 targets. 4 subjects had mean reaction times below 500 msec., 5 had mean times between 500 msec. and 600 msec. and 3 had values between 600 msec. and 700 msec. The mean of all the choice data is 540 msec. The associated standard deviation, the mean is 67, shows that each volunteer still had a broad range of reaction times.

Choice reaction time		
Subject	**Mean Choice Reaction Time (msec.)**	**St Dev**
S1	675	49
S2	549	54
S3	426	83
S5	671	68
S6	533	77
S7	433	55
S8	494	55
S9	475	51
S10	655	69
S11	555	86
S12	522	82
S13	503	71
Mean	**540**	

Table 3.6
The table shows the mean reaction time and the standard deviation of the data for each subject, who is choosing among three targets.

Looking at the basic parameters of the experimental behaviour, the first relationships are now tested: the values of no choice and choice actions and the values of dominant and either arm movements.

Table 3.7 presents the comparison between no choice and choice reaction times in these twelve subjects. Ten volunteers had shorter mean reaction times in the no choice experiment. The means are: 501 msec., 63 the standard deviation in no choice situation and 540 msec, 67 standard deviation choice conditions. This difference is significant (paired t-test, p value is 0.006).

No choice and choice reaction time				
Subject	**Mean reaction time (msec.)**			
	No choice	**St Dev**	**Choice**	**St Dev**
S1	622	52	675	49
S2	505	54	549	54
S3	448	77	426	83
S5	573	79	671	68
S6	487	51	533	77
S7	445	42	433	55
S8	465	63	494	55
S9	471	57	475	51
S10	577	122	655	69
S11	474	54	555	86
S12	502	77	522	82
S13	450	31	503	71
Mean	**501**		**540**	

Table 3.7
The table shows the reaction time and standard deviation of each subject touching one target or choosing between three targets.

The boxplots in figure 3.5 show the different distribution of the data and the different means.

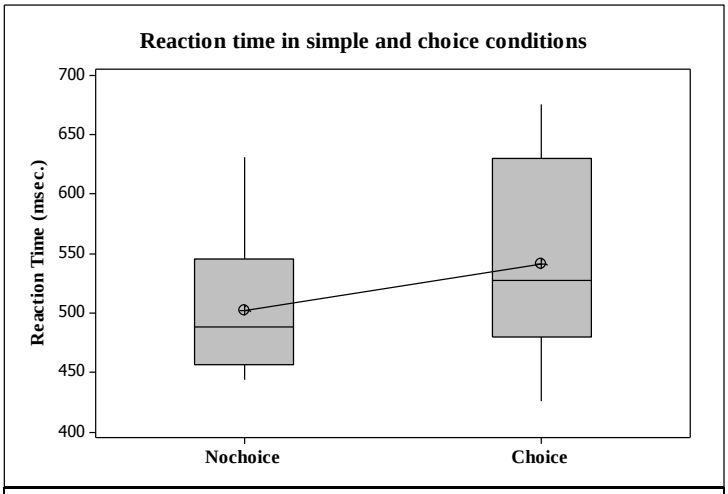


Figure 3.5
The figure presents the reaction time of volunteers touching one target or choosing one of the three targets.

3.6.1 REACTION TIME, CORRECT AND INCORRECT ANSWER

A new final analysis was performed by 9 subjects to investigate if reaction times for correct choice responses were different from incorrect choice responses. This will give a new basic parameter useful at the next stages of the research. Each volunteer, from sitting position, made 2 sets of 20 responses, using the dominant arm. Their movements were directed at one among 3 target positions. The summary data are shown below in table 3.8 and 3.9.

Table 3.8 compares the reaction times in the 2 sets. One way ANOVA was applied to compare the data of the first and the second series. The means, 593 msec. and 595 msec., are very similar. P value was 0.963, not significant.

Reaction Time during Set 1 and Set 2		
Subject	**Set 1**	**Set 2**
	Mean Reaction Time (msec.)	**Mean Reaction Time (msec.)**
S1	619 ± 94	623 ± 105
S2	525 ± 114	501 ± 124
S3	588 ± 48	572 ± 28
S5	579 ± 64	580 ± 45
S8	707 ± 50	701 ± 54
S9	613 ± 80	528 ± 50
S10	629 ± 105	627 ± 119
S13	572 ± 145	569 ± 121
S14	509 ± 88	652 ± 97
Mean	**593 ± 59**	**595 ± 62**

Table 3.8
The table shows the mean reaction times and the associated standard deviations for the first and the second set of data for the Scottish volunteers.

The synthesis of the values is presented in table 3.9.

Set 1 and Set 2 Reaction Time	
Subject	**Reaction time (msec.)**
S1	621 ± 99
S2	513 ± 118
S3	580 ± 92
S5	579 ± 55
S8	704 ± 51
S9	570 ± 78
S10	628 ± 111
S13	570 ± 132
S14	580 ± 116
Mean	**594 ± 95**

Table 3.9
The table shows the synthesis of the mean reaction time data and the standard deviation for each subject.

In table 3.10 one way ANOVA was applied to compare the data of correct and incorrect answers. The means, 594 msec. and 605 msec., were not significantly different. P value was 0.419. The result remains inside the degree of error rate.

The subjects gave 142 correct responses and 210 incorrect responses, the effect of chance.

Reaction time and number of correct and incorrect responses in the 2 sets of data

Subject	Reaction time of correct responses	Number of correct responses	Reaction time of incorrect responses	Number of incorrect responses
S1	546 ± 87	7	639 ± 94	32
S2	497 ± 112	18	523 ± 121	22
S3	655 ± 104	9	660 ± 89	31
S5	568 ± 40	18	590 ± 64	11
S8	680 ± 38	16	716 ± 53	23
S9	570 ± 85	21	568 ± 74	19
S10	639 ± 123	18	615 ± 98	22
S13	585 ± 129	12	564 ± 136	26
S14	605 ± 110	17	570 ± 121	23
Mean	**594**	142	**605**	210

Table 3.10
The table shows the times of reaction, the number of correct and incorrect responses and the standard deviation for each subject in sequences 1 and 2.

3.6.2 REACTION TIME AND DELAY

The same data of the previous experiment were analyzed to investigate the effect of the delay, the time between the "get ready" and the "go" signal, on the subsequent reaction time. Table 3.11 shows pooled data from 249 trials in all 9 subjects. The data are organized by delay duration and mean reaction times are shown.

Range of delay and Reaction Time

Delay time	Mean RT	St Dev	Number of events
1 sec.	582	92.1	43
2 sec.	603	75.1	16
3 sec.	541	100	22
4 sec.	516	93.9	28
5 sec.	505	104	30
6 sec.	498	70.5	18
7 sec.	530	82	29
8 sec.	482	90.8	38
9 sec.	538	135	25

Table 3.11
The figure shows reaction times, standard deviation and number of events related to the range of delay time, from 1 to 9 seconds.

The boxplot in figure 3.6 summarizes the results. It shows that mean reaction time is little affected by the duration of the delay. The shortest mean reaction time was 482 + 91 msec. for the delays of 8 seconds. The longest mean reaction time was 582 + 92 msec. for the 1

second delays. These differences were not statistically different (ANOVA, p value 0.289).

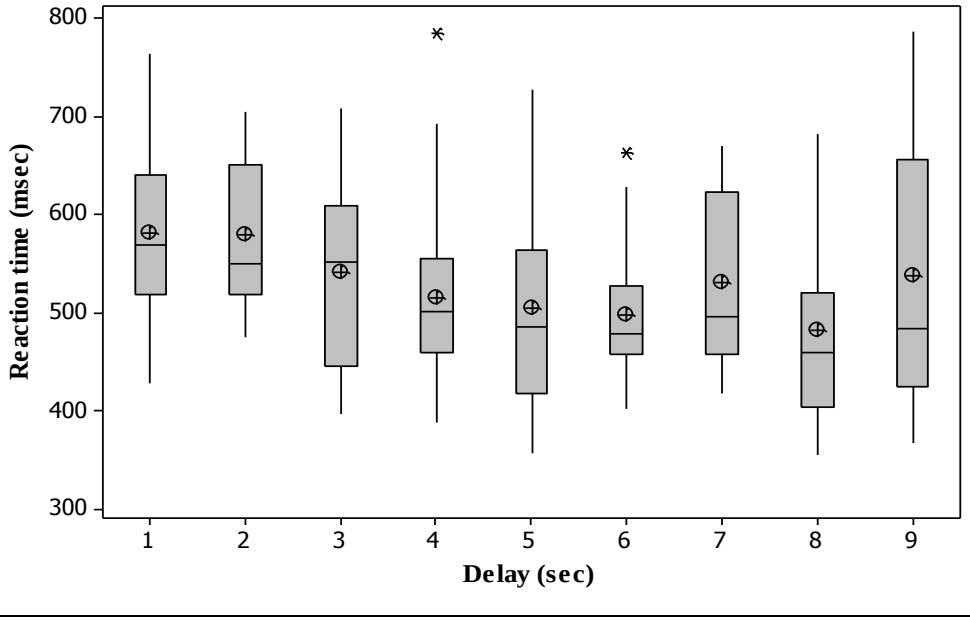


Figure 3.6
The figure shows the time of reaction related to choice and the range of delay, from 1 to 9 sec.

3.7 DISCUSSION

The overall aim of the experiments described in this chapter was to fix and to check an experimental protocol suitable for the next stages of the research and to ensure the reaction timer and associated software operated satisfactorily.

Specific aims were established:

1) to measure reaction times in a series of volunteers in no choice situation where one

responds only to one target position.

The data show that there is no significant difference in no choice reaction time, when subjects touch each of the 3 targets using the nearest arm: the left for pad 1, the right for pad 3 and the dominant for pad 2.

The differences are not significant when the reaction times of the subjects, right or left arm dominant, are compared in no choice condition.

This is not consistent with the studies on right, left arm preference, pointing at speed or movement accuracy, and with the studies on reaction time for ipsilateral and contralateral targets, proposed by Carson (1989, 1990), Carson et al. (1995), Van Donkelaar and Franks (1991) and Mieschke et al. (2001).

2) to measure reaction times in the same volunteers in a more complex situation where the volunteer responds to a series of targets with one arm, the dominant or the nearest to the chosen pad.

No choice reaction time values, compared to the choice ones, confirm that choosing takes more time than the simple reaction to the "go" light. The difference is significant. This is consistent with the studies on the field of Umilta' and Nicoletti (1990), Rosenbaum and Kornblum (1982).

3) to measure reaction times in the same volunteers when the choice includes which arm to move and a series of targets is available

Two ways were proposed for the choice behaviour: touching the target using the dominant arm and either arm.

The data confirm that there is no reaction time difference between the time of the action performed by the dominant and non dominant arm. Again, even in a more complex situation, the different attributes in right and left arm action compensate each other.

The same results were found when people, right or left arm dominant, perform dominant or either arm focal action.

Schluter et al. (2001) and Ortiz et al. (1993) studied the choice situation and focal action. They emphasized the discriminative processes, which affect the choice. According to the data from the experiments, even if reaction time values of dominant and non dominant arm were similar, the mean reaction times are much higher than the results from simple choice.

4) to investigate if there is a difference between reaction times for correct and incorrect answers

The first experimental situation cannot be representative of a proper guessing experience, which includes clues useful for the prediction. The factor will be examined later on. Here it is useful to fix the first connections between correct and incorrect answers, even if the sequences are random, so the positive responses are the result of chance. The means are similar and confirm that the difference is not significant. So the subject reaction times were not affected by the positive or negative feedback given by the device and there was no positive or negative effect of feedforward, as suggested by Rabbit (1966), Laming (1979), Monsell (1978), Jonides et al. (1998), Kawato et al. (1987).

5) to investigate how the duration of delay between get ready and go signals affects the reaction time

The data were analysed to investigate the effect of a range of delays, from 1 to 9 seconds, on reaction time. The magnitude of the delay between get ready and go signals does not have a significant effect on the mean reaction times.

The figures do not show big differences. The higher values linked to the delay of 1 and 2 seconds suggest that the signal was not expected early. Medium values were found between 4 and 9 seconds. The studies from Requin et al. (1991), Laming (1979), Niemi and Naatanen (1981), Los and Van der Heuvel (2001) suggest differences in reaction times for short, unexpected foreperiods and also for long foreperiod, which cannot be measured and managed by the subject, so he/she cannot be ready at the right time.

These results gave a basic idea on the way delay affects the volunteers time of reaction. The connection will be explored in one of the next experiments.

6) to identify an experimental protocol for future experiments

The devices were checked and the first experiments gave some basic parameters on the variables involved: reaction time, choice, arm, delay, correct and incorrect answer. They will be a useful comparison in the next experiences, focused on one variable each time. It was concluded that the protocol is workable.

According to this first level of results, the protocol of the next experiment will be: choice situation, dominant arm performing the focal action, random delay and the volunteer in sitting position in front of the reaction time device.

The time of reaction will be analysed with or without reward.

CHAPTER 4

THE EFFECT OF REWARD ON REACTION TIME

4.1 INTRODUCTION

The experiments described in this chapter aim to investigate the relationship between reward and reaction time during choice reactions. Two 20 trial sequences are proposed. For the second one only a reward is offered to the person who gets most choices correct. The condition may decrease the time the volunteers take during option selection.

The choice reaction time for each volunteer is measured using the protocol described in the previous chapter i.e. 20 trials in which the volunteer is directed to one of three targets. There is a pseudo-random delay between the get ready and go signals. Then on a second testing session, immediately after, the protocol is repeated. At this stage the volunteers know they are in competition with the others. There is a reward for the volunteer who gets most choices correct rather than the fastest person. The focus is not on the conditioning of a direct, immediate benefit for the "right" response, but on the effect of developing the probability to win it. It was hoped that this would reflect what happens in the real life, for example for a student planning to pass the exams to get a bursary.

4.2 AIMS

The aim of these experiments was to compare the choice reaction times in a series of volunteers in two conditions: when a reward was offered and when it was not offered. The experimental hypothesis predicts a quicker reaction time for the "rewarded" sequence.

4.3 METHODS

The approach, methods and materials are substantially the same as those used during the experiments described in chapter 3.

One important difference was that the subjects are informed about their chance to win a cash prize during the second phase of the experiment. £ 100 was offered to the volunteer, who had the greatest number of correct answers.

4.4 VOLUNTEERS

These experiments took place in Italy, at Universita' agli Studi di Padova. The volunteers were 14 undergraduate students, 6 males and 7 females. They were all in good health. They were recruited from the students of the Corso di Laurea in Scienze Motorie, Facolta' di Medicina. The Council of the Corso di Laurea in Scienze Motorie at Universita' agli Studi di Padova gave the authorisation to carry out the experiment.

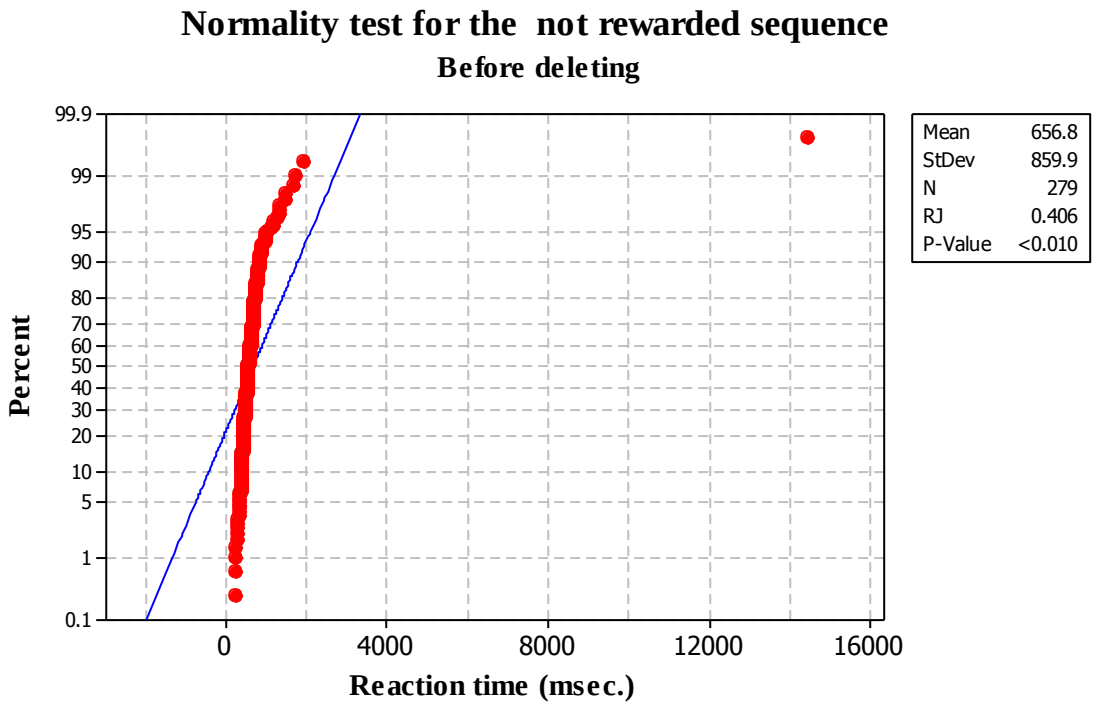
4.5 STATISTICS

Normality test was first applied. After deletion One Way ANOVA analyzed the data in two different conditions.

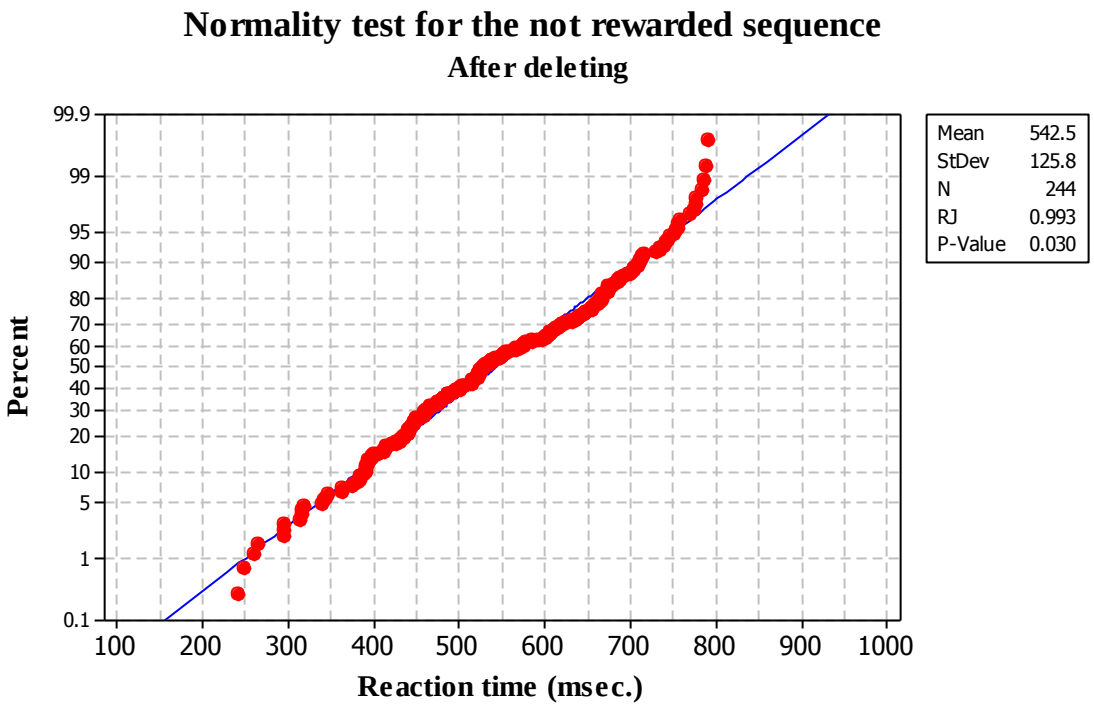
4.6 RESULTS

The data in sequences 1 and 2 are presented in figure 4.1 A and C. It shows in the two cases very long reaction times and a not normal distribution.

The data were edited to eliminate the values above 800 msec. Among the initial 279 trials in sequence 1 and 2, 35 trials were deleted in the not rewarded series and 17 in the rewarded one. Their normality was confirmed using similar process to those described before. Figures 4.1 B and D present the red lines of the data basically corresponding to the blue lines, the sign of normally distributed values. Some trials show figures very close the given limit of 800 msec. Their number was more than expected.



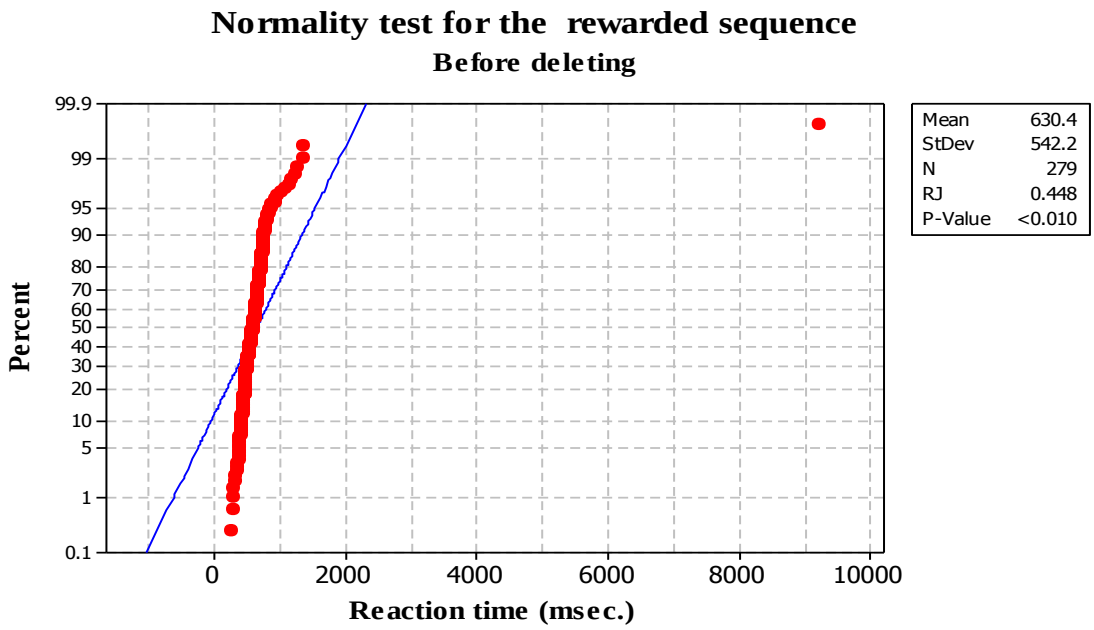
A



B

Figure 4.1 A, B
The figure shows the results of Normality test for the not rewarded sequences before and after the deleting.

C



D

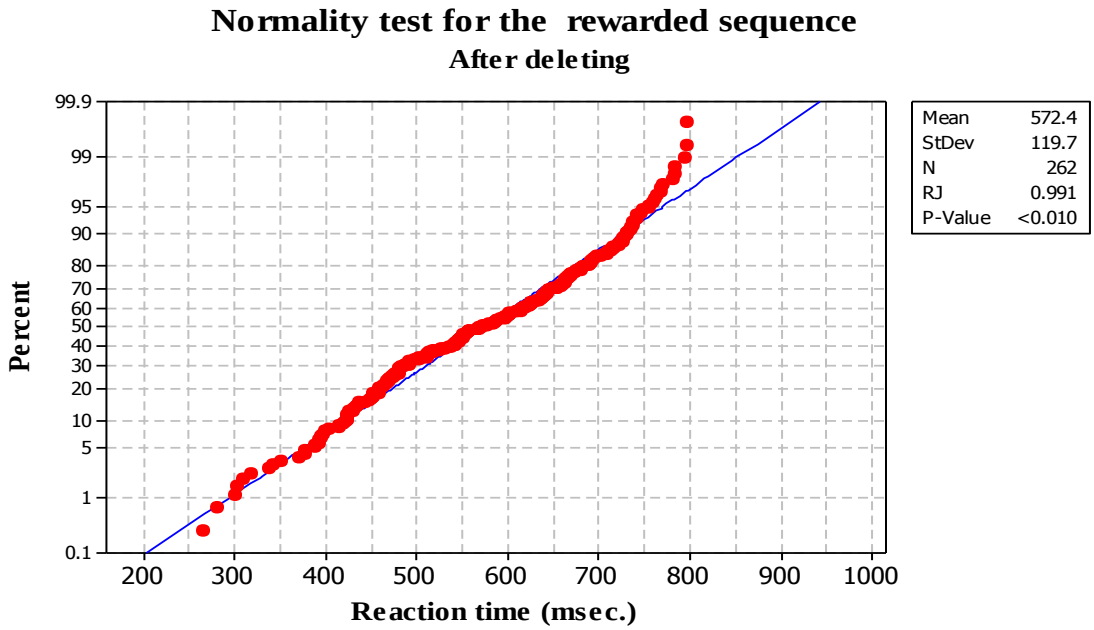


Figure 4.1 C, D
The figure shows the results of Normality test for the rewarded sequences before and after the deleting.

The mean reaction times of the data and the number of correct answers are presented in table 4.1. The columns headed ‘no reward’ and “reward available” show the mean reactions times of volunteers during the not rewarded and the rewarded sequences. Comparison of the two different data sets with 2 sample t test confirms that the means are significantly different (p value 0.006), that is the subjects were quicker in the first set.

Reaction Time Reward and correct answers		
	No Reward	**Reward Available**
Subject	**Mean Reaction Time (msec.)**	**Mean Reaction Time (msec.)**
S 1	469 $\pm$ 67	478 $\pm$ 56
S 3	475 $\pm$ 94	451 $\pm$ 68
S 4	568 $\pm$ 97	600 $\pm$ 85
S 5	556 $\pm$ 62	540 $\pm$ 66
S 6	467 $\pm$ 110	493 $\pm$ 121
S 7	685 $\pm$ 43	704 $\pm$ 53
S 9	576 $\pm$ 78	561 $\pm$ 62
S 10	426 $\pm$ 125	522 $\pm$ 119
S 12	487 $\pm$ 123	588 $\pm$ 101
S 13	725 $\pm$ 48	710 $\pm$ 33
S 14	449 $\pm$ 114	441 $\pm$ 101
S 15	627 $\pm$ 87	649 $\pm$ 71
S 16	665 $\pm$ 73	684 $\pm$ 54
S 17	509 $\pm$ 88	642 $\pm$ 88
Mean	**542** $\pm$ 126	**572** $\pm$ 120

Table 4.1
The table shows the mean reaction times and the associated standard deviations for the Italian volunteers. The column on the right presents the data when a reward is available, the column on the left the unconditioned data in the same volunteers.

The reaction times of each volunteer were divided into two groups: those with correct and those with incorrect answers. T test gave a not significant value, 0,462. The mean reaction times and the total number of correct answers are presented in table 4.2.

Reaction Time **Correct and Incorrect Responses**			
Subject	**Mean Reaction Time (msec.)**		**Mean Reaction Time (msec.)**
Subject	**Correct responses**	**Number of correct answers**	**Incorrect responses**
S 1	470 ± 50	19	475 ± 69
S 3	477 ± 72	14	456 ± 82
S 4	579 ± 86	20	586 ± 97
S 5	551 ± 54	13	546 ± 69
S 6	522 ± 89	8	481 ± 122
S 7	701 ± 44	11	691 ± 52
S 9	655 ± 68	10	599 ± 80
S 10	459 ± 106	14	463 ± 94
S 12	537 ± 90	12	541 ± 104
S 13	737 ± 26	11	704 ± 40
S 14	448 ± 108	15	442 ± 110
S 15	647 ± 89	15	638 ± 82
S 16	693 ± 53	15	663 ± 69
S 17	586 ± 91	17	679 ± 91
Mean	**576** ± 73	**194**	**569** ± 85

Table 4.2
The table shows the mean reaction times, the associated standard deviations and the total number of correct answers for correct and incorrect responses for each volunteer.

The reaction times associated with correct and incorrect answers were divided for both not rewarded and rewarded series of tests.

In Set 1 the subjects got 97 correct responses, in Set 2 the number was the same, 97. Subject S1 gained the reward. The data are presented in table 4.3.

Reaction Time and Reward						
	No Reward			Reward Available		
Subject	**Mean 1 RT Correct (msec.)**	**Mean 1 RT Incorrect (msec.)**	**Number Correct Answers**	**Mean 2 RT Correct (msec.)**	**Mean 2 RT Incorrect (msec.)**	**Number Correct Answers**
S 1	466	471	8	475	480	11
S 3	504	461	8	451	451	6
S 4	569	566	12	589	607	8
S 5	547	560	7	555	552	6
S 6	464	467	4	480	496	4
S 7	692	680	6	710	702	5
S 9	655	588	1	544	571	9
S 10	390	410	5	529	517	9
S 12	451	502	8	623	581	4
S 13	756	701	6	718	707	5
S 14	443	452	7	454	432	8
S 15	620	635	10	674	642	5
S 16	677	657	8	710	670	7
S 17	512	508	7	651	630	10
Mean	**553**	**547**	**97**	**583**	**574**	**97**

Table 4.3
The table shows the mean reaction times of correct and incorrect responses in the not rewarded and rewarded sequences and the number of correct answers .

4.7 DISCUSSION

The aim was to give an answer to a preliminary question: do reaction times reduce, when a reward is offered for the best guesser? These experiments compared the choice reaction times in a series of volunteers in two conditions: when a reward was offered and when it was not offered.

The effect of the variable was isolated, presenting a first set of trials without it and the second one with it. It was maintained the same structure of the last experiment presented in Chapter 3.

The data analyses confirm that:

- there is no significant difference between the not rewarded and the rewarded sequences: 542 and 572 msec. The subjects took more time to react to the second one.
- there is not significant difference between the total means of correct and incorrect answers: 576 and 569 msec., and the same means for Set 1: 553 and 547 msec., and for Set 2: 583 and 574 msec.
- there is no difference in number of correct answers between the not rewarded and the rewarded sequence. This is possible because the series are random, so the figures of correct or incorrect responses are the result of chance.

The offer of a reward does not make any significant difference in reaction time. Some volunteers were slower in the reward sequence, some were quicker. The final mean data gave balanced numbers.

At these conditions, the data disagree with other studies in the field. Reward, in this case, does not encourage "associations between responses and outcomes", that is correct answers (Dickinson and Ballein, 1994), nor does it "reinforce the strategy used before", or "influence memory process" (Adam et al. 2010, Ramnani and Miall, 2003, Schultz, 1998).

The results might correspond to the behaviour of a normal population or might be a subjective outcome of that particular unrepresentative small group of subjects.

The central point is the reward factor. One hundred pounds was estimated a reasonable amount for University students to activate the processes described above, included taking part in a competition to get them. The mere possibility of reward may be not a sufficient stimulus. Instead an immediate, tangible bonus can make the difference. Or the issue could be the amount of the prize. How can a prize be defined, in terms of high, low and middle level, inside the experimental situation and inside the group of subjects?

CHAPTER 5

REACTION TIME AND DELAY, THE TIME BETWEEN 'GET READY' AND 'GO' SIGNAL.

5.1 INTRODUCTION

The experiments described in this chapter continue the investigation of factors affecting choice reaction times. The experiments described in chapter 3 used a pseudo randomised delay lasting between 1-9 seconds. After the initial first level examination on delay, discussed in chapter 3, the variable is now isolated and examined in specific experiments, which test two ways in which the stimulus can be presented, random and fixed. In one series of tests the established protocol is followed and a randomised delay of 1-9 seconds separates the get ready and go signals. In the other condition, the delay is fixed at 6 seconds. The choice of the specific time comes from the previously analyzed results. The purpose is to test 2 sequences both at random and fixed delay, to be in the position to compare different results using the same basic arrangement.

As it was discussed in the Literature Review chapter, reaction time is related to preparation time, which starts before the go signal. The delay duration, the possibility of foreseeing or not foreseeing when the green light will appear may affect the condition to be ready at any time and the time of reaction.

Another perspective inside the same field is to verify what happens in the muscles during the foreperiod. EMG recording was undertaken to check contractions of representative muscles during option selection and choice time.

New specific aspects are also taken into account: the subjects are in a standing position, they perform using either arm, lifted from the side position to the chosen target after the green light.

Knowing the effect of the delay variable on reaction time and on the organism, the muscles, will help to focus on the next final experiment, on the topic which is the centre of the research: the sequence of events leading to the response.

The experimental hypothesis predicts: fixed delays will result in quicker reaction times.

5.2 AIMS

The double perspective and the reciprocal support of the data give the direction of the path to achieve the aims:

- to find differences in reaction time, the time of preparation, when random or fixed delay are applied
- to look for signs of preparatory activity in the muscles of the arms and legs associated with the time between the get ready and the go signals.

5.3 METHODS AND MATERIALS

Methods and materials were substantially similar to those used in chapters 3 and 4. There are some differences. Volunteers were tested on two days. On each day they were presented with 2 sequences of 20 trials with either random delays between the get ready and go signals or with fixed delays between the get ready and go signals. The sequences

are presented in Appendix III, table 5.1, page 182. The order of presentation of random or fixed delay sequences was planned. If, for example, on the first experimental day the random delay of sequence 1 was presented first, sequence 2 with fixed delay will follow. On the subsequent day the fixed delays in sequence 1 and the random delay in sequence 2 were used. This structure of the tests allows cross comparisons within the same type of delay or within the same sequence, to explore if the variations in reaction time data come from the sequence or from the different delays. The focal action is directed to three targets, as described in the previous experiments. The volunteers were given no information about the nature of the delays used. In addition, whilst the volunteers performed the reaction time experiments, EMG recordings were made from the left and right anterior deltoid muscles and the left and right soleus muscles. The EMG electrodes used during experiments were integrated into skin mounted preamplifiers. They have a rectangular shape 3 x 2 x 1 cm. They weighed 8.4 grams. Examples are shown in figure 5.1. The amplifier unit has 3 electrodes and a fixed gain of x 5000. Each of them is silver and is 0.5 cm in diameter. Two are connected to a differential amplifier. The third electrode is a common or earth electrode. There is a distance of 2 cm between the 2 recording electrodes. Its bandwidth was between 10 Hz and 1 KHz, -3db at these frequencies. The input impedance was 10 MOhms.

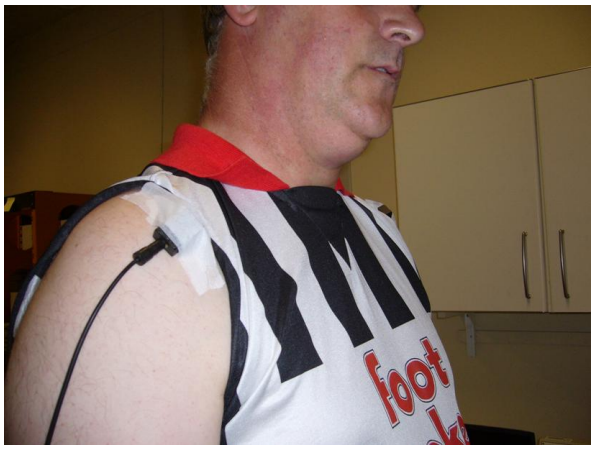
Figure 5.1
This photograph shows four skin mounted EMG amplifiers with integrated electrodes. Each amplifier is 3 cm. by 2 cm. by 1 cm. The spacing between the two recording electrodes is 2 cm.

The skin at the recording sites was prepared to improve electrical contact resistance. Fine sandpaper was used to abrade the skin and to remove hair. Any grease on the skin was removed with Blue Dot cleansing wipes.

The electrodes were attached with 3M Double-Stick Disks. Sigma Electrode Crème improved the contact resistance and the electrodes were fixed in place with Micropore TM tape. The electrodes positions are shown in figure 5.2 A and B. The amplified EMG signals were digitised by CED 1401 Micro Interface (C.E.D. Ltd, Cambridge, England) at a sampling rate of 5000 Hz and recorded *by* a computer. Data were processed using Spike 2 version 5.03. Digital filters available in Spike 2 were used to remove any offset in the signal before rectification.

Movement artefacts were also rejected by high pass filtering at 10 Hz. Each channel was rectified and smoothed through Spike 2 channel process functions. EMG averages were calculated using the ‘get ready’ signal from the reaction timer as a trigger. Averages of up to 10 seconds before and 5 seconds after the get ready signal we*re* calculated. This includes background EMG, any response at ‘get ready’, any preparation for movement and the movement itself.

A



B

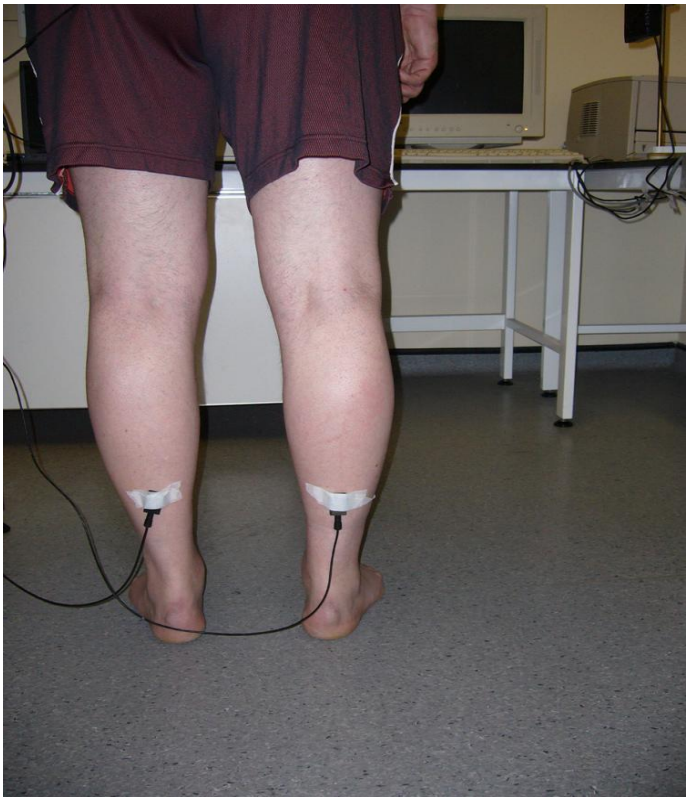


Figure 5.2 A and B
This shows photographs of a skin mounted EMG amplifiers in position. The upper photograph shows an amplifier over the right anterior deltoid of a volunteer. The lower photograph shows amplifiers in position over the left and right soleus muscles.

A specimen of typical experimental data is shown in figure 5.3. The figure shows 20 trials recorded over a period of about 5 minutes. The channels are in sequence from bottom up: the time scale, the fours channels of EMG, the trigger channel shows the instant of the ‘go’ signal derived from the channel above. The first channel, from the bottom, refers to right deltoid contractions, the second to right soleus, the third to left soleus, the fourth to left deltoid. The channel labelled ‘light’ indicates the illumination of the ‘get ready’ LED by an upwards deflection and the illumination of the ‘go’ LED by a downwards deflection. Thus the horizontal lower line shows the interval between successive trials and the horizontal upper line shows the delay period between ‘get ready’ and ‘go’. In this example a fixed delay series are shown.

The top two memory channels are added after the data capture to show which responses were identified as correct (4 trials in channel 7) and which as incorrect (16 trials in channel 8).

The EMG recording gives the synthesis of the information related to the contractions of the 2 representative muscles. It allows checking the reaction of muscles before and after the alarm and the go signal. This time is the focus of the discussion, which analyses the action from 2 perspectives: the time distance between the go signal and the switch touching and muscle activity before and after the light signals, that is preparation phase, choice and action. It also allows for the defining of timing and intensity of contractions as a function of the specific categories, the same used for reaction time, for example correct and incorrect answers.

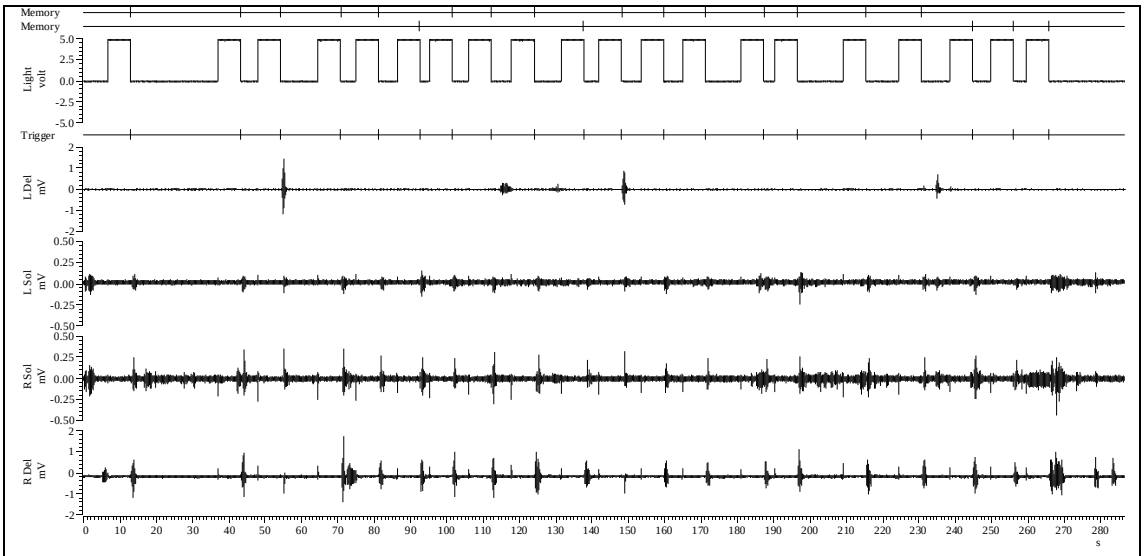


Figure 5.3
The figure shows the standard display of experimental data recorded over a period of about 5 minutes during which 20 trials are recorded. The figures show 4 channels of EMG and the LED illumination sequence. The EMG signals are shown after amplification.

Peri-stimulus averages of the EMG channels were calculated using the trigger, channel 7 and 8 markers. The EMG channels were high pass filtered, -3dB at 10 Hz and full wave rectified using Spike 2 before averaging. In general, the averages were constructed to show the period of 1.5 sec. and 6.5 sec. before the trigger and 0.5 sec after the trigger.

1.5 sec. is the time immediately before the go signal, an index of the preparation phase. The duration of the fixed delay was 6.5 sec., including an additional half a second ,that was used to investigate what happens before this standard time. The action is examined for 0.5 seconds after the trigger to have a more complete image of the contractions during the reaction.

5.4 VOLUNTEERS

12 students, 6 males and 6 females, aged between 21 and 35, took part to the experiments. They were drawn from the undergraduate and postgraduate members of FBLS, University of Glasgow.

The experimental protocol was reviewed and approved by the FBLS Ethics Committee for Non Clinical Research using Human Subjects.

5.5 STATISTICS

The distribution of reaction time in the experiments described in this chapter differed substantially from those in chapters 3 and 4. Specifically, most volunteers had many reaction times longer than the 800 msec. cut off used in previous chapters. Details of the values are described later in this chapter. It was decided not to reject 40% of the trials and to accept all the values. Means and standard deviations of random and fixed delay sequences were computed. Normality test was applied to the mean differences of the 2 delay conditions, for each subject, and the results showed a nearly normal distribution. The calculation of 95% Confidence Interval gave not significant outcomes.

5.6 RESULTS

The two devices recorded two different kinds of data. The Reaction Time data are presented first. The EMG results will follow.

5.6.1 REACTION TIME RESULTS

Each volunteer performed two sets of tests; one presented a get ready signal and then a go signal after a random delay between 1 and 9 seconds. The second series of tests used a fixed delay of 6 seconds between get ready and go signals. Half the volunteers did the fixed delay sequence first, the others started with the random delay series.

Many volunteers showed very long reaction times in both conditions. In the previous chapters, the reaction times longer than 800 msec. were deleted. Typically less than 10% of the data were rejected. Table 5.2 shows the effect of applying this criterion to the experimental data.

The reaction time data for subjects 6, 8 and 9 are similar to those seen in the previous chapters. Approximately 10-20% of the data would be rejected using the original cut off value for reaction times above 800 msec. However, subjects 7, 10, and 11 would have more than 90% of their data deleted. The deletion rate for the other subjects varies between 20 to 61% of the total trials. In summary, if the same cut off parameter is maintained, for random delay sequences, 208 trials among 480, have to be deleted 42% and for fixed delay sequences, 190 trials, among 480, have to be deleted 38%.

	Number of trials		Number of trials not rejected		Number of rejections		Percentage of rejections		Total
Subject	**Random**	**Fixed**	**Random**	**Fixed**	**Random**	**Fixed**	**Random**	**Fixed**	**Percent**
1	40	40	31	25	9	15	22%	38%	30%
2	40	40	15	16	25	24	42%	40%	41%
3	40	40	28	35	12	5	30%	12%	21%
4	40	40	28	23	12	17	30%	42%	36%
5	40	40	28	36	12	4	30%	10%	20%
6	40	40	35	37	5	3	12%	8%	10%
7	40	40	5	1	35	39	88%	98%	93%
8	40	40	34	37	6	3	14%	8%	11%
9	40	40	33	38	7	2	18%	5%	11%
10	40	40	5	3	35	37	88%	92%	90%
11	40	40	2	1	38	39	94%	96%	95%
12	40	40	28	38	12	2	30%	5%	18%
Total	**480**	**480**	**272**	**290**	**208**	**190**	**42%**	**38%**	**40%**

Table 5.2
The table shows for each subject the number and percentage of rejected and not rejected trials in random and fixed delay conditions, after deleting above 800 msec.

Table 5.3 shows the effect of this radical data deletion on the mean reaction times. Obviously, the mean of the whole data set is longer if no deletions are made. The deletions have a smaller effect in subjects 6, 8 and 9, typically <50 msec. and a larger effect in subjects 7 and 11, typically >350 msec.

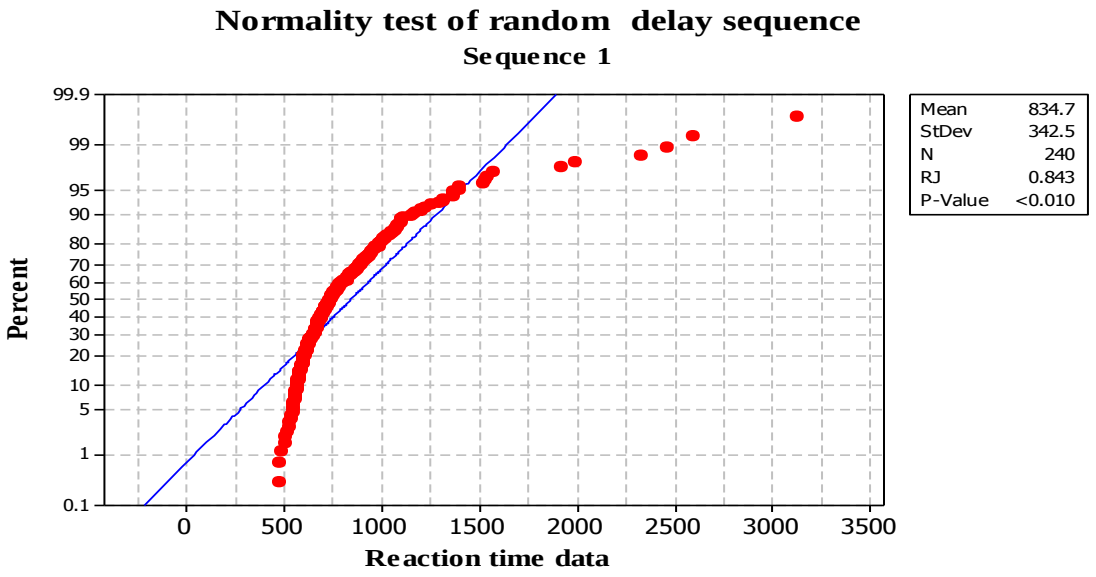
	Reaction time after deleting (msec.)		Mean data without deleting (msec.)	
Subject	**Random**	**Fixed**	**Random**	**Fixed**
1	641	621	746	778
2	698	617	907	898
3	698	678	805	714
4	713	713	842	795
5	638	647	886	676
6	639	693	688	704
7	752	748	1058	1082
8	647	651	695	663
9	641	647	742	664
10	752	763	1034	915
11	749	696	1110	1079
12	651	675	740	704
Mean	**685**	**687**	**856**	**806**

Table 5.3
The table shows the means of reaction time data, if deleting is done and the means of the data without deleting.

It is significant that the reaction times in these experiments are also far from normal distribution. Many very long reaction times are recorded. This is clearly seen in figures 5.4 A and B and 5.5 A and B.

Thus, if the reaction times above 800 msec. are removed, substantial quantities of data are deleted. If no deletion is made, the data are not normally distributed. In either event, the data are quite different from that recorded in the previous chapters.

A



B

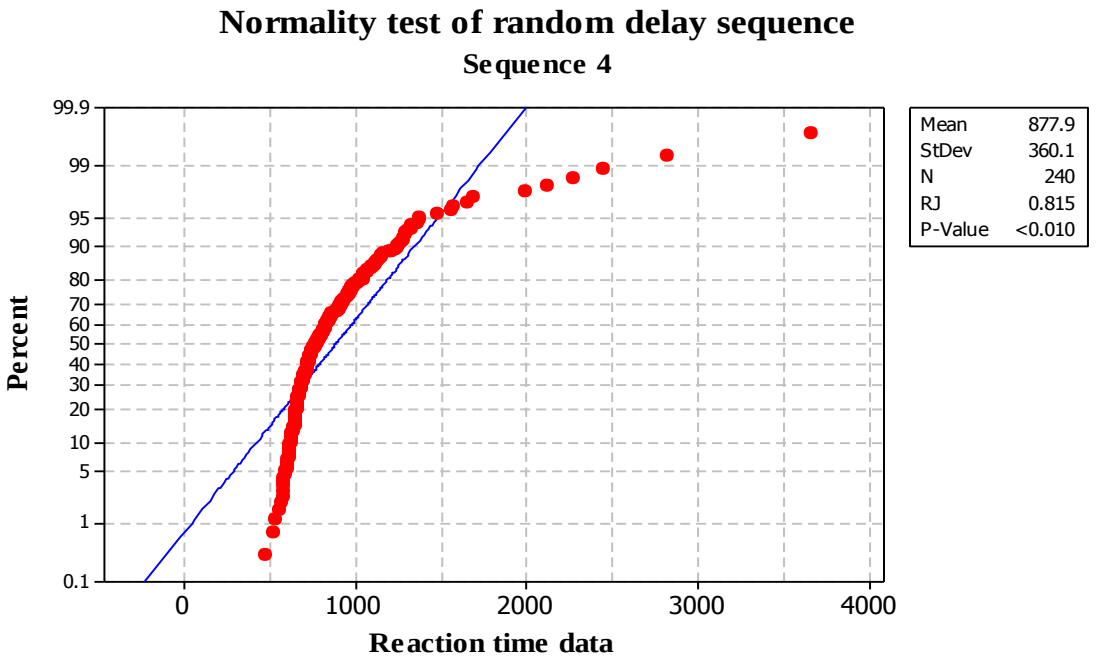
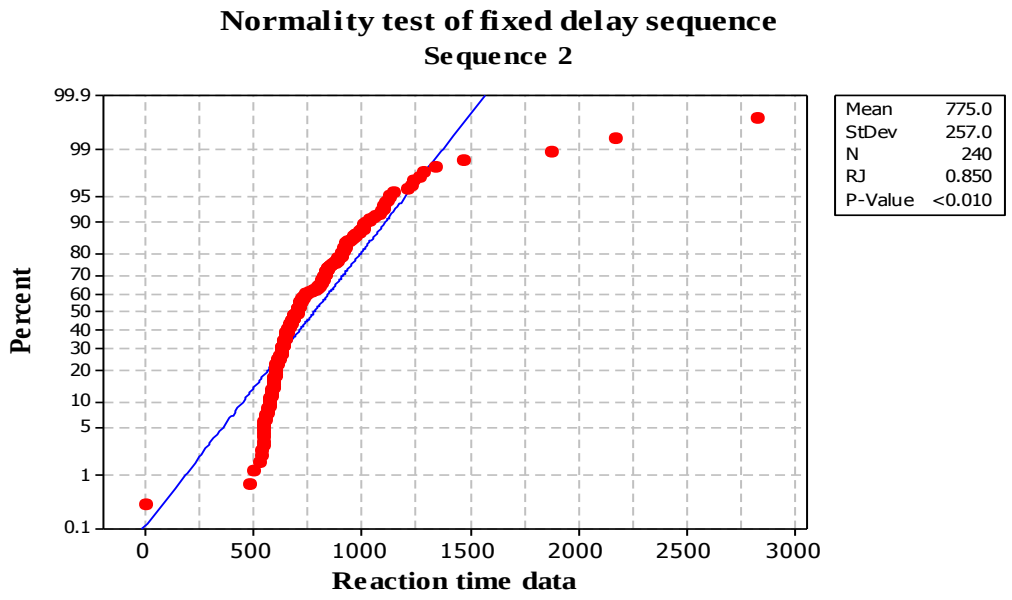


Figure 5.4 A and B
The figures show the Normality test for the random delay reaction time data of sequences 1 and 4.

A



B

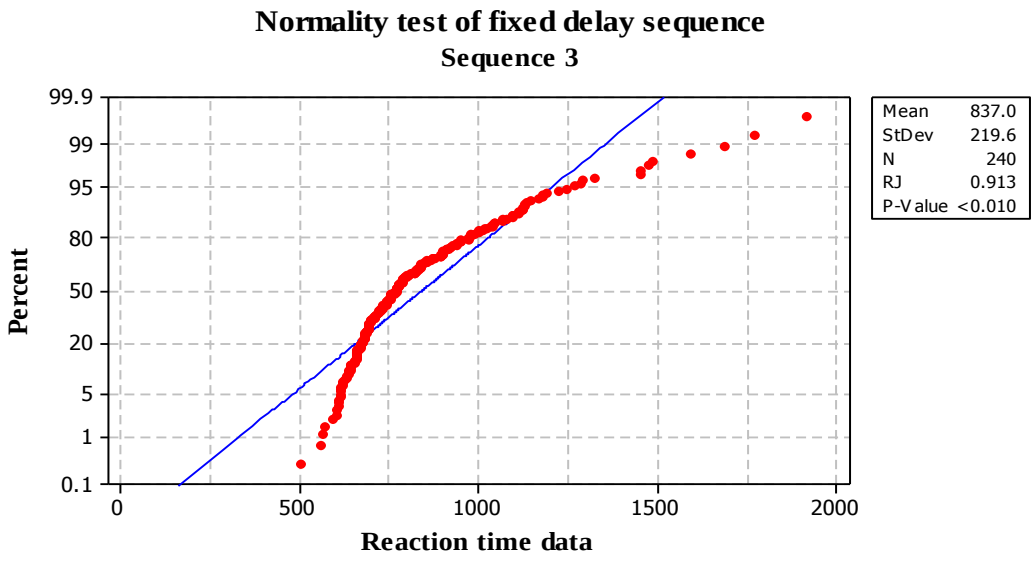


Figure 5.5 A and B
The figures show the Normality test for the fixed delay reaction time data of sequences 2 and 3.

Figure 5.6 shows the reaction times plotted against the delay, from 1 to 9 seconds, in random delay sequences. The horizontal line shows the 800 msec. cut off point. Clearly many data points lie above the cut off. Shorter delays tend to produce more extremely long reaction times.

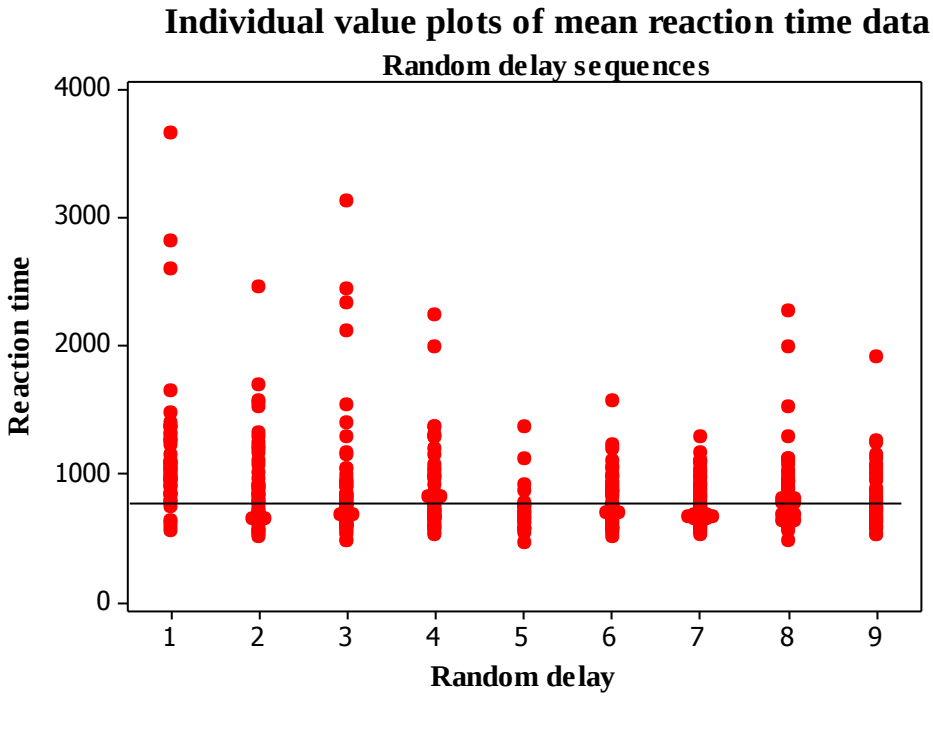


Figure 5.6
The figure presents the time of reaction at each delay, from 1 to 9 seconds.

The data of figure 5.6 are shown in table 5.4. The means of delay 5, 6 and 7 are within the limit accepted for the previous experiment, 800 msec. The means of the delay 3, 4, 8 and 9 remain within 900 msec. The means of the delay 1 and 2 are far beyond 900 msec.

Mean reaction time and delay without deletion			
Delay	**Number of trials**	**Mean Reaction time**	**Standard Deviation**
1	48	1157	554
2	48	919	377
3	72	874	454
4	49	834	279
5	24	725	193
6	48	794	208
7	71	770	169
8	72	817	289
9	48	808	250
Mean		**855**	**308**

Table 5.4

The table presents the reaction time data of sequences 1 and 4 linked to the delay.

In table 5.5 the comparison between the data of the random sequences, 1 and 4, and the results of the fixed delay sequences, 2 and 3, is not significant (p value 0.423). Anyway it shows the longer reaction times of the random sequences and higher values of standard deviation. The effects of fixed delay sequences are quicker reactions and less fluctuation from trial to trial.

Reaction time data and delay Random and Fixed				
	Random delay Sequences 1 and 4		Fixed delay Sequences 2 and 3	
Subject	**Mean reaction time**	**Standard Deviation**	**Mean reaction time**	**Standard Deviation**
1	742	249	664	103
2	695	157	663	93
3	740	153	704	170
4	1034	523	915	137
5	688	146	704	73
6	1134	269	1079	183
7	751	222	778	223
8	886	531	676	109
9	805	226	714	121
10	1058	439	1082	360
11	907	350	901	279
12	842	298	795	141
Mean	**857**	**297**	**806**	**166**

Table 5.5

The table shows the reaction times and the standard deviations of each subject during the random delay sequences, 1 and 4, and during the fixed delay sequences 2 and 3.

In an attempt to continue further with this analysis, the difference in mean reaction times between the fixed and random delay sequences was calculated for each subject. This was

done by subtracting the first reaction in the fixed delay sequence and the first reaction time in the random delay sequence, then repeating the process for the second, third and fourth pairs and so on. The hope was that the differences would be more normal than the original values. This was the case and figure 5.7 shows the normality tests for the mean differences in all 12 volunteers.

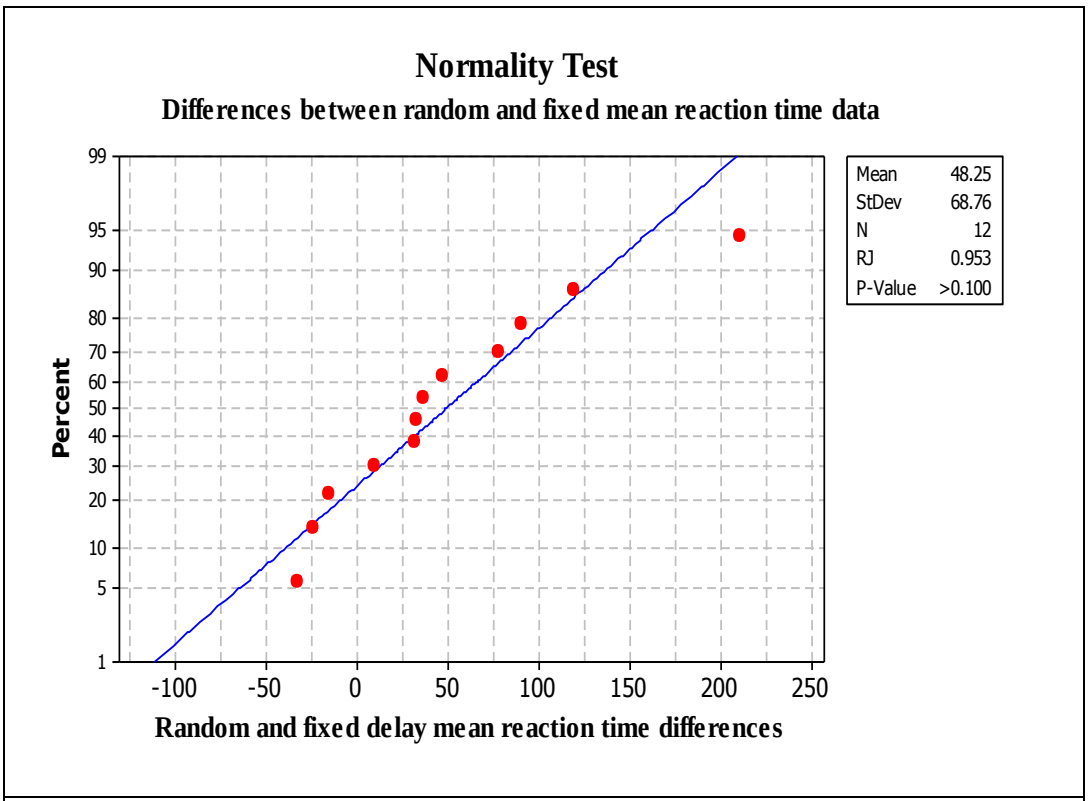


Figure 5.7
The figure shows the trend of the differences between random and fixed delay mean reaction time data.

Table 5.6 shows the mean difference in reaction time and the 95% confidence intervals calculated for the mean difference in reaction times in each subjects. Negative differences show that the volunteer is faster in the random delay experiments than in the fixed delay

experiments. The mean differences tend to be small and can be positive or negative. The associated confidence intervals are large and include zero in all twelve cases. It was concluded that there were no significant differences between the reaction times measured with fixed and random delays.

Subject	Mean reaction time difference (msec.)	Confidence Interval (msec.)	Significance
1	-33	+615 to -681	Ns
2	9	+877 to -859	Ns
3	90	+624 to -444	Ns
4	47	+ 733 to -639	Ns
5	210	+ 1358 to -938	Ns
6	-16	+ 342 to -294	Ns
7	-24	+ 1224 to -1200	Ns
8	32	+ 330 to -266	Ns
9	78	+ 626 to -470	Ns
10	119	+ 1227 to -989	Ns
11	31	+ 757 to -695	Ns
12	36	+ 476 to -404	Ns

Table 5.6
The table shows the mean differences between the 2 delay conditions for each subject, confidence interval and the significance.

5.6.2 EMG ANALYSIS OF PREPARATION FOR MOVEMENT

The EMG signals record activity in deltoid as an example of a muscle involved in focal movement and in soleus as an example of a muscle involved in postural adjustments. After the "go" light the volunteers have to respond and touch the chosen target.

Figure 5.8, upper trace, shows the EMG recorded in deltoid in one volunteer during three reactions in a fixed delay sequence. The lower trace shows the times of illumination of the get ready light, upward deflection, and go light, downward deflection. The volunteer clearly activates their deltoid at each go signal. In the first example shown there is also a smaller EMG burst when the get ready light is switched on. This happened in some tests. It might be a mistake of the subject.

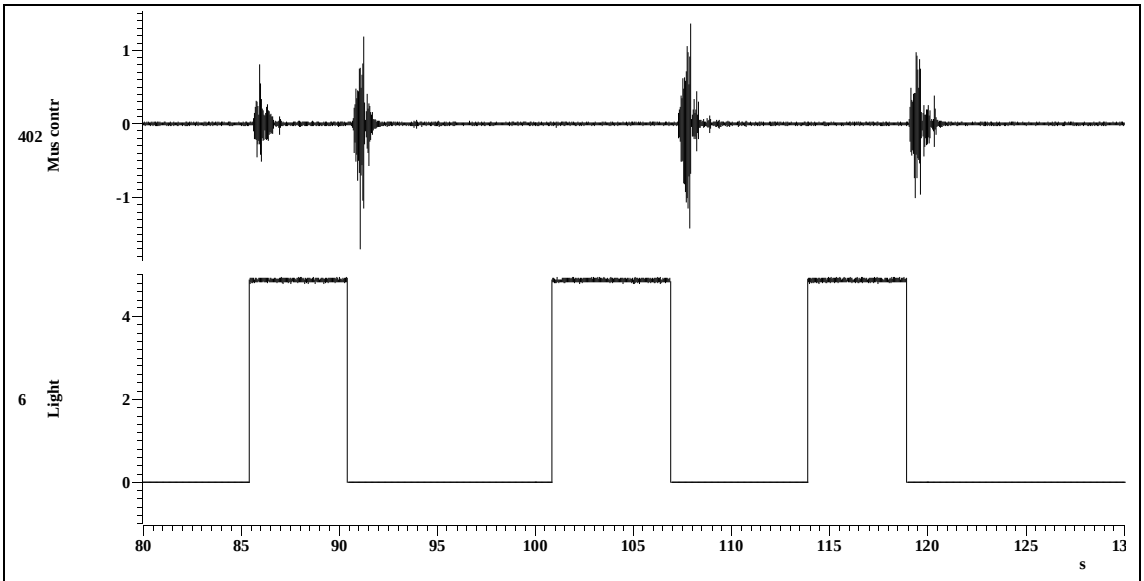


Figure 5.8
EMG recording right deltoid contractions at the red and green light. The figure shows the light event at the bottom and the correspondent muscle activity above. The light signal is ascendant at the "alarm" light, parallel to the basic line, during the delay time, and descending at the "go" light. Full deltoid contractions are registered after the 3 green signals and a smaller one at the first red "alarm" light.

The EMG signal from deltoid was rectified, integrated and averaged as described in the in section Methods and Material. Figure 5.9 A and B gives an example of peri-stimulus averaged EMG. In figure A the go signal, the trigger, occurs at 0 sec. It shows 1.5 seconds before go and 0.5 seconds after go. The EMG activity increases substantially 100 msec. after the go signal as the focal movement is initiated. No variation the averaged EMG is seen in the EMG before the go signal is delivered. In figure B the averaged reaction time is measured from 0 to the time of the highest peak, when the subject touches the switch.

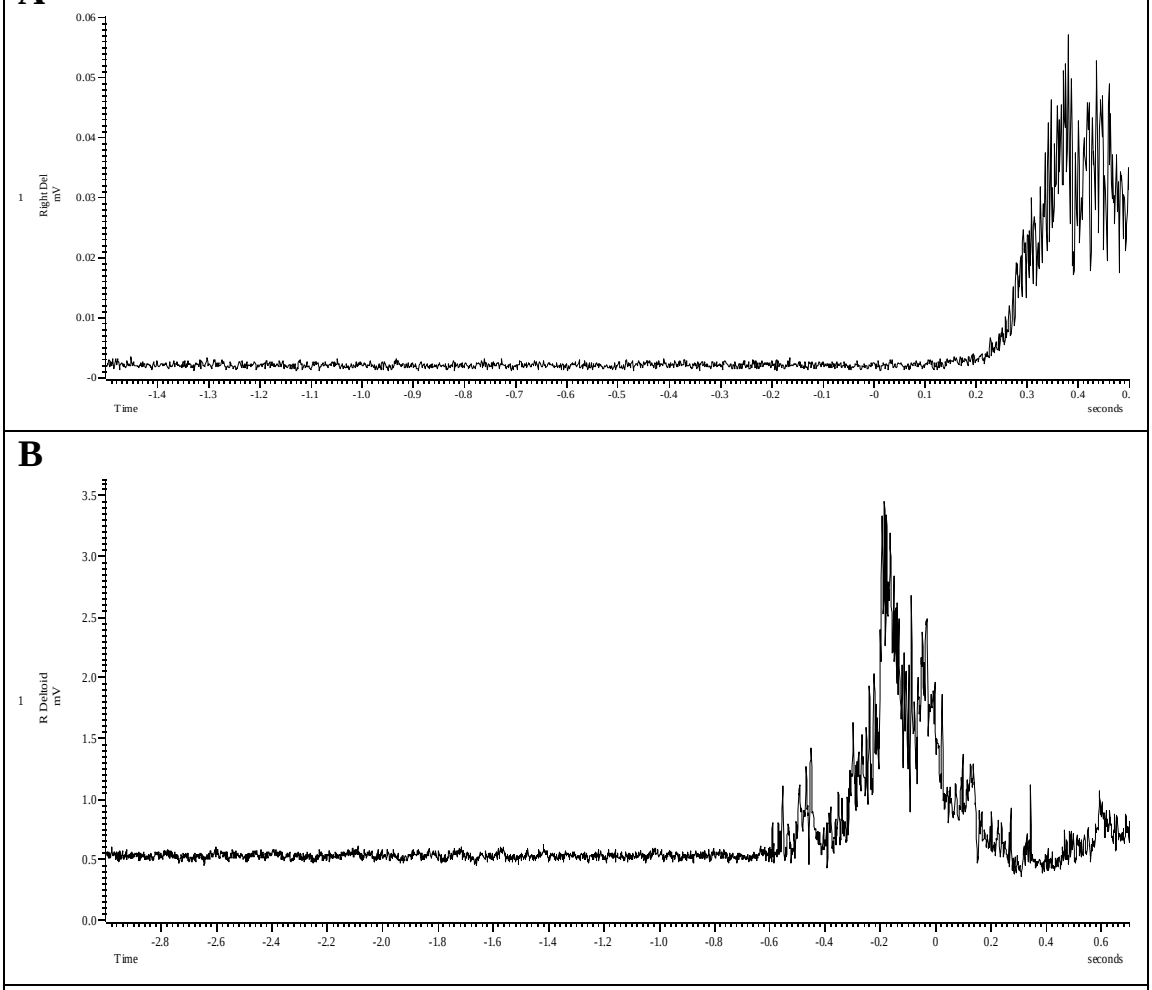


Figure 5.9 A and B
The figures A and B show the EMG of right deltoid contraction before the "go" light in fixed delay conditions. In figure A 0 is at the go signal. The signal occurs 0.3 msec. before contact. No EMG before go. In figure B 0 is at the point of contact with switch. Sharper EMG rise close to contact.

An example of the rectified, integrated and averaged EMG in soleus recorded concurrently is shown in figure 5.10. In this case the EMG is unaffected for about 100 msec. after the go signal. There is then a short reduction in EMG followed by a later increase at 350 msec. after the go signal. There is no sign of any modulation of the EMG before the go signal.

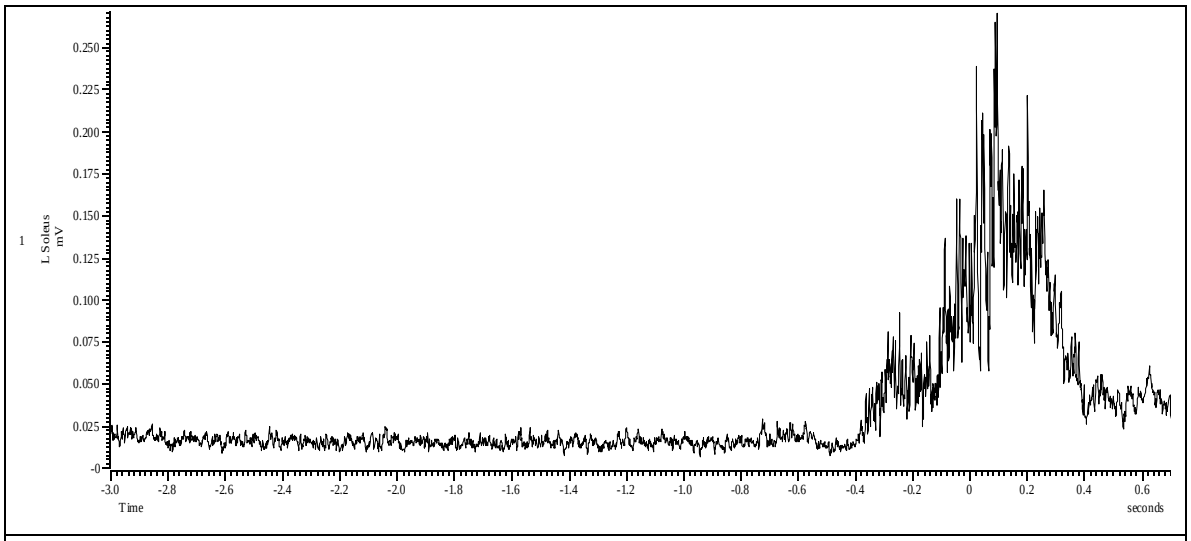


Figure 5.10
The figure shows the contraction of left soleus 1.5 seconds before the "go" light in fixed delay conditions.

Few subjects present sensitivity, revealed by muscle contraction, to the "alarm" light. Figure 5.11 registers the right soleus activity at the red light stimulus in fixed delay condition. It might be also an artefact.

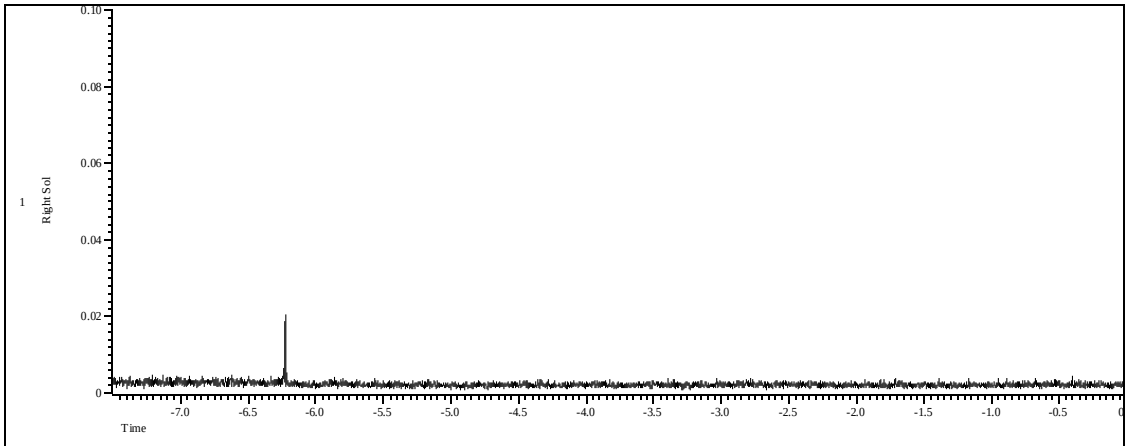


Figure 5.11
The figure shows the averaged rectified smoothed EMG recorded from the right soleus of one volunteer during 20 reaction time tests. The go signal is given at 0 seconds. In this case the delay is fixed and the get ready light is illuminated just before 6 seconds. This can be seen as a sharp spike between -6.5 and-6 seconds. The EMG signal shows no modulation at about the get ready signal or before the go signal.

Inspection of table 5.7 show that all 12 volunteers behaved in this way. None showed any modulation of their deltoid or soleus EMG in the 1.5 seconds before the illumination of the go signal. Three volunteers, subject 2, subject 4 and subject 12, showed a response in their averaged EMG associated with illumination of the get ready light.

Subject	Deltoid Response at Get Ready	Deltoid Preparation before Go	Soleus Response at Get Ready	Soleus Preparation before Go
S1	No	No	No	No
S2	Yes	No	Yes	No
S3	No	No	No	No
S4	Yes	No	No	No
S5	No	No	No	No
S6	No	No	No	No
S7	No	No	No	No
S8	No	No	No	No
S9	No	No	No	No
S10	No	No	No	No
S11	No	No	No	No
S12	Yes	No	No	No

Table 5.7
The table shows the reaction of the subjects at alarm signal and the time of preparation before the trigger in deltoid and soleus muscles.

5.7 DISCUSSION

There were two distinct sets of results. The reaction time results are discussed first and then EMG analysis will follow.

5.7.1 DISCUSSION ON REACTION TIME DATA

A first question is the extent to which the nature of the delay affects the reaction time: which of the two conditions, random or fixed delays, produces faster reactions?

Three characteristics were evident in the reaction time data:

- the reaction times measured were frequently much longer than the ones in previous experiments
- if the protocol of rejecting reaction times above 800 msec. were continued, a large amount of data would be lost.
- the reaction time data were far from normal in their distribution.

The radical deleting procedure was excluded, because it couldn't lead to any valid result. It was decided to analyse all the data. The first aim was to test for differences in reaction times when fixed and randomised delays were used. When differences between the conditions, test by test and subject by subject were calculated, it was clear that the differences were normal and that they were not significantly different from zero. The aim could be achieved, the reaction times were not different from each other, even though they were different from those in the previous chapters.

The ultimate cause of the difference remains uncertain. There are several possibilities: the long reaction times could be due to chance, or to distraction, caused by the introduction of the EMG equipment, or to some technical malfunction. The large number of unusually long reaction times and the frequency, with which volunteers showed long reaction times, makes it very unlikely that these are chance observations.

In the earlier chapters only about 10% of data was rejected and no volunteer ever had to be excluded because of persistent slow responses. The volunteers were drawn from the same population of undergraduate and postgraduate students. They were all young people, experienced in the scientific field, and so it is not probable that they were slow because they were concerned with damaging the EMG equipment.

The engineer who designed the device was consulted. He confirmed that software problems were very improbable. In his opinion, it was possible that there was a poor functioning of a switch or several switches in the reaction timer device.

It was unfortunate that the inadequate working of the switch had not been detected during the experiments, where the main part of the experimenter's attention had been given to recording the EMG data. However, the data could be analysed by the difference method. Care must be taken in the interpretation of these data given the uncertain nature of the technical problems with the equipment.

The main studies on this topic are described in the Literature Review, section 1.12 delay. One focus of previous studies has been on comparing random and fixed delay and on the effect of the length of the delay. The data do not confirm the studies of Niemi and Naatanen (1981), Bertelson and Tisseyre, (1968), Durup and Requin (1970), Vidal et al., (1991), but they agree with some previously published papers in *a* few points linked to short and long delays.

In summary the results of the effect of the nature of the delay reported here need to be treated with caution. This synthesis comes from experiments performed in a range of conditions and making a generalised conclusion might be impossible.

5.7.2 DISCUSSION ON EMG DATA

There were no technical problems with the EMG data. These gave an unambiguous image of muscle contractions during option selection. The processing after the go signal describes a clear, sharp image of focal action and postural adjustment contractions. The EMG in deltoid began to increase sharply after 100-120 msec. and this is entirely consistent with completion of the mechanical action when the finger closes the switch in 400-600 msec.

Relatively few examples were seen where volunteers make errors and initiated deltoid EMG activity at the get ready signal, anticipating the go signal. At the alarm signal, 2 subjects, among 12, showed contraction to deltoid muscle and 1 was responsive both in deltoid and soleus muscles. Thus few people activated their deltoid muscles in the "the state of readiness" described by Birbaumer et al., (1990). For the majority of the volunteers in these experiments, option selection stage did not involve muscle activity.

The EMG signals show no increases of preparation during option selection time when either random or fixed delays were used. It suggests that whatever neurophysiologic processes operate at central level, there is no preparation at a neuromuscular level. This is consistent with the studies of Macar and Bonnet (1987), Hasbroucq et al. (1997). Planning is a higher level function, programming is activity at low level (Brunia, 1999). The consequence of motor programs is the focal action.

In conclusion: the data presented in this chapter show no clear signs of EMG activity preceding the go signal. The nature of delay, random or fixed, makes no difference in

terms of EMG activity. Any preparation for reacting must take place up stream of the motor neurones.

The nature of the delay also seems to have no significant effect on the reaction times, given these experimental conditions.

CHAPTER 6

THE EFFECT OF PATTERNS ON REACTION TIME AND ON THE NUMBER OF CORRECT CHOICES

6.1 INTRODUCTION

The experiments described in this chapter were done to investigate the core of the process of choosing: the possibility of guessing the next answer. The focus is on the structure of the sequence. The question to be answered is: when the series shows a schema of trials repeated more times, is there a change in reaction time and an increase in the frequency of correct responses?

One particular problem encountered in chapter 5 was the number of very long reaction times. If they were eliminated, the data sets could become very small. A new approach is introduced in this chapter, a mathematical and a statistical model, to analyse all the data without deletions.

The complex matter needed special help. Dr. Nair, senior lecturer of Number Theory at Mathematics Department at University of Glasgow, proposed the specific stimuli patterns, their logic and their allocation inside the sequence. He also proposed a new way to determine the random numbers. It is described in the Methods and Material section below. Dr Kilborn, senior lecturer at Psychology Department at University of Glasgow provided useful suggestions on option selection process. The statistical model was proposed by Dr. Bondarenko, senior statistician at Biostatistics Department at Ann Arbor University, in Michigan, U.S.A.

A specific novel feature of the new experiments is that some sequences of stimuli contain embedded patterns: i.e. a repetition of the same stimulus 3 times. The schema of 3 numbers is presented 4 times inside the series of 20 trials. The remaining 8 trials are random. The subject is not informed about this and has to discover it. In the experiments reported in earlier chapters the sequences were random, so right or wrong responses could be attributed to chance.

Tools are the sequence and the repeated schemas linked to the 3 pads. Section 1.14 of the Literature Review describes how people process and identify regular features of stimuli. In the same way it is expected that the subject, using the feedback from previous trials, will be able to differentiate between random and repeated trials, 'the pattern'. The identification of the pattern leads to prediction of future trials. Long reaction times may be expected, possibly due to additional central processing required for the identification of a cue as part of the pattern. The application of the new statistical model allows these longer times to be included in the analysis. Their proper interpretation is now possible because all the other variables have been already tested.

6.2 AIMS

The experimental hypothesis states that:

- correct answers delivered in response to a stimulus sequence containing a pattern will have shorter reaction times than those recorded when no pattern is present
- the frequency of correct answers will be higher when patterns are present in the stimulus sequence

- the frequency of correct answers will increase when more repetitions of the patterns are presented.

The experiments were performed to test these hypotheses.

6.3 METHODS AND MATERIALS

The protocol was reviewed and approved by the Ethics Committee of Glasgow University. The experiment used the same reaction timer and switches as in previous chapters. The subjects were 21 undergraduate and postgraduate students of FBLS, University of Glasgow. Their age ranged between 22 and 56 years old. Ten males and eleven females performed the tests.

The experiment was organised to encourage the "guessing" of the schema. The subject was not informed about the features of the four sequences. All tests used a fixed delay of 6 seconds between the "get ready" and "go" signals to help the subjects to maintain their focus on the sequence.

The patterns consisted of sequences of switch pads selected. Each pad stands for a number. The one on the left of the subject is number 1, the one on the right is number 3, and the one in the middle is number 2. The patterns were suggested by Dr. Nair. Four sequences were used. In sequence 1 the arrangement of pad numbers was randomised. The data will be a reference to compare reaction times and correct answers with the results of the patterned sequences. Sequences 2, 3 and 4 contained a pattern of 3 numbers, repeated 4 times in the 20 trial sequence. The remaining 8 trials were randomised. The randomisation was done by throwing a die, which has 6 faces. The condition gives double

probability for each of the 3 numbers to be selected. It is possible that this does not guarantee 'randomness', but Dr Nair was satisfied; the procedure was acceptable, in this experimental context.

Sequence 2 contains as repeated pattern 3, 3, 3, i.e. a simple repetition of the same switch pad. Sequence 3 contains the pattern 1, 2, 3, i.e. a natural progression left to right on the 3 pads. Sequence 4 contains a more complex pattern, 2, 1, 2. Sequences 1, 2 and 3 were presented to the volunteers in a randomised way. Sequence 4 was used last in all experiments.

6.4 RECORDING PROTOCOL

Each subject attended two experimental sessions. The order of the stimulus sequences used was randomized. Details of the sequences are presented in Appendix III, table 6.1 and 6.2, pages 181 and 182.

6.5 STATISTICS

A longitudinal statistical model was used to analyse the series of reaction times. Its structure was proposed by Dr. Bondarenko. Details are given in Appendix II, page 171**.** The analytical model relies on the data being normally distributed. Where necessary, logarithmic transformations were used to satisfy this condition.

The features of the 4 sequences were tools to make horizontal and longitudinal comparisons among the series and within the same sequence. The goal was to find positive differences between random and patterned trials, as sign of guessing, and to

detect a possible increasing number of pattern correct answers at the trial presentation. This could be a sign of learning.

The longitudinal model is made up by 4 steps:

- the effect of pattern: a reaction time investigation on the presence of a pattern in the stimulus sequence, compared to random data
- learning effect, trial by trial: an investigation to analyse the total progressive gaining of knowledge, that is positive responses
- the effect of sequence: an investigation to check if the features of the sequence make the difference in number and percentage of correct answers
- learning effect, sequence by sequence: an investigation to determine if there are progressive positive and pattern positive responses in each sequence.

Step 1 is aimed at the comparison between the reaction time of patterned trials, correct, incorrect, previous correct and previous incorrect pattern responses, and the reaction time of random trials. Step 2 examines the number of correct answers of the 4 sequences from trial 1 to trial 20. Step 3 detects the total percentage of correct answers for each sequence. Step 4 analyses number, percentage of correct answers and pattern correct answer trial by trial for each sequence.

The distributions of reaction times were tested for normality using Ryan Joiner tests and if necessary, they were subsequently corrected with a log transformation.

6.6 RESULTS

Effects on reaction times and numbers of correct answers are presented separately.

6.6.1 REACTION TIME RESULTS

Figure 6.1 shows the reactions times of all volunteers tested in all 4 sequences.

It is clear by visual inspection of the data that most reaction times lay below 1 second. It is also clear that there is a substantial number of reaction times beyond 1 second and that the distribution looks far from normal. With the exception of the relatively small number of very long reaction times, say beyond 5 seconds, there is no obvious difference in the distributions of reaction times between the 4 sequences.

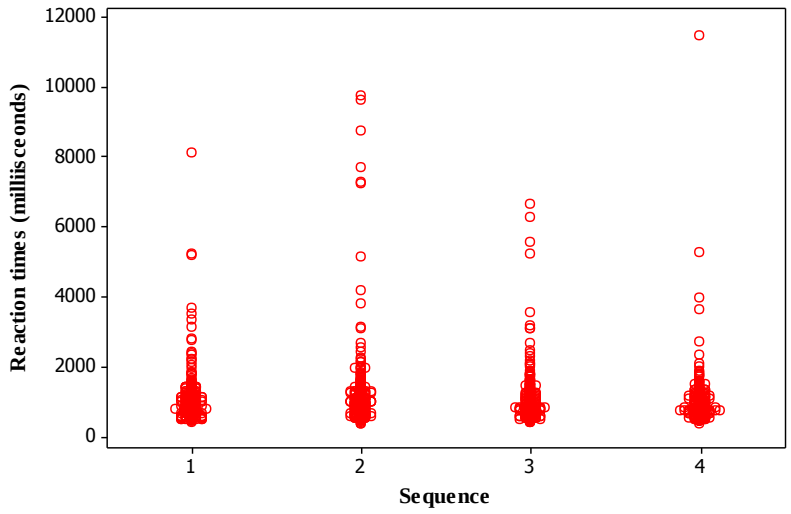


Figure 6.1
The figure presents the distribution of reaction times for all 21 volunteers. The reaction times are shown for each sequence of stimuli.

The data shown in figure 6.1 were tested for normality using Ryan Joiner tests. The results are shown in figure 6.2 A, B, C and D. These confirm the visual impression gained by inspecting figure 6.1. The results show the irregular distribution of the numbers in each sequence, random and patterned. The assumption of the statistical tests is the normality of the data. When they are not, a function can be applied to make them normal. According to the suggestions of Dr. Bondarenko was used the function RT -350.

The Ryan Joiner tests for the transformed data are shown in figure 6.3 A, B, C and D. The direction of the lines becomes reasonably normal. It was decided to continue the reaction time processing according to the statistical model.

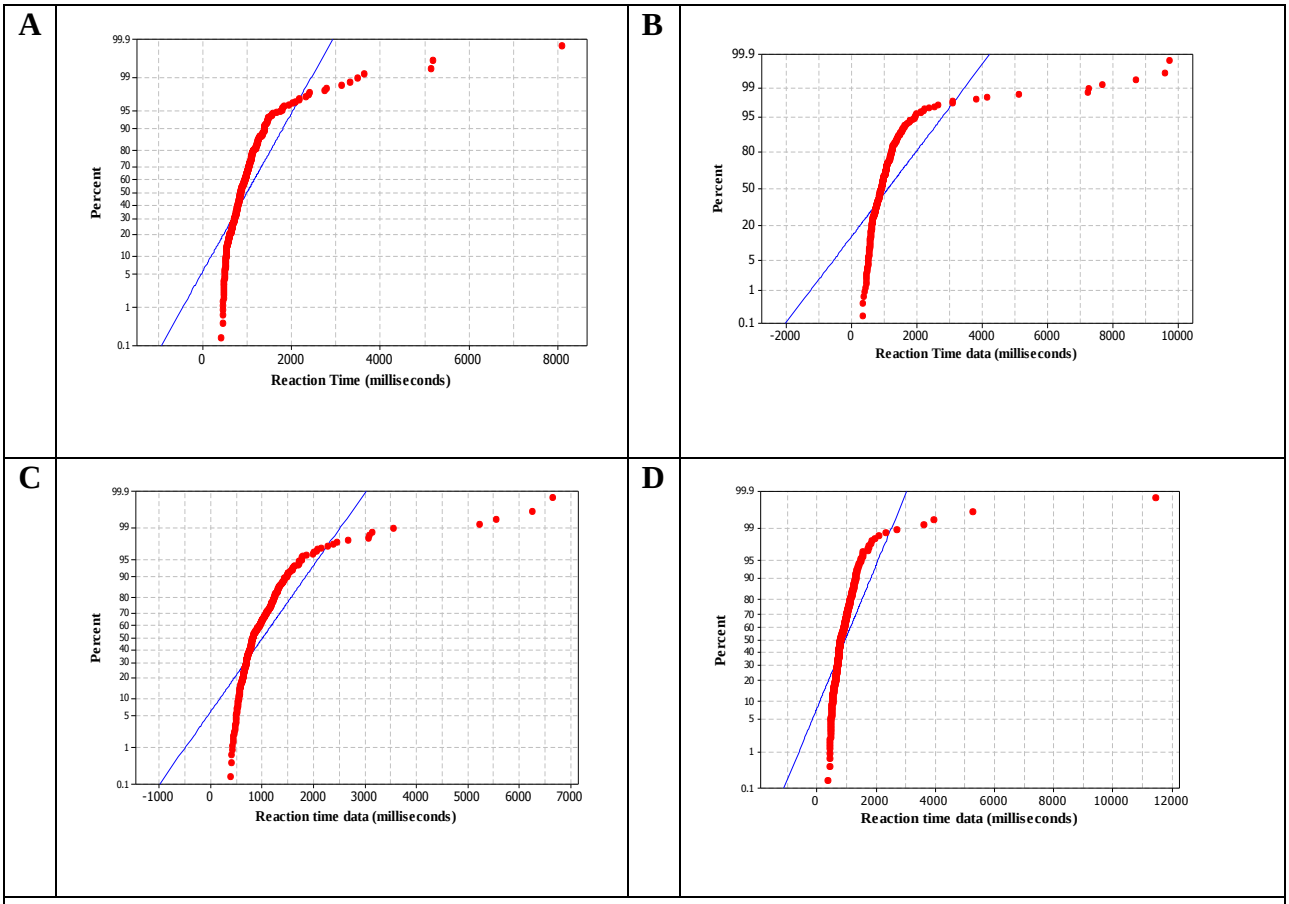


Figure 6.2 A, B, C and D

The figure shows the results of Normality test, Ryan Joiner. These tests were applied to all the reaction times of the 21 volunteers. Each panel shows the results of tests for reaction times in one sequence. A sequence 1, B sequence 2, C sequence 3 and D sequence 4. These tests confirm that the raw data are far from normality, p value is < 0.010.

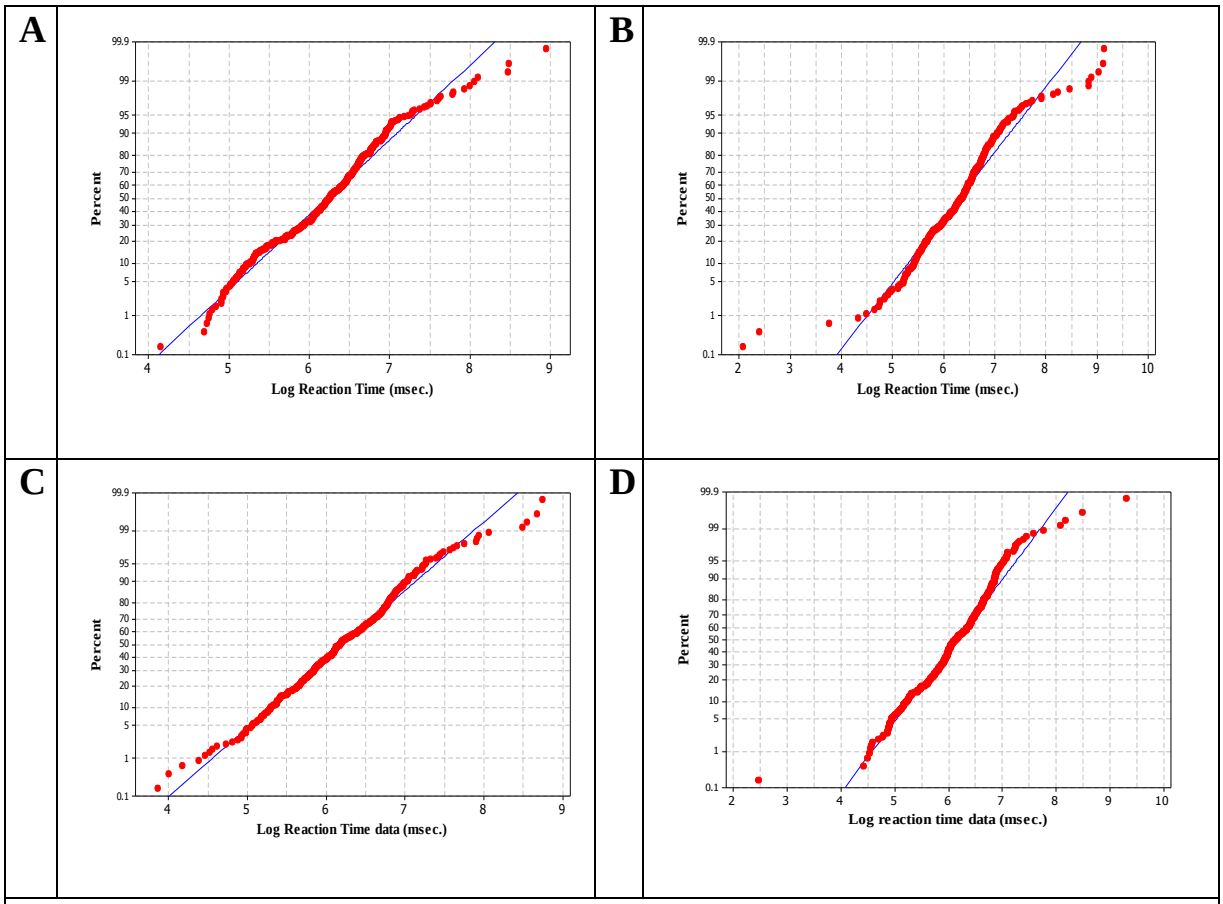


Figure 6.3 A, B, C and D
The figure shows the results of Normality test, Ryan Joiner. These tests were applied to all the reaction times after it had been log transformed. Each panel shows the results of tests for reaction times in one sequence: A sequence 1, B sequence 2, C sequence 3 and D sequence 4. The p values for each sequence are < 0.010.

The volunteer, whose data are shown in figure 6.4 A, shows consistently short reaction times. In contrast, the data shown in figure 6.4 B, show another volunteer who shows consistently long reaction times. Figure 6.4 C examines the data of a volunteer whose responses are very variable. Figure 6.4 D gives an example of a volunteer whose reaction times are very consistent in all the sequences.

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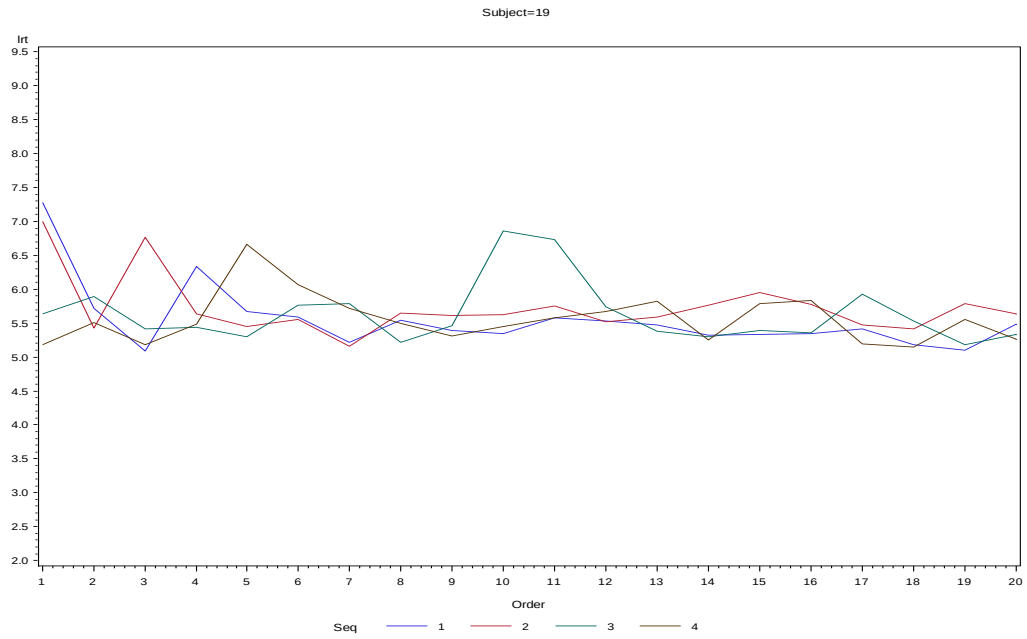
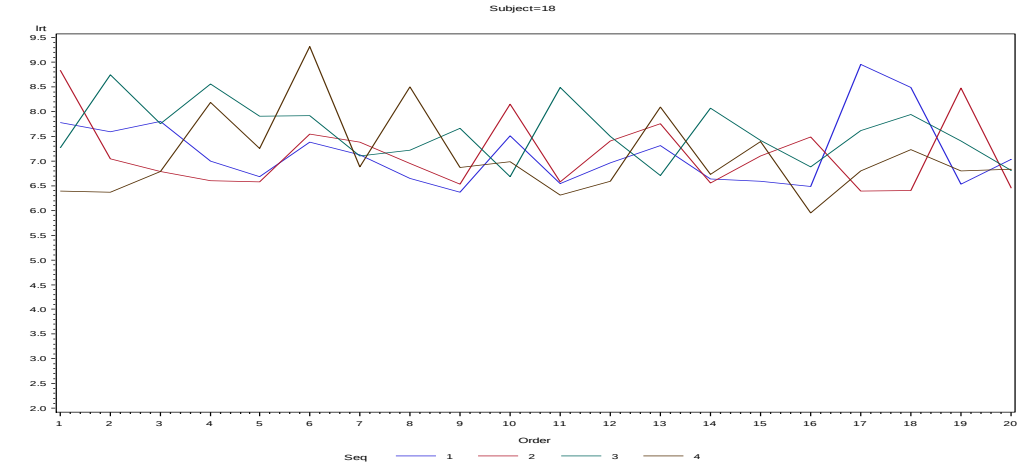
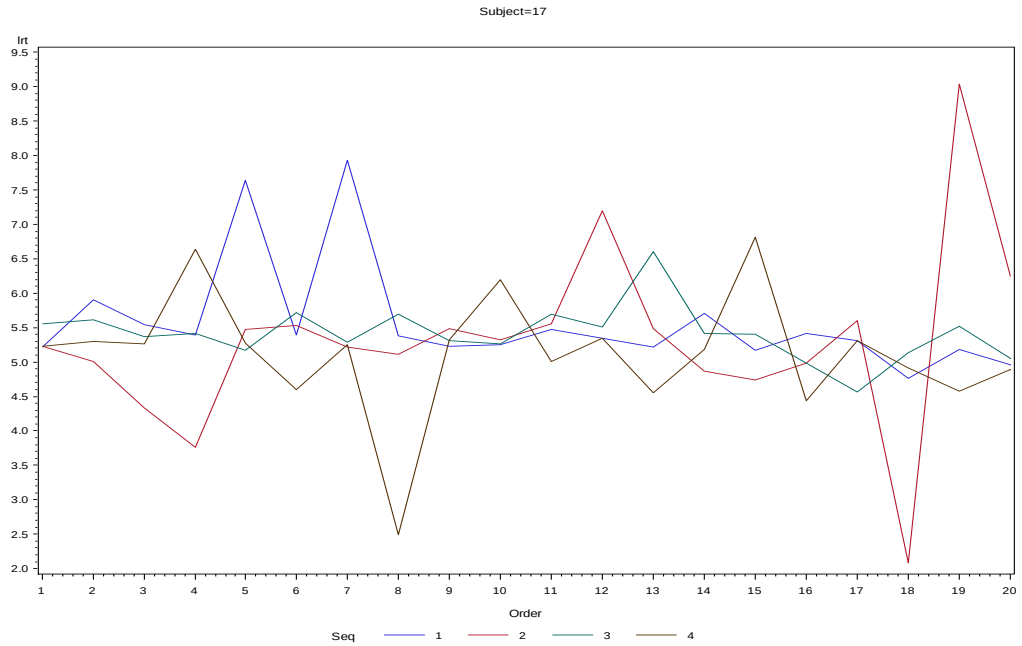


A

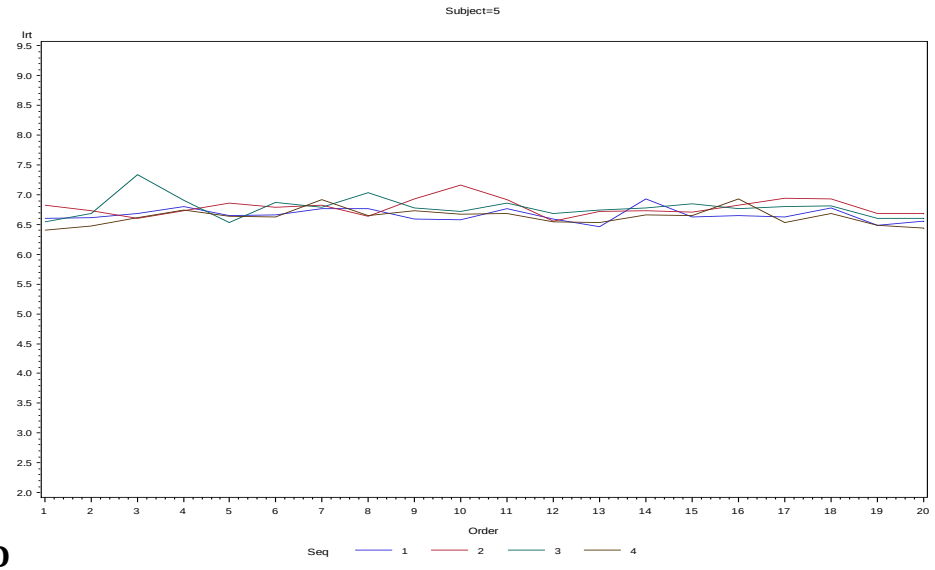


B

Figure 6.4 A and B
The figure presents the Log reaction time in sequences 1, 2, 3 and 4, for 2 subjects, who have constantly low numbers, in figure A or high numbers, in figure B.



C



D

Figure 6.4 C and D

The figure presents the Log reaction time in sequences 1, 2, 3 and 4, of 2 subjects. In figure C the values fluctuate inside the sequences. In figure D the level of the responses is consistent in all the 4 sequences.

Figure 6.5 registers the distribution of the standard deviations in each subject for sequences 1, 2, 3 and 4. Several subjects show large variations in sequence 2.

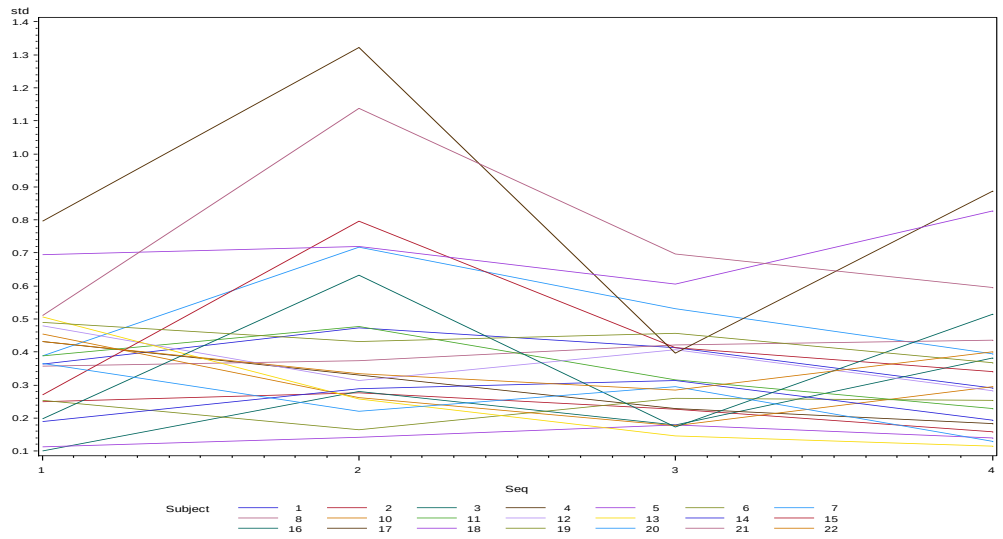


Figure 6.5
The figure shows the distribution of the standard deviation from the Log reaction time data for each subject in each sequence.

After this initial data processing, it was followed the Bondarenko statistical model.

6.6.1.1 THE EFFECT OF PATTERNS ON REACTION TIME

The statistical model includes the comparison of all the data. Log transformation of the reaction time data are presented in figure 6.6. The figures of all the random trials, coming from sequence e1, the random part of sequence 2, 3 and 4, and the values of the patterned trials of sequences 2, 3 and 4 are computed. The means are very similar in the 4 conditions.

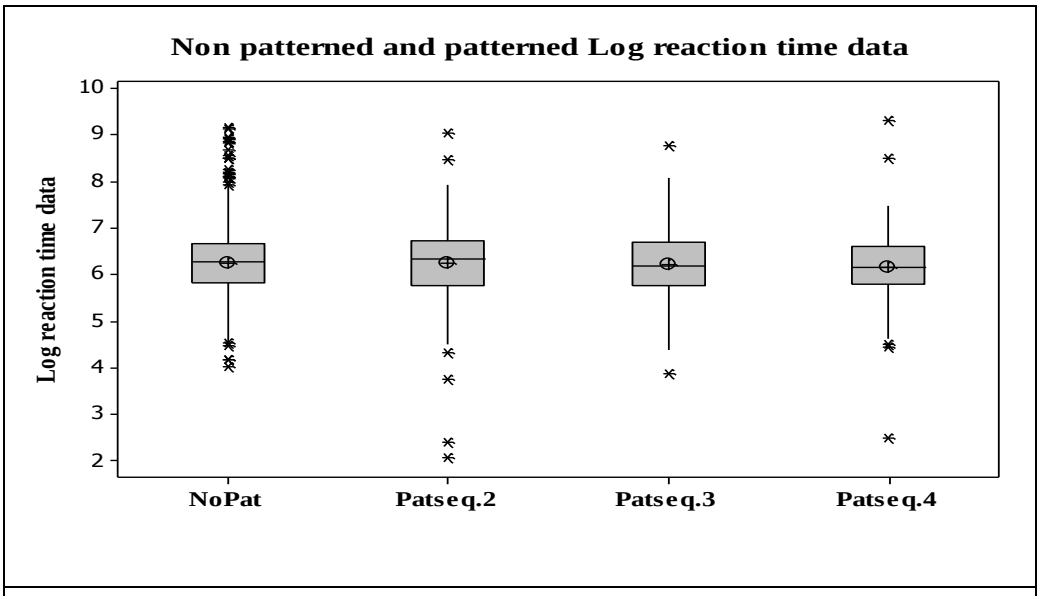


Figure 6.6
This shows all the Log reaction time data, assembled in no pattern section, 924 trials, and in sequences 2, 3, 4 pattern section, 252 trials each. There are individual dots corresponding, even after log transformation, to very long reactions.

In tables 6.3 A, B, C and D, in Appendix III, pages 185 and 186, a series of comparisons were made having as parameters the reaction times of the randomised trials, the reaction times of the patterned trials, correct and incorrect responses and correct choice from the patterned trials.

These comparisons were done using the transformed data and ANOVA tests. No significant differences were found between mean reactions in randomised trials and the patterns correct answers in sequence 2, 3 and 4. The p values were: 0.079, 0.883 and 0.167 respectively.

A similar analysis showed no significant difference in reaction times to randomised stimuli when volunteers made incorrect choices during trials, when sequences 3 and 4 were used (p values were 0.915 and 0.524). A significant difference was found between randomised stimuli and incorrect responses during sequence 2. The p value was 0.032.

The next step of the analysis looked at the effect of the previous answer and the reaction time. The mean reaction times after correct answers and after incorrect answers were not significantly different from those reactions during randomised stimuli. The p values ranged between 0.230 and 0.848.

The results from the p coefficients suggest that reaction times of pattern correct, pattern incorrect answer, are not significantly different from the values of the random trials. The values do not change, according to the characteristics of the sequences and the previous feedback.

6.6.2 THE FREQUENCY OF CORRECT ANSWERS

Figure 6.7 presents the percentage of correct answers for the 21 subjects when they respond to the 4 sequences. A group of volunteers reported a low percentage of positive responses at sequence 1, between 15% and 20%, and higher values, between 30% and 50% in sequence 2 and 3, between 35% and 50% in sequence 4.

A second group registered in sequence 1 a positive level of correct answers, between 35% and 45%, in sequence 2 a lower level of performance, between 15% and 30%, a pick of positive results in sequence 3, between 55% to 80%, and a decreasing percentage in sequence 4, from 25% to 45%. The remaining subjects showed medium level of positive percentage, between 25% and 45%, from sequence 1 to sequence 4.

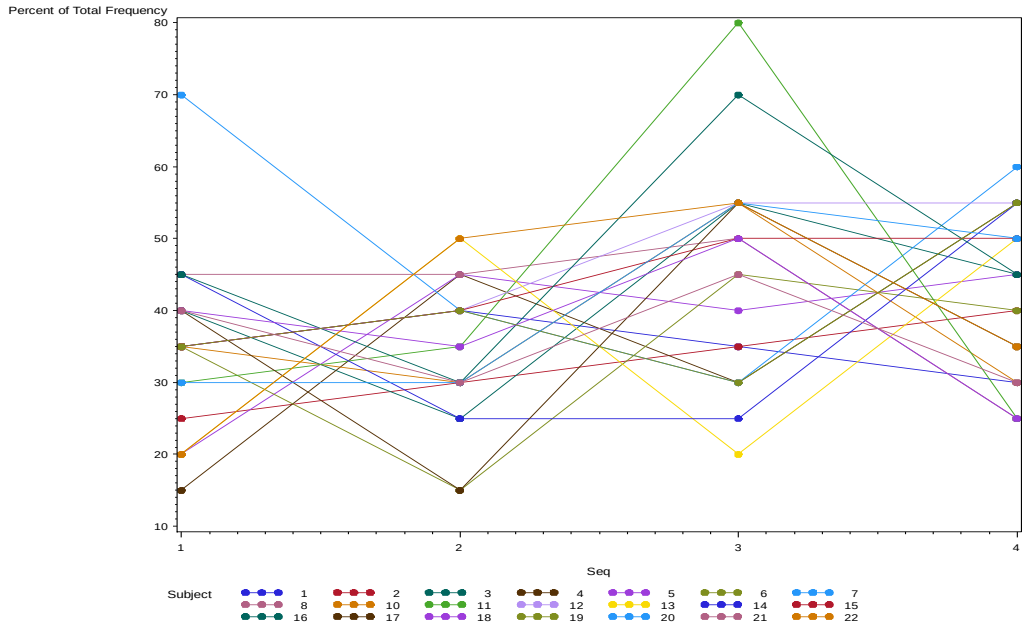


Figure 6.7
The figure shows the percentage of correct answer for each subject in sequences 1, 2, 3 and 4.

6.6.2.1 THE EFFECT OF PATTERNS ON THE NUMBER OF CORRECT ANSWERS

The results on correct choice are analysed. Table 6.4 shows the number of correct answers trial by trial for the patterned sequences. The counts are sums of all 21 volunteers. For example, the first row shows the results of the first trial in all 21 volunteers in all the sequences. The 'expected' column shows the number of correct answers by chance. Given the 3 pads, and one has to be chosen, the percentage of the right choice is 33%, that is 7 in each trial. The observed number of correct answers in sequence 1 (random) is 8. The observed number in sequence 2 is 4 and so on. The figures shown in red in table 6.4 indicate the position of the pattern in each sequence i.e. trials 1,

2 and 3 in sequences 3 and 4. The percentage correct is calculated by adding all the correct answers in sequences 1 to 4 and dividing by the total of 84 (21x 4) first trials etc. It was expected that 140 answers, 34%, of 420 trials for each sequence would *be* correct by chance. In sequence 1, in which the trials are randomised, there were 147 correct answers, 35%. This is not significantly different for the expected number when tested with a Chi Square test, p value 0.057. Sequence 2 has the same number of correct answers as sequence 1, 147, that is 35%, even though it contains a patterned sequence. Thus the presence of the pattern in sequence 2 has no significant effect. Chi Square p value is 0.024. Sequence 3 generated more correct answers, 193 in total, 46%. This is significantly more than expected. Chi Square p value is 0.309. Sequence 4 generated 176 correct answers, 42% and also these numbers were significantly more than expected by chance. Chi Square p value is 0.117. The frequency of correct answers, related to the random and to the 3 patterned sequences, shows that the presence of patterns in sequences 3 and 4 significantly increases the number of correct responses. Focusing on the patterned trials of the sequences, in sequence 2 5 trials, among the 12 patterned, trial 10, 15, 18, 19 and 20, got 50% of correct answers. In sequence 3 the very positive results on patterned trials were on trials 2, 3, 6, 7, 13, 18, 19, 2: 8 trials among the 12 patterned. In sequence 4, 10 or more people guessed the patterned trials 1, 3, 7, 8, 10, 11, 12, 17: 8 trials among the 12 patterned.

Number and percentage of correct answers trial by trial						
Trial	**Expected**	**Seq. 1**	**Seq. 2**	**Seq. 3**	**Seq. 4**	**Correct**
1	7	8	4	**8**	**12**	38%
2	7	10	3	**10**	**6**	35%
3	7	3	12	**13**	**10**	45%
4	7	11	**9**	10	3	39%
5	7	12	**2**	**6**	8	33%
6	7	12	**2**	**16**	**8**	45%
7	7	7	8	**11**	**10**	43%
8	7	7	**1**	6	**13**	32%
9	7	4	**8**	11	9	38%
10	7	8	**10**	3	**14**	42%
11	7	6	8	12	**15**	49%
12	7	7	4	**4**	**10**	30%
13	7	11	7	**10**	7	42%
14	7	3	**7**	**9**	13	38%
15	7	8	**12**	9	**5**	40%
16	7	11	**8**	7	**5**	37%
17	7	4	8	13	**10**	42%
18	7	6	**11**	**12**	6	42%
19	7	3	**12**	**10**	3	33%
20	7	6	**13**	**13**	9	49%
Total	**140**	**147**	**147**	**193**	**176**	
Total percent	**34%**	**35%**	**35%**	**46%**	**42%**	**Mean 40%**
ChiSquare P value		**0.057**	**0.024**	**0.309**	**0.117**	

Table 6.4
The table shows the number and percentage of correct answers for sequences 1, 2, 3, 4. The position of the patterns and the related number of correct answers are underlined using the red colour.

6.6.2.2 THE EFFECT OF PATTERNS AND THE INCREASING NUMBER OF CORRECT ANSWERS

Figure 6.8 shows a scatterplot of the total number of correct answers in each set of 3 trials where a pattern is present. In each set of three trials there will be 63 trails and 21 might be expected to be correct by chance. The two parallel lines give the lower and upper

range of 95% probability that the result comes by chance. The points lying outside the lines at 21 ± 7 are significantly different in their position from that expected by chance.

The figures of pattern 1, 2 and 3 in sequence 2 are inside the confidence interval line. Pattern 4 registers a clear positive value, an increase of positive numbers above the threshold, the line of chance probability. Sequence 3 has clearly positive results for pattern 1 and 2, a decrease in correct numbers, inside the critical zone, in pattern 3, and very high number of positive responses in pattern 4. Sequence 4 has a high percentage of correct answers when the first pattern is presented. It must be the result of chance, because the subject cannot know, identify and recognise the series of 3 numbers. Pattern 2 and 3 are above the "chance" threshold, but pattern 4 had a decrease of correct answers, below the confidence interval line.

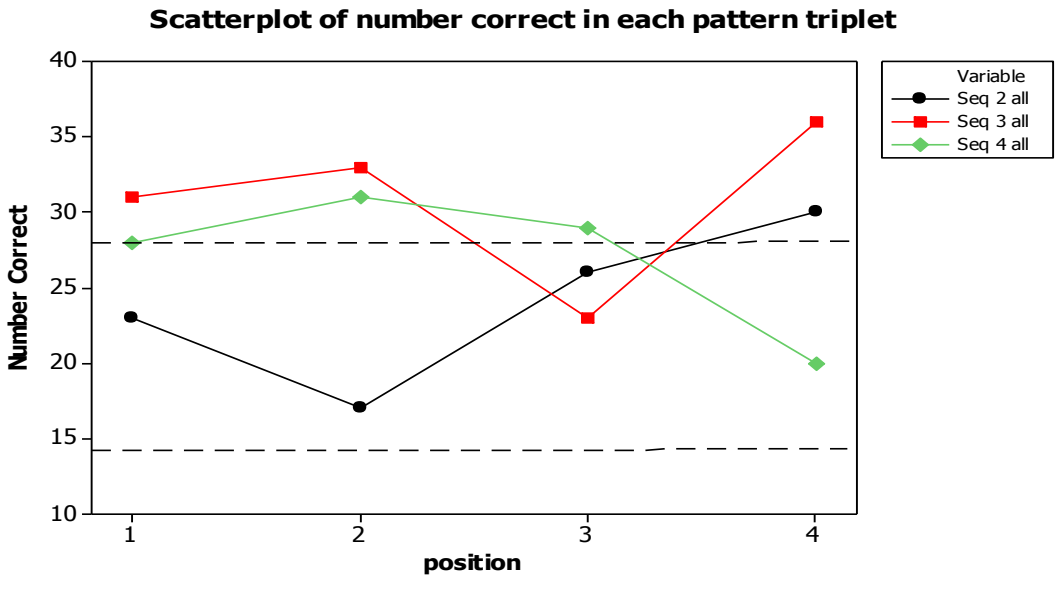


Figure 6.8
The figure shows the number of correct answers in pattern 1, 2, 3, 4 of the patterned sequences, 2, 3, 4. The horizontal lines show the 95% confidence intervals for chi square tests.

The scatterplot in Figure 6.9 shows the sums of total number of pattern correct answers in sequences 2, 3 and 4, from the first to the fourth presentation of the patterns. As in the previous figure the upper and lower horizontal lines indicate the 95% confidence interval calculated using Chi Square tests. All the data points lie inside these and there is no evidence of statistical significant more correct answers later in the experiment.

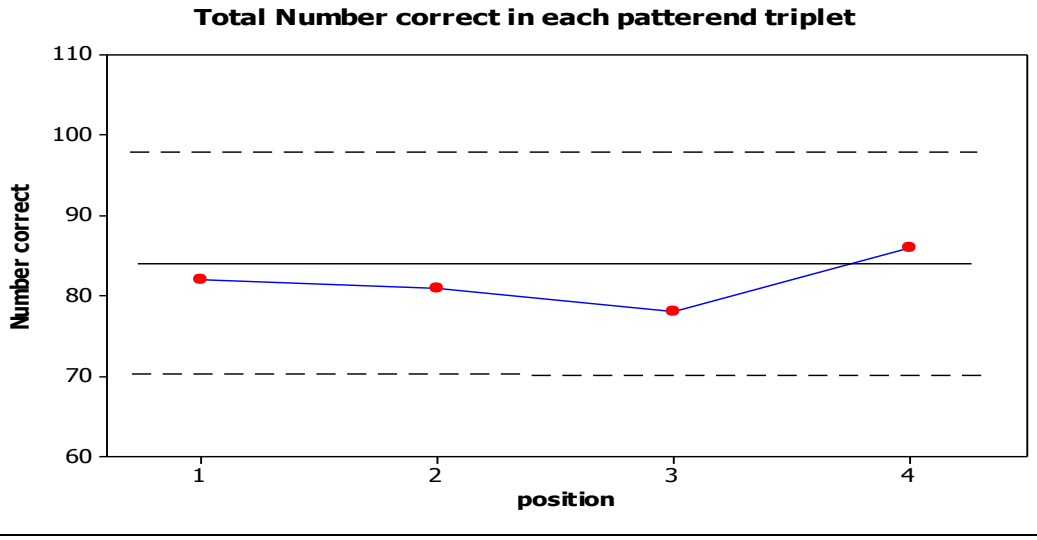


Figure 6.9
The figure shows the total number of correct answers in sequences 2, 3, 4 related to pattern 1, 2, 3 and 4.

The two parameters of the statistical computation, number of correct answers and learning effect, trial by trial, give the following results:

- a number of pattern correct answers, in sequence 2, similar to the probability figures,

147, corresponding to 35% chance of being correct, a very high number of correct answers in sequence 3: 193, corresponding to 46% and in sequence 4: 176,

corresponding to 42%. In percentage terms, 46 and 42 are far from chance probability, 34. The number of pattern correct answer differs by sequence. There are 95 positive responses at pattern position in sequence 2, 38%, 121 correct answers in sequence 3, 48%, and 117right responses, 46%, in sequence 4.

- the increasing number of correct answer, trial by trial, can be seen from the related percentage from trial 10 to 20 in table 6.4, page 125
- the guessing of patterns, from pattern 1 to pattern 4, is represented by the numbers above the line of confidence interval and by the direction of the lines.

In figure 6.8, page 126, sequences 2 and 3 show an increasing number of pattern correct answers, above the line, in pattern 4. The positive results of the pattern trials of sequence 4 register decreasing values in pattern 4. The total trend for sequence 2, 3 and 4, is an improving of the pattern results for pattern 4, as presented in figure 6.9**,** page 127.

6.7 DISCUSSION

In this last experiment the aim was to encourage volunteers to predict or guess the outcomes. In this last series of experiments, short sequences or "patterns" of 3 target positions, for example 1, 2, 3 or 3, 3, 3, were repeated in the stimulus sequence. It is assumed that it will lead to identification and recognition of the scheme, to a proper

prediction of the next pattern trials, to a decrease in reaction time and to an increase in pattern correct answers.

The experiments tested the following hypotheses:

-correct answers delivered in response to a stimulus sequence containing a pattern, will have shorter reaction times than those recorded when no pattern is present

-the frequency of correct answers will be higher when patterns are present in the stimulus sequence

-the frequency of correct answers will increase when more repetitions of the patterns are presented.

For the first factor, reaction time, the analysis took account of the possible perspectives: correct, incorrect answers and previous correct, incorrect answers, using 2 techniques for calculation: the reaction time data and log transformation (RT -350), as explained at page 114.

The results show irregular distributions, means, which have similar values, similar p values, and some very slow individual trials, in each sequence. The pattern values, for each sequence and each level of pattern, do not give significant coefficients.

The first question was: is there a pattern effect on reaction time? The results say that the reaction time of patterned trials, however it is analysed, in terms of correct, incorrect answers, or after correct, after incorrect answers, is not significantly different from the reaction time of random trials. A reaction time learning effect, the decrease of the values at pattern presentation, was not found.

The studies on reaction time, signal of recognition and knowledge acquisition from Nissen and Mullemer (1987) were not confirmed in this investigation. The reasons might be at least two:

- the subjects did not recognize the patterns and maintained the same time behaviour in the two conditions, random and patterned. The probability to touch the right pad, among the 3, is 1/3, 34%.
- the subjects recognized the pattern, may be because they were too few, and took sometimes less, sometimes more time to weight and to select the options at the pattern repetition. The final values were a balance between their quick and slow reactions.

The second factor, the number of correct answers, is a crucial element for determining the prediction effect. It implies an increasing number of correct answers at pattern trials.

Taken the chance probability of correct answers, 34%, as reference, the random sequence confirmed the percentage, 35%. Sequence 2 had a simple pattern, easy to be identified, the repetition 3 times of the same switch, pad 3, but the final number of correct answers and pattern correct answers remains near the chance probability. Only pattern 4, in this sequence, is above this threshold.

The subjects predicted successfully, in sequence, 3, the pattern, that is the touching, in sequence, pad 1, 2 and 3. This is easy to detect, it is natural series. The result, 46% of total correct answers and 48% of positive pattern responses, means that near half of the answers were correct. In particular pattern 4 got the best count.

Sequence 4 had a more complex scheme: 2, 1, 2. The data register 42% of total positive responses and 46% of pattern correct answers, a high level above the 33% of chance probability. There is a decrease of results for pattern 4.

48% and 46 % are much more than chance probabilities. Is this a sign of learning, of correct prediction, of guessing? Specific further tests with the same volunteers were not planned. Did the subject gain knowledge of the regularities inside the 20 trials? Taking account that the subjects were not informed about the patterns and that they experienced different presentations of the first 3 sequences, these numbers, 48% and 46%, lead to give a positive answer, even if they are not statistically significant.

A proper explanation to the difference of the total percentage of correct answers between sequence 2 and sequences 3 and 4 cannot be given. It may be concluded that in 2 sequences, out of the 3, this percentage is above the chance level.

It has to be underlined the change in the number of positive responses in pattern 4. The trend was positive, above the confidence interval line, in sequences 2 and 3. This suggested that the volunteers guessed the patterns. Sequence 4, after successful results in pattern 1, 2 and 3, had a decrease of correct answers just at the last pattern. This again does not have an adequate explanation.

The initial question on an expected increase of correct answers, pattern by pattern, has an answer. The total numbers do not show significant differences; nevertheless the percentage at patterned trials, from the first to the fourth pattern, shows increasing numbers.

The studies on the basic process of keeping information, retrieving, maintaining and using the relevant rules, re-exposing the stimulus, development of abstract associations and models (Rogers and Monsell, 1995, Heuer et al. 2001, Bunge et al., 2001, Garavan et al., 2002, Acuna, 2002, Keele et al., 2003, Yarkoni et al., 2005, Opris and Bruce, 2005, Crone et al., 2006, Horner and Henson, 2008) were not properly supported by the results on number of correct answers.

This might be due to the specific conditions given by the experiments:

- no information was given to the subjects about the patterns

- an immediate reward might be proposed for the correct answers

- the random and patterned sequences might be a confusing experience for the subjects

- the presentation to the subjects of the first 3 sequences followed a different order, and this might have affected the comparison of the results inside the same sequence.

The conclusions of the investigation are:

1) when volunteers choose among options, the reaction times are not affected, when cues, in the form of patters, are present
2) in contrast, the frequency of correct answers can be significantly increased by the presence of cues. This is not true for all the patterns.

CHAPTER 7

GENERAL DISCUSSION

The event of choosing is an every day life experience. Sometimes we have to take simple decisions, which have immediate effects (at what time will I take the train to London?), sometimes we have a long term goal (I want to become a researcher) and we need to follow a path, a chain of connected steps, to build up the conditions to realise it.

We are pushed to learn from previous events, choices, and results coming from them, to predict what will be the reality, to define our plans, to guide the actions and to achieve our aims. The preparation phase is the basic step of the goal-directed-actions.

The choice situation, that everyone has to face repeatedly, becomes crucial in sport events, box*ing* and tennis for example, where guessing, what is going to happen between an athlete and the opponent, and choosing quickly are tools to get the score in a single action and to win the match.

The long run goal is identifying the weighting and the calibration of the conditions at the moment of the choice and determining how, and how quick, a person reacts. An investigation on this area might be a better understanding and an improvement for every person, and might help, in a competition, managing more effectively with the actions: the player taking quicker decisions, the opponent player understanding the action and reacting immediately, the trainer stimulating both skills and preparing him/her adequately to the crucial decision phase.

The scientific domain, to some extent, is an overlapping of Neuroanatomy and Psychology. Its complexity requires the identification of specific directions to be taken and the analysis of the related relevant aspects. It was decided to work on two main factors: reaction time and choice.

The study examined two factors of the decision making situation: time of reaction and choice. The first one deals with the period of the preparation phase: the time of option selection, the time of the focal action, from the beginning to its conclusion, detected by the device. It covers the period of neurological processes and mechanical execution, described in chapter 1, Literature Review, which can be identified and measured directly. The time of reaction includes also choice and" learning effect" duration. The 2 elements cannot be estimated precisely, because some other variables can come into play. For example in some experiments we found quick and slow volunteers. How to disentangle the two factors and to assign the different times to the processes? Specific solutions were found according to the single experiments.

The second factor, choice, refers to the weighting of the alternatives, the selection, the correct or not correct choice and it is quantified by the number and percentage of correct answers. In the last experiments cues were presented, the repetition of a 3 number pattern, to measure if the guessing trials could lead to a higher number of correct answers, compared to not cued trials.

The components evaluated in this investigation are: the focal action performed by dominant or non dominant arm, no-choice and choice situation, reward, delay, random or cue condition (pattern). The final result of the prediction is a positive or negative response and this will be the measure of the choice effectiveness.

The beginning of the pathway was the analysis on the relevant concepts. In the Literature review chapter the main studies on the neurophysiologic processes and the main concepts involved are presented.

The next stage was the identification of the variables affecting the situation: choice, delay, reward, sequence. It was specified their relevance and it was decided the order of their presentation in the experimental phase. A critical role was assigned to the cue element; without it a proper prediction and a proper choice, cannot be made. It was decided to examine first the other variables in order to have the parameters to weight them and to test at the end the main one, the cue, to be able to interpret properly all the components of the situation.

The qualities of the experimental situation were defined, according to the aims and the specific attributes to be evaluated. It had to be representative of a choice experience: 3 alternatives for the chosen action were planned. The time factor was measured from a "go" signal, the starting of the action, to its conclusion, the touching of a switch. It was planned also an "alert" signal to inform the subject of the coming green "go" light and to encourage the state of readiness. This is the delay time.

The real situation was planned and specified in details: devices, tools, behaviour of the subjects, behaviour and communication of the experimenter, measurements, general and specific aims.

The device was designed and tailored on the characteristics of the experiments. Their authorisation was given by the Ethics Committee of Glasgow University.

The Research path was designed as a chain of 4 logical steps, from the simple to the more complex one, representing the construct of the main aspects of a choice situation. Each stage was centred on one factor, testing its influence and its relationship with other factors in the experimental situation.

The basic setting changed very little at each experiment: the subjects were sitting during the first tests and standing during the last ones. The main focus was on the last experiment, which presented cues to realise a proper decision making and choice situation. The proposal of a complex final situation supposed the previous evaluation of the other concurrent variables.

The experimental pathway maintained the idea of progressive achievement of knowledge inside the situation. First, no choice and choice factors were tested, to have some basic measurements. The second step was the examination of no reward and reward components. The third step was on delay factor and the fourth step examined the organised sequence, comparing random and patterned series.

The project was realised. Here there is a synthesis of the results and the conclusions. The experiments in chapter 3 consist of 2 series of tests. The first ones were aimed on measuring reaction time in simple choice condition using dominant and non dominant arm. Random sequences were presented. The second series of tests, on choice, fixed the main parameters on reaction time and allowed to identify some categories of results, related to correct, incorrect answers, and to different delay times, from 1 to 9 seconds. As expected, the numbers in the middle, 4, 5, 6 seconds got the best outcomes. At this initial stage we cannot weight these categories with proper value, the issue will be developed later on, but their processing remains as first reference on these variables. The data

registered no relevant difference in reaction time, when the nearest arm, dominant or non dominant, is touching the pad. As expected, choice conditions required more time for reacting.

The basic protocol on choice behaviour was maintained in all the next experiments. The tests in chapter 4 were aimed at evaluating the effect of a possible reward on choice reaction time. The results showed that the possible reward had no decreasing or increasing effect on reaction time. The sequences were random, so the correct answers came by chance.

In chapter 5 the delay variable was examined. The subjects were in standing position; EMG electrodes were applied to representative muscles to check the initiation of the actions from the focal muscles and the effect on postural adjustments. During the 2 sections, each of the 2 sequences was presented in both conditions: random and fixed delay, to avoid any "sequence" effect and to define which of the 2 foreperiods, stable or variable, gave shorter reaction time data.

The results registered no significant difference in reaction time data. The EMG figures showed no contractions of postural adjustment and focal action muscles during the preparation phase, so it was concluded that random and fixed delays do not affect the reaction time performance and that the stage of option selection and choice do not involve muscle activity at peripheral level.

After the analysis of the previous variables, delay and reward, and having concluded that each of them does not modify the reaction time during a choice, the main factor, the cue, was tested. The experiments were presented in chapter 6. Three among four sequences had inside one pattern, repeated more times. Through the feedback, the subjects were in

the position to recognise the regular arrangement of 3 numbers and to predict correctly the next patterned trial.

In 2 sections and from standing position, the data of the random and patterned series were compared. It was computed the reaction time effect, the number, the percentage of pattern correct answers and the "learning effect", the expected increasing in number of pattern positive responses. The transformed data, Log (RT-350), did not give significant results for reaction time factor that is there is no difference between random and patterned reaction times. The figures on number of correct answers, compared to pattern correct section, registered a constant small increase of the percentage of the pattern section. A high percentage of positive responses (46% and 42%) and patterned trials (48% and 46%) was found in sequences 3 and 4, 2 series among 3, and in particular the last repeated pattern, pattern 4, registered more correct responses in 2 among 3 sequences. Even if the results were not statistically significant, it has to be underlined that nearly half of the subjects gave correct responses in the pattern trials in sequence 3 and in sequence 4.

The conclusion of the experiment was that when cues are presented, the time data fluctuate among the subjects and within the same subject, giving short and long reactions and this, at the end, produced flat, balanced results. In terms of statistical coefficients, the analyses were not significant, but we have to remember that guessing and predictions probably don't follow strictly the usual parameters.

The point, the non significant p values, does not allow generalising the conclusions to the population. The data suggest that the volunteers guessed the patterns at least in 2 out of 3 sequences and learned the 3 numbers of the scheme during the experience, responding more correctly at pattern 4. This extent of number of correct answers and its progressive

increment, from the initial to the final trials, was not observed in the previous experiments, where all the sequences were random. Probably the specific result is the effect of the patterns.

Considering the factors analysed during the investigation, the initial questions of the research and the responses that, step by step, were given, it is possible to define a framework of the field:

- in a choice situation the weighting of options is subjective and leads to different reaction times within the same person. It cannot be proved if there is a quicker reaction, when the subject is in the position to detect the presented cues and to guess the next response. The neurophysiologic process often takes more time for selecting the alternative. The centre of attention of the subject is to give the correct answer, not to be quick in touching the pad.
- other variables linked to reaction time: delay and reward make no difference on the duration of the reaction
- EMG data registered no preparation and no sign of weighting the alternatives, both in the focal and in postural adjustment muscles. The choice is done at higher level in the brain, at the specific experimental conditions
- the choice factor, relevant when the correct option is chosen in cue situation, registers a higher percentage and an increasing number of positive results, when people are in the position to guess and to have the feedback. The "learning" effect is a relevant aspect of the choice issue. The right choice has to be seen also from a broad perspective, looking at all the trials.

When the subjects grasp the scheme of the pattern and choose consequentially, they get an increasing number of correct answers. This is true at least for some of the subjects.

Within the limits of the results of this research and for the reasons already given, the 2 factors, choice and reaction time, have to be discussed separately. There was not found to be a direct, significant relationship linking correct answers and any precise change, increase or decrease in time of reaction, even if several studies tested this, as discussed above, page 130.

The future research on the same topics has to take account that some subjects have slow reactions, some are quick. In addition, during the patterned trials, the reaction times fluctuate, because the subjects take sometimes short, sometimes long time for choosing the target. At the end the values on time were balanced. An initial choice reaction time test, before the starting of new experiments in the same area, can help to find the appropriate category, quick or slow, for the subjects and to process the data accordingly.

The actual results might be due to the specific conditions of the experiment, may be some variables must be better weighted, for instance reward, or, may be, some new variables needed to be analysed. New tools might be used in addition, i.e. developing the EMG connections to check in addition other muscle contractions, or using a specific device to measure the body pressure on a platform, to improve the probability to detect changes during the selection phase.

The positive results on number of pattern correct answers give new indications for the next experiments; the guessing situation can be developed identifying different sequence conditions, different categories of cues, levels of difficulties, from more simple to

complex. A change in the number of the alternatives might play a role in the experimental setting.

After a new definition of the parameters, the reward variable might be tested again, in cue conditions, proposing different calibrations, immediate reward and checking both the reaction time factor and correct responses.

Expanding the perspective to the sport situation, considering for instance tennis or boxing, the correct actions of a player might lead to winning the match. As soon as the opponent player reads the body language (the cue) of the other participant, that is muscle contractions at very early stage, he/she can guess the action, choose the options and react immediately, trying to revert in his/her favour the outcome of the action.

Among the specific variables involved in sport field, it has to be mentioned emotion, which connects the rational components of the mind, involved in every choice, and sport movement techniques. Probably before an action there is a threshold of intensity of single different components; if it is experienced at the same time a high level of emotion, planning and programming, higher level functions, might involve the starting of action executions (possible actions), which could be read by the opponent player. The investigation did not explore the variables at this second level, which, possibly, is determinant and it is the real sport situation.

At a further stage, the athletes can learn how to detect the scheme arrangement, the possible actions of the opponent, from few representative signs, and then they could be trained to react quickly and in an unexpected, effective way.

The factors and the experiments examined in this study were a basic step on choice reaction time path. They could be a starting point for future investigations.

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APPENDIX I

ETHICS COMMITTEE AUTHORISATION

UNIVERSITY OF GLASGOW
FACULTY OF BIOMEDICAL AND LIFE SCIENCES

ETHICS COMMITTEE FOR NON CLINICAL RESEARCH INVOLVING HUMAN SUBJECTS, MATERIAL OR DATA

APPLICATION FORM FOR ETHICAL APPROVAL

NOTES:

THIS APPLICATION FORM SHOULD BE TYPED, NOT HAND WRITTEN.

ALL QUESTIONS MUST BE ANSWERED. "NOT APPLICABLE" IS A SATISFACTORY ANSWER WHERE APPROPRIATE.

Project Title: A STUDY ON MUSCLE CONTRACTION PATTERNS DURING OPTION SELECTION TASKS

Is this project from a commercial source? No

If yes, give details and ensure that this is stated on the Informed Consent form.

Date of submission to be entered_25th April 2007

Name of all person(s) submitting research proposal

Paola Rizzi

Position(s) held

PhD. student (NBS-FBLS)

Division: Neuroscience and Biomedical Systems

Address for correspondence relating to this submission: Paola Rizzi, Lab 245 West Medical Building.

Name of Principal Researcher (if different from above e.g., Student's Supervisor)

Dr Ronald Baxendale

Position held Reader (NBS-FBLS)

1. Describe the purposes of the research proposed.

The long term aim of this study is to investigate how human motor systems behave when people are asked to make fast movements and fast choices of target. The first two applications have been reviewed and approved, reference numbers 0503 and 0507.

The immediate purpose of this study is to investigate

1) if, in a choice situation, there is some recurrent identifiable electromyographic pattern present before a person sees the "go" signal to move.

2) if the patterns are maintained, modified or enhanced in a when the person is offered a 'reward' for making correct choices.

There is a body of scientific literature (see below 1, 2, 3, 4) about single aspects of decision making and about the single variables which play a role in the situation, e.g. delay, sequence, neurophysiological processing in connection with feedback, feedforward movement preparation, anticipation, postural adjustments, the time taken to make voluntary reactions. These studies have not investigated in depth how the postural contraction interacts with the focal movement before the choice is made.

The present study intends to investigate:

- the EMG patterns in response to a randomised and a predictable sequence of instructions.
- the EMG patterns in responses when the possibility of reward exists.

For example, are the EMG patterns initiated earlier when the sequence is predictable or the volunteer may gain a reward.

2. Please give a summary of the design and methodology of the project. Please also include in this section details of the proposed sample size, giving indications of the calculations used to determine the required sample size, including any assumptions you may have made. (If in doubt, please obtain statistical advice).

There are no data in the scientific literature to allow statistical power calculations to be performed. This application concerns a pilot study to provide such data.

We seek permission to invite 12 adults to participate in the experiment. It is hoped that they will represent the 'normal' adult population.

Volunteers will be adults (18-55 years) with no history of neurological disease. Both males and females are invited to participate since there is no reason to believe they have different muscle reaction. The volunteers will have no particular history of participation in sports.

Each person will attend the lab for two visits lasting approximately 45 minutes each. During this period they will be familiarised with the experiment and informed consent will be sought. They will then proceed to choose, inside a sequence of 20 trials, each time one switch among three. The subjects will have the feedback from one of the 2 devices. During the first session two sequences are proposed, the first is random, the second will follow logical principles. This is related to guessing. During the second session there are two non-random sequences, the second is related to a reward for the best guesser of the group, who will win 20 pounds. The volunteers are free to terminate the experiment at any stage.

3. Describe the research procedures as they affect the research subject and any other parties involved.

The volunteer is invited to participate, given an information sheet, the nature of the experiment is explained and any question answered. The volunteer is then invited to sign the consent form.

If they give consent:
Four sets of EMG electrodes are attached to skin over muscles in the arms and legs.
The volunteer stands before a set of three lights and switches.
When one of the sets of lights is illuminated the volunteer reaches to press the appropriate switch as fast as possible. Thus the volunteer must choose which target and when to move. If they predict and move early they may be mistaken. Alternatively, they can choose to be slower and possibly more correct often.

The sequence of targets and delays can be adjusted to deliver pseudorandom sequences or predictable sequences. The EMG is measured continuously. The times to make contact with switches and the switch chosen are also logged automatically.

Each sequence of twenty stimuli lasts for 5 minutes or less and two sequences are run in any one experiment session. Thus the volunteer participates for about 45 minutes on each of two days.

4. What in your opinion are the ethical considerations involved in this proposal? (You may wish for example to comment on issues to do with consent, confidentiality, risk to subjects, etc.)

In our opinion the ethical considerations are very minor.

Informed consent is sought before the experiment starts.

The experiment is short and puts the volunteer at no risk.

The file naming strategy ensures the volunteer's anonymity.

5. Outline the reasons which lead you to be satisfied that the possible benefits to be gained from the project justify any risks or discomforts involved.

There is a reasonable balance between risk and benefit.
The "risk" or "discomfort" as explained above is very mild, if it exists at all. The gain is in terms of a better understanding of the central nervous system in a decision making situation.

6. Who are the investigators (including assistants) who will conduct the research and what are their qualifications and experience?

Paola Rizzi B.Ed (Pedagogy and Physical Education), M. Phil (Psychology): The investigator is a part time Ph.D. student and the University of Glasgow and a lecturer in Motor Sciences at Padova University in Italy.

Ronald Baxendale BSc PhD is a Reader in the Division of Neuroscience in Glasgow University.
Both have extensive experience of testing motor skills in humans.

7. Are arrangements for the provision of clinical facilities to handle emergencies necessary? If so, briefly describe the arrangements made.

No. The applicants do not think such an emergency is likely.
There is a first aid box in the laboratory where the experiment will take place. There is a telephone to call for assistance

8. In cases where subjects will be identified from information held by another party (for example, a doctor or hospital) describe the arrangements you intend to make to gain access to this information including, where appropriate, which Multi Centre Research Ethics Committee or Local Research Ethics Committee will be applied to.

There is no possibility of subject identification.

9. Specify whether subjects will include students or others in a dependent relationship.

Students are not in a dependent relationship with the experimenter.

10. Specify whether the research will include children or people with mental illness, disability or handicap. If so, please explain the necessity of involving these individuals as research subjects.

The experiment will not test children or people with mental illness, disability or handicap

11. Will payment or any other incentive, such as a gift or free services, be made to any research subject? If so, please specify and state the level of payment to be made and/or the source of the funds/gift/free service to be used. Please explain the justification for offering payment or other incentive.

12. Please give details of how consent is to be obtained. A copy of the proposed consent form, along with a separate information sheet, written in simple, non-technical language MUST ACCOMPANY THIS PROPOSAL FORM.

The volunteer will be given an information sheet. They will be invited to discuss the experiment and any questions answered. They will be invited to sign a consent form.

13. Comment on any cultural, social or gender-based characteristics of the subject which have affected the design of the project or which may affect its conduct.

In our opinion there are no cultural, social or gender-based issues in this project

14. Please state who will have access to the data and what measures which will be adopted to maintain the confidentiality of the research subject and to comply with data protection requirements e.g. will the data be anonymised?

The experimenter will have access to the data.
The data will be anonymised using a code known only to the experimenter.
The data files will be destroyed at the end of the experiment, to comply with the Data Protection Act..

15. Will the intended group of research subjects, to your knowledge, be involved in other research? If so, please justify.

It is possible that the volunteers will participate in other experiments.
It is not the intention to recruit from other experiments.
The simple nature of this study will not place the volunteer at any additional risk

16. Date on which the project will begin 1st May 2007 and end 30th July 2007

17. Please state location(s) where the project will be carried out.

Laboratory 245, West Medical Building, University of Glasgow.

18. Please state briefly any precautions being taken to protect the health and safety of researchers and others associated with the project (as distinct from the research subjects) e.g. where blood samples are being taken

The researchers are at no additional health and safety risk.

Signed _____ Date _____

(Proposer of research)

Where the proposal is from a student, the Supervisor is asked to certify the accuracy of the above account.

Signed _____ Date _____

Supervisor of student)

Email the completed form to: S.Morrison@bio.gla.ac.uk

And send the signed hard copy to:

Stuart Morrison

Faculty Research Office
Faculty of Biomedical & Life Sciences
West Medical Building
University of Glasgow
Gilmorehill
Glasgow
G12 8QQ

CONSENT FORM

Volunteer identification number

TITLE OF THE PROJECT: AN ELECTROMYOGRAPHIC STUDY OF ARM MOVEMENTS AND POSTURAL CONTRACTIONS IN A 3-CHOICE SITUATION

Name of the Researchers: PAOLA RIZZI and RON BAXENDALE

1) I confirm that I have read and understood the information sheet for the above mentioned study and I have had the opportunity to ask questions

2) I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason.

3) I agree to take part in this study.

Name date signature

Researcher date signature

VOLUNTEER INFORMATION SHEET

TITLE OF THE PROJECT: AN ELECTROMYOGRAPHIC STUDY OF ARM MOVEMENTS AND POSTURAL CONTRACTIONS IN A 3-CHOICE SITUATION

You are invited to take part in a research study. Before you decide it is important for you to understand why the research is being done and what it will involve. Please read the following information carefully and discuss it with others if you wish. Ask us if there is anything that it is not clear or if you wish more information. Take time to decide whether or not you wish to take part. Thank you for reading this.

FREQUENTLY ASKED QUESTIONS

WHAT IS THE PURPOSE OF THE STUDY?

The purpose of this study is to investigate muscle contraction before and during the choice behaviour. There is a body of scientific literature about decision making and voluntary reactions. These experiments have not investigated in depth how the postural adjustments, before the movement is initiated, reflect the option and the choice phase.

The immediate purpose of this project is to record the activity of muscles in the arms and legs before, during and after movements towards a target.

The longer-term purpose is to explore the processes associated with decision making at the border of consciousness. This can help to understand the links between intentions, decisions and movements.

WHY HAVE I BEEN CHOSEN?

You have been chosen because you are a healthy adult aged between 20 and 55 years.

DO I HAVE TO TAKE PART?

It is up to you to decide whether or not to take part you will be given an information sheet and you will be asked to sign a consent form. If you decide to take part you are still free to withdraw at any time and without giving a reason. You will be part of an initial group of 12 people.

WHAT WILL HAPPEN IF I TAKE PART?

You will come for 2 sessions. Each time you will be standing, 2 devices are near you, one ahead, one behind. The one behind is connected with 4 electrodes fixed to the shoulders and posterior, low part of the legs. The one ahead is the choice device. You will see a red light switched on in front of you and, after 6 seconds, a green light. You will make your choice touching the switch panel as quickly as possible, trying to give the correct answer.
4 recording electrodes are taped to your skin over muscles in your shoulder and leg. Before the tape is applied to your skin you will be wiped with alcohol and a thin smear of gel applied.
After a few trials to familiarise you with the task and if you are happy to continue, the experiment will be carried out. Two sets of twenty trials are proposed each time. Each set will last approximately 10 minutes.

WHAT ARE THE POSSIBLE DISADVANTAGES AND RISKS OF TAKING PART?

The experiment is short and there is no significant additional risk associated with participation.

WHAT ARE THE POSSIBLE BENEFITS OF TAKING PART?

The “risk” or “discomfort” to you is very small, if it exists at all. The gain is in terms of a better understanding of the relationship between movements and choices.

WHAT IF SOMETHING GOES WRONG?

The chances of something going wrong are extremely small. All the procedures involved in this study are very low risk.
In the unlikely event that you are harmed due to someone’s negligence, you may have grounds for a legal action, but you may have to pay for it.

WILL MY TAKING PART IN THIS STUDY BE KEPT CONFIDENTIAL?

All the information collected about you during the course of the research will be kept strictly confidential. Any information about you which leaves the University will have your name and address removed so that you cannot be recognised from it.

WHO HAS REVIEWED THE STUDY?

This study has been reviewed and approved by the Research Ethics Committee.

CONTACT FOR FURTHER INFORMATION

Any questions about the procedures used in this study are encouraged. If you have any doubts or questions, please ask for further explanations by contacting either:

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You will be given a copy of this information sheet and a signed consent form to keep for your records.

APPENDIX II

STATISTICAL MODEL FROM DR. BONDARENKO

The focus of the study is on the following effects:

1) Effect of Correct Answer on Reaction Time
2) Effect of Previous Correct Answer on reaction Time
3) Effect of patterns inside the sequence
4) Effect of the sequence itself on Reaction Time.

I suggest that you should do repeated measures analysis, or longitudinal analysis, through 4 steps to have the basic statistical references.

The factors are:

-outcome measures, Reaction Time

-predictors: Correct Answer (YES/NO)

Sequence: Sequences (1, 2, 3, 4) can be seen as a treatment #of trial

Sequences (from trial 1 to trial 20) can be seen as a learning time

ANALYSIS

I. To see if there is effect of pattern

Take sequence1 and one of the other sequences and create an indicator variable for patterned part of the sequence and do the following 2 tables:

Previous answer	Patterned part of seq(#)	Seq.1+random part of seq (#)
Correct	Mean(RT)(SE)	Mean(RT)(SE)
Incorrect	Mean (RT(SE)	Mean(RT)(SE)

Current answer	Patterned part of seq(#)	Seq.1+random part of seq (#)
Correct	Mean(RT)(SE)	Mean(RT)(SE)
Incorrect	Mean (RT(SE)	Mean(RT)(SE)

II.To see if there is learning effect (# of the trial effect):

1)Plot Reaction Time by the number of trial

2)See how Reaction Time changes with time do the table:

# of trial	Mean (RT) (SE)	% of correct answers
1		
2		
20		

From the last table you want to establish if you observe a monotone learning process. Or it's rather a jump function. If so, where it happens.

III .To see if there is effect of sequence you may want to do the table:

# of sequence	Mean (RT) (SE)	% of correct answers
1		
2		
4(5)		

IV. To see if learning effect (# of trial) differs by #of sequence

Table 1**.** Mean (RT) (SE) for each cell, I. To see if there effect of pattern

Table 2**.** Percentage of Correct Answer in each cell

	# of Sequence			
# of trial	#1(random)	#2	#3	#4
1				
2				
20				

APPENDIX III

CHAPTER 3

FIRST EXPERIMENTS TO MEASURE REACTION TIMES

IN DOMINANT AND NON-DOMINANT ARMS

Random order of pads	
Subject	**Pad**
1	1, 2, 3
2	1, 3, 2
3	2, 3, 1
4	2, 1, 3
5	3, 2, 1
6	3, 1, 2
7	1, 2, 3
8	1, 3, 2
9	2, 3, 1
10	2, 1, 3
11	3, 2, 1
12	3, 1, 2
13	1, 2, 3
14	2, 3, 3
15	3, 1, 2

Table 3.1
The table shows the random order of pads for 15 subjects in no choice conditions.

Sequences for either arm and dominant arm and subject order					
Trial	**Either arm**	**Trial**	**Dominant arm**	**Subject**	**Subject order**
1	2	**1**	3	**1**	1
2	1	**2**	2	**2**	2
3	3	**3**	3	**3**	1
4	2	**4**	2	**5**	1
5	2	**5**	2	**6**	2
6	1	**6**	1	**7**	1
7	1	**7**	1	**8**	2
8	1	**8**	2	**9**	1
9	3	**9**	3	**10**	2
10	2	**10**	3	**11**	1
11	3	**11**	3	**12**	2
12	1	**12**	1	**13**	1

Table 3.2
The table shows either arm, dominant arm sequences and the subject order.

CHAPTER 5

REACTION TIME AND DELAY, THE TIME BETWEEN "GET READY" AND "GO" SIGNAL

Experiment on Delay Sequence 1 and Sequence 2			
Trial	**Sequence 1**	**Trial**	**Sequence 2**
1	2	**1**	3
2	1	**2**	2
3	3	**3**	3
4	2	**4**	2
5	2	**5**	2
6	1	**6**	1
7	1	**7**	1
8	1	**8**	2
9	3	**9**	3
10	1	**10**	3
11	3	**11**	3
12	1	**12**	1
13	2	**13**	1
14	3	**14**	1
15	1	**15**	2
16	1	**16**	1
17	1	**17**	2
18	2	**18**	3
19	2	**19**	2
20	3	**20**	3

Table 5.1
The table presents the 2 series of 20 trials, sequence 1 and sequence 2.

CHAPTER 6

THE EFFECT OF PATTERNS ON REACTION TIME AND ON THE NUMBER OF CORRECT CHOICES

Order of sequences		
Subject	**Group**	**Order of sequences**
1	1A	1, 2, 3, 4
2	1B	1, 3, 2, 4
3	2A	2, 1, 3, 4
4	2B	2, 3, 1, 4
5	3A	3, 2, 1, 4
6	3B	3, 1, 2, 4
7	1A	1, 2, 3, 4
8	*1B*	1, 3, 2, 4
9	2A	2, 1, 3, 4
10	2B	2, 3, 1, 4
11	3A	3, 2, 1, 4
12	3B	3, 1, 2, 4
13	1A	1, 2, 3, 4
14	1B	1, 3, 2, 4
15	2A	2, 1, 3, 4
16	2B	2, 3, 1, 4
17	3A	3, 2, 1, 4
18	3B	3, 1, 2, 4
19	1A	1, 2, 3, 4
20	1B	1, 3, 2, 4
21	2A	2,1, 3, 4
22	2B	2, 3, 1,4

Table 6.1
The table presents the order of the sequences according to the number of each subject.

Sequences and patterns					
Trial	**Sequence 1**	**Sequence 2**	**Sequence 3**	**Sequence 4**	**Pattern number**
1	1	3	1	2	2
2	3	1	2	1	2
3	3	2	3	2	2
4	2	3	3	1	1
5	2	3	1	3	2
6	1	3	2	2	3
7	2	1	3	1	2
8	1	3	1	2	2
9	1	3	2	3	1
10	3	3	1	2	2
11	3	1	2	1	1
12	1	3	1	2	2
13	2	2	2	1	1
14	3	3	3	2	2
15	3	3	2	2	2
16	2	3	3	1	2
17	3	1	2	2	1
18	1	3	1	1	2
19	1	3	2	1	2
20	1	3	3	3	2

Table 6.2
The table shows the 4 series of 20 trials in sequences 1, 2, 3 and 4, the patterns and their position.

A

	Pattern section		Random section		P value
Seq. 2 PACA	6.345512	**Seq.1+RAS2**	6.304415	**Seq. 2**	0.079
Seq. 3 PACA	6.190442	**Seq.1+RAS3**	6.205885	**Seq. 3**	0.883
Seq. 4 PACA	6.109843	**Seq.1+RAS4**	6.189871	**Seq. 4**	0.167

Table 6.3 A
The figure shows the comparison between the Log reaction time of pattern correct answer of the 3 patterned sequences and the random section. The related p values are presented.

B

	Pattern section		Random section		P value
Seq. 2 PAIA	6.129994	**Seq.1+RAS2**	6.304415	**Seq. 2**	0.032
Seq. 3 PAIA	6.226032	**Seq.1+RAS3**	6.205885	**Seq. 3**	0.915
Seq. 4 PAIA	6.160436	**Seq.1+RAS4**	6.189871	**Seq. 4**	0.524

Table 6.3 B
The figure shows the comparison between the Log reaction time of pattern incorrect answer of the 3 patterned sequences and the random section. The related p values are registered.

C

	Pattern section		Random section		P value
Seq. 2 Previous PACA	6.335536	**Seq.1+RAS2**	6.304415	**Seq. 2**	0.427
Seq. 3 Previous PACA	6.13711	**Seq.1+RAS3**	6.205885	**Seq. 3**	0.260
Seq. 4 Previous PACA	6.112749	**Seq.1+RAS4**	6.189871	**Seq. 4**	0.233

Table 6.3 C
The figure shows the comparison between the Log reaction time of previous pattern correct answer of the 3 patterned sequences and the random section. The related p values are presented.

D

	Pattern section		Random section		P value
Seq. 2 Previous PAIA	6.190614	**Seq.1+RAS2**	6.304415	**Seq. 2**	0.230
Seq. 3 Previous PAIA	6.242815	**Seq.1+RAS3**	6.205885	**Seq. 3**	0.656
Seq. 4 Previous PAIA	6.190271	**Seq.1+RAS4**	6.189871	**Seq. 4**	0.848

Table 6.3 D
The figure shows the comparison between the log reaction time of pattern previous incorrect answer of the 3 patterned sequences and the random section. The related p values are registered.