Relationships Between Physical Activity and Motor and Cognitive Function in Young Children

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Declaration page

Author's declaration

I declare that the work contained in this thesis is original, and is the work of one author, Abigail Fisher except where otherwise stated. The information reported from other authors has been quoted with their name and source of publication. The relative contributions in terms of study design, data collection and analysis has been highlighted at the beginning of each research chapter.

Supervisor's declaration

I certify that the work reported in this thesis has been performed by A Fisher and that during the period of study he has fulfilled the conditions of the ordinances and regulations governing the Degree of Doctor of Philosophy.

Name ____________________ Date _________________

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Abstract

Background: There is evidence suggesting a relationship between physical activity and movement skills in adolescents. Evidence, primarily from animal and older adult data, suggests that physical activity can improve cognitive function. Both motor and cognitive function are essential components of school readiness. If these relationships exist in young children, promotion of physical activity may have a significant impact on school readiness and academic achievement.

Participants and Methods

Study 1: 394 children (mean 4.2 SD 0.5 years; 209 boys/185 girls) were recruited from 36 Glasgow preschools. Physical activity (PA) was measured using the Actigraph accelerometer, movement skills (MS) were assessed using a test based on the Movement Assessment Battery. **Studies 2-4:** 64 children (mean age 6.2 yrs SD 0.3; 33 boys / 38 girls) were recruited from 6 Glasgow primary schools. Psychological outcome measures were the Cambridge Neuropsychological Test Battery (CANTAB) (working memory), the Attention Network Test (reaction time) the Cognitive Assessment System (CAS) (executive function), and the short form of Connor's Parent Rating Scale (CPRS:S) (behaviour). Physical activity was measured using the Actigraph GT1M accelerometer. A specialist and trained teacher-led physical activity intervention (active games) was run in intervention schools 2 hours per week for 10 weeks. The control PE sessions were specialist and teacher led standard curriculum, increased to 2 hours per week.

Results: Study 1: There was a statistically significant, but very weak (r 0.18, p <0.001), correlation between MS and PA. Boys and girls in the highest quartile for MS had significantly greater time spent in MVPA than girls and boys and girls in the lowest quartile, but this difference was small; median difference between girls in Q4 and Q1 0.9%: 95% CI 0.2-1.6% p 0.01), median difference between boys in Q4 and Q1 (median difference 0.9% 95% CI 0.0-0.2% p 0.04). **Studies 2-4:** Test and 3 week retest intraclass correlations (ICC) from the Cambridge Neuropsychological Test Battery (CANTAB) and Attention Network Test (ANT) suggest these measures are not sufficiently reliable in to be used an outcome in a future RCT in this age group (CANTAB spatial span r 0.51 p<0.001; spatial working memory r 0.49 p<0.00.1; strategy r 0.08, p<0.52) (ANT reaction time 0.32 p<0.05; accuracy 0.62, p<0.001). The CAS was accepted well by young children, has good previously established reliability, and would be a suitable outcome measure for a full scale RCT. There was no significant difference between the intervention and control group change in CAS scores (Full scale t=-0.74, p=0.48) or any of the subscales (p all >0.05). Physical activity was significantly higher during the intervention, than the control physical education (PE) sessions (median difference 628 cpm 95% CI 460, 786 p= <0.0001). During the standard curriculum PE sessions children in the control group spent 58% of their monitored time in sedentary behaviour. The existing data suggest that a 10 week intervention may improve spatial working memory (t=2.78, p 0.01) and aspects of behaviour (CPRS:S Cognitive Problems/ Inattention (t=2.00 p=0.04) in this age group, but further research in larger samples, with a more robust measure of SPW would be required to confirm these findings. The data allowed a power calculation for a future full scale RCT to be calculated (based on the CAS Planning scale), based on data from the current study a sample size of n=75 in each arm would be required, recruiting 100 in each arm to allow for drop-out.

Conclusion

The present data suggest only a weak relationship between MS and habitual activity, and questions the strong emphasis placed on movement skill development in the preschool curriculum. The present thesis provides data to adequately design and power a future full scale RCT to examine the effects of exercise and cognitive function.

List of publications

JJ Reilly, **A Fisher**, S Ashworth, C Boreham, Physical Activity and Health in Children and Adults (2008) Editors G. O' Donavan and S.J. Biddle, Human Kinetics Champaign, Illinois. Based on **Chapter 1.**

A Fisher, JJ Reilly, LA Kelly, C Montgomery, A Williamson, JY Paton, S Grant. Fundamental movement skills and habitual physical activity in young children. *Med Sci Sports Exerc 2005; 37: 684-688.* Based on **Chapter 3.**

A Fisher, JJ Reilly, JY Paton, JE Boyle, P Tomoropowski, J McColl Effect of a school physical education intervention on cognitive function and behaviour in 7-8 year olds: exploratory randomised controlled pilot. *Under preparation.* Based on **Chapters 5 and 6**.

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Other publications

L A Kelly, J J Reilly, **A Fisher**, C Montgomery, A Williamson, J H McColl, J Y Paton and S Grant. Effect of socioeconomic status on objectively measured physical activity. *Arch Dis Child 2006: 91: 35-3*

JJ Reilly, LA Kelly, C Montgomery, A Williamson, **A Fisher**, JH McColl, R LoConte, JY Paton, S Grant. Physical activity to prevent obesity in young children: cluster randomised controlled trial. *BMJ 2006;333:104*

A Fisher, JJ Reilly, LA Kelly, C Montgomery, A Williamson, JY Paton, S Grant. Seasonality in physical activity in young children. *Pediatr Exerc Sci* 2005; 17: 31-40

Contents

List of tables

List of figures

Glossary

Acetylcholine: a neurotransmitter at cholinergic synapses in the central, sympathetic, and parasympathetic nervous systems. It is the most prevalent neurotransmitter in the body and is crucial to arousal, learning, memory, and motor function.

APOE e4 allele: genetic risk factor for dementia**.**

BDNF: (Brain-derived neurotrophic factor) is a member of the neurotrophic family that support the health & functioning of glutamatergic neurons (the primary neuron type in the brain). Brain-derived neurotrophic factor is capable of mediating the beneficial effects of exercise on brain plasticity BDNF is synthesised in the cell body, then transferred back and forth to synapses *(see Cotman & Engesser-Cesar, 2001 p75).*

BOLD fMRI- Blood oxygen level dependent functional magnetic resonance imageing that relies on changes in hemoglobin oxygenation.

BRdU can be incorporated into the newly synthesized DNA of replicating cells (during the S phase of the cell cycle), substituting for thymidine during DNA replication. Antibodies specific for BrdU can then be used to detect the incorporated chemical (see immunohistochemistry), thus indicating cells that were actively replicating their DNA

CREB (cAMP response-element-binding) stimulus induced transcriptional regulator, has a significant role in adaptive response and long-term memory formation. Found in mRNA. Neural marker of plasticity.

Dementia Cognitive impairment (e.g. loss of memory) that is significant enough to affect normal functioning. Specific types of dementia are **Altzeimer's disease** and **Vascular dementia.**

EEG - Electroencephalography is the measurement of electrical activity produced by the brain as recorded from electrodes placed on the scalp.

Executive functions - 'higher' cognitive processing**,** for example making goals, planning, response inhibition, working memory.

Exercise - is a sub-category of physical activity, which involves "planned, structured, and repetitive movements done to improve or maintain one or more components of physical fitness" (Caspersen *et al* 1985).

fMRI- (functional Magnetic Resonance Imagining) is a type of specialised imageing scan that measures the movement of blood related to neural activity in the brain or spinal cord of humans or other animals.

Glutamanergic neurons – The primary neuron type in the brain. They connect cognitive, sensory and motor brain regions.

Acetylinecholine is released by neurons at the neuromuscular junction that causes muscle contraction

Muscaniric receptors – acetylcholine receptors.

Neuron – neurons are the key cells in the brain.

Physical activity (PA) is defined as bodily movement produced by the contraction of skeletal muscle that increases energy expenditure above the basal level (Caspersen *et al.,* 1998; Power *et al.,* 1990). Habitual physical activity is a representation of an individual's usual physical activity.

Synapse: The region of a neuron where communication occurs.

Synapsin I: Found within mRNA. Neural marker of plasticity**.**

TrkB – the BDNF receptor**.**

Chapter 1: Literature review

1.1. Exercise and cognitive function: background

Note: Review studies will have only been cited when making general statements, as a guide for original research references and as an indicator of future research directions. Where a review is cited an [R] will appear beside the citation. ***For key reviews & meta-analyses on this topic see*** **Table 1. 1.**

Physical activity improves human brain health (Dishman et al., 1996[R]). There has been a resurgence of interest in the relationship between exercise and human cognitive function in recent years (Tomporowski, 2008[R]; Colcombe & Kramer, 2003; Sibley & Etnier, 2003). In the 50's and 60's this was an area of interest in research, however in the 1970's the research trends shifted to the physical benefits of exercise (Kirkendal 1986[R]). The large, and continuously growing, body of animal literature, and advent of new brain imageing techniques (e.g. blood oxygen level imageing (BOLD) and functional magnetic resonance imagine (fMRI) – see glossary for descriptions- in humans have greatly advanced researchers understanding of how exercise may impact on brain structure and function in adults (Kramer, 1999). Researchers are now developing interest in determining whether the exercise-related benefits on cognition seen in adults also apply to children.

The original research in this thesis relates to the relationship between physical activity and aspects of child cognitive function, and relationships between physical activity and motor function. However, as there is a paucity of child data examining the relationship between physical activity and cognitive or motor function at present (Tomporowski, 2008[R]; Etnier, 2006; Fisher et. al, 2005) and no previous experimental data on children under 7 years, key references from adult and animal data will be discussed also.

1.2. Physical activity and cognitive or motor function: animal data

For detailed descriptions of studies see

***Table 1.* 2.**

There is a wealth of very convincing animal data suggesting that physical activity can alter brain structure and function, impacting on learning and behaviour (see **summary Table 1.2)**. It is beyond the scope of this thesis to review all the animal literature, but the studies that are deemed chronologically important (both by the thesis author and by consistent citations in expert reviews) and most relevant to the current thesis will be discussed. Animal studies will be presented in chronological order to emphasise the development of the field.

Black et al. (1990) carried out a post-mortem examination of the cerebellar cortex of 38 10 month old rats that had been kept for 10 days in one of 4 experimental conditions; the Acrobatic condition (AC) which involved progressively more difficult balance beams, see-saws and ropes; the Forced Exercise condition (FX) (progressive treadmill walking); the Voluntary Exercise condition (free access to a running wheel) and the Inactive Condition (IC) which allowed minimal opportunity for exercise. Increased synaptogenesis (formation of new synapses) was seen only in the Acrobatic condition, whereas increased angiogenesis (formation of new blood vessels) was seen in both Forced and Voluntary Exercise conditions, relative to the Acrobatic and Inactive animals. The authors suggested that an element of motor learning must be present (i.e. progressively more difficult / new challenges) for synaptogenesis to take place (in rats) (Black et al., 1990).

Fordice & Farrar (1991) provided evidence that aerobic exercise can alter and enhance neurotransmitter systems; chronic treadmill running increased hippocampal high-affinity choline uptake (HACU) and muscaniric (membrane-bound acetylcholine receptor) receptor density in the rat hippocampus, resulting in enhanced spatial memory performance, as compared to acute treadmill running and control rats, (Fordice & Farrar, 1991). See

Table 1. 2 for details. There is also evidence that exercise can counteract the age-related decline in dopamine function in rats (MacRae et al., 1987).

Animal data suggest that exercise may enhance other systems in the molecular brain systems (Neeper et al., 1995). There is increasing support for the view that exercise induces brain-derived neurotrophic (BDNF) factor gene expression (Cotman & Engesser-Cesar, 2002[R]). BDNF is a growth factor that supports the health and functioning of neurons. BDNF targets the primary neuron type in the brain; the glutamanergic neuron (Cotman & Engesser-Cesar, 2002[R]). Neeper et al., (1995 & 1996) report evidence that voluntary wheel running in rats may increase gene expression of brain-derived neutrotrophic factor (BDNF) (Neeper et al., 1995 & 1996). BDNF is a neurotrophin (nerve growth factor) which supports the function and survival of neurons, and may help protect neurons from free radical damage. Neeper et al., (1995) found a direct correlation between BDNF messenger ribonucleic acid (mRNA) in the hippocampus, and distance run by the animal, and note that the greatest effects of exercise on BDNF were found in areas of high brain plasticity (changeable areas, responsive to environmental stimuli) (Neeper et al.1995).

BDNF is important in learning, and the formation of new memories via long-term potentiation (LTP). In LTP, synaptic stimulation and activity lead to the long-term potentiation of the synaptic response (Cotman and Engessar-Cesar, 2002). LTP is BDNF dependent.

Tong et al. (2001) provide further supporting evidence of enhanced hippocampal BDNF gene expression in rodents in response to exercise (wheel running). These authors also found that exercise led to changes in expression of a large number of other genes in the mouse hippocampus known to be associated with neuronal activity, structure of the synapse, and neuronal plasticity (Tong et al., 2001)

Evidence suggests that environmental enrichment can positively influence cognitive function (Kemmperman, 1997). However, in animal studies, results are often confounded by the fact that 'enrichment' includes more social interaction, and more opportunity for physical activity, than control conditions (van Pragg et al. 1999). van Pragg et al., (1999) attempted to control for this in a mouse study, by separating the components of enrichment to include Standard housing (with the same amount of space as Enrichment group); Enrichment; Exercise (voluntary wheel running) Swimming; and a control group. Their findings indicated that, post-mortem, the mice in the Exercise and Enrichment groups displayed enhanced neurogenesis in a hippocampal area called the dentate gyrus. The dentate gyrus is associated with neural plasticity, and storing of memories (van Pragg et al., 1999). Interestingly, the Swimming group did not differ from the control in terms of neurogenesis. The authors suggest this may be as the forced exercise periods (Swimming) were much shorter than the voluntary wheel running and/or the forced exercise may have caused stress which may 'counterbalance' the positive effect of exercise on the brain (van Pragg et al., 1999).

Overall, the animal studies to date provides convincing evidence that exercise has a beneficial effect on cognition, and this benefit may come from changes in the 'architecture' of the brain (Tong et al., 2001).

1.3. Physical activity and cognitive function in adults

For detailed descriptions of studies see Table 1. 3 & Table 1. 4.

Adults over the age of 85 are the fastest growing segment of our population (McAuley et al., 2004[R]). The incidence of dementia increases dramatically from mid-life to old age (Matthews et al., 2005) with approximately 1 in 10 adults aged 85-89 years developing dementia (Jorm & Jolley, 1998), and there are huge associated economic costs (McAuley et al., 2004[R]). Maintaining brain health and plasticity through life is, therefore, an extremely important public health goal (Rockwood & Middleton, 2007[R]; Rovio et al., 2005), and it is increasingly clear that exercise can help achieve it (Rovio et al., 2005; Cotman and Berchtold, 2002[R]). Over the past decade, a number of studies on humans have shown the benefits of exercise on brain health and function, particularly in ageing populations (Rockwood & Middleton, 2007; Cotman and Berchtold, 2002). Historically, exercise participation has consistently emerged as a key indicator of improved cognitive function in older adults (Berkman, 1993; Hill, 1993; Rogers, 1990; Blomquist and Danner, 1987) and recent research suggests that exercise is associated with a reduced risk of cognitive impairment (e.g. dementia and

Alzheimer's disease) (Rovio et al. 2005; Lytle et al., 2004; Weuve et al., 2004; Laurin et al, 2001), especially in those genetically susceptible – i.e. carriers of the APOE $_{e}$4 allele (Rovio et al. 2005). However, interaction between the APOE allele and exercise has not been confirmed in all studies (Podewils et al., 2005).

A 5-year prospective study of 4615 individuals indicated that physical activity was associated with lower risks of non-dementia cognitive impairment (CIND), Alzheimer's disease (AD) and dementia (Laurin et al., 2001). Similarly, Abbott et al., (2004) found a relationship between distance walked per day, and probability of developing Alzheimer's up to eight years later, in their sample of 2257 71 to 93 year old men. A retrospective study found that behavioural stimulation and physical activity reduced the risk of developing AD (Friedlands, et al., 2001). These data from humans are supported by the animal research demonstrating that exercise and / or behavioural enrichment can increase neuronal survival and resistance to brain insult (Stummer et al., 1994; Carro et al., 2001) promote brain vascularisation (Black et al., 1990; Isaacs et al., 1992) stimulate neurogenesis (van Praag et al., 1999), enhance learning (van Praag et al., 1999; Young et al., 1999), and contribute to maintenance of cognitive function during ageing (Escorihuela et al., 1995).

In a cross-sectional study of 55-79 year olds in the USA, age-related declines in cortical tissue density were significantly reduced as a function of cardiovascular fitness. These associations were greatest in the frontal, prefrontal and parietal cortices (Colcombe et al., 2003). These regions show the greatest age-related declines in humans (Raz, 2000). Importantly, they are also thought to support executive functions (Colcombe et al., 2004) which show the greatest improvement with cardiovascular training in ageing humans (Colcombe & Kramer 2003).

There is the suggestion from the animal literature that early life physical activity may be especially important, because it enables optimal neural development, resulting in a neural reserve that can be drawn upon in old age (Black, Isaacs and Greenough, 1991). Dik et al., (2003) carried a longitudinal study in 3107 of the participants in the Longitudinal Ageing Study Amsterdam (LASA) examining whether early life physical activity could influence cognition (measured by Mini Mental-State Exam, MMSE) in old age. After controlling for age, sex, verbal intelligence, socio-economic status, lifestyle (early life physical work demands, current PA levels, smoking status, alcohol consumption) and health indicators (diabetes, cardiac disease, depression), there was a significant positive association of early life physical activity with information processing speed (in men only) (Dik et al., 2003). Information processing speed declines rapidly with ageing, and is thought to be the basic component of most cognitive functions (Salthouse, 1996). A major limitation of this study was that early life physical activity was assessed using retrospective self-report, based on a single question. Participants with cognitive impairment were excluded from this study; however the misclassification of previous physical activity by the elderly is likely (Falkner et al., 2001).

A number of recent large prospective studies on older adults have examined the relationship between physical activity and cognition. Yaffe et al., (2001) reported a study of 5925 community dwelling women (>65 years of age), who were characterised by the distance (number of blocks on the street) they walked per week. The central question was whether higher levels of activity would serve a protective function 6-8 years later. These authors found that women with greater baseline physical activity levels were less likely to experience cognitive decline, measured by the mini-mental status exam (MMSE) during 6-8 year follow-up. This effect remained after controlling for age, education, health status, depression, diabetes, stroke, smoking and oestrogen use. A similar study (Barnes et al., 2003) with 349 participants (>55 years of age) found that baseline fitness level predicted higher levels of cognitive performance six years later. This study is noteworthy as it used both measures of aerobic fitness and self-report measures of physical activity, and assessed a wider range of cognitive processes. Higher levels of aerobic fitness (measured by $V0^2$ peak) predicted better performance of measures of attention and executive function (Barnes et al., 2003).

Richards et al., (2003) found that self-reported physical activity level at 36 years of age was predictive of higher levels of verbal memory in a sample of 1919 participants, from 43-53 years. Rovia et al., (2005) demonstrated that mid-life physical activity is associated with reduced risk of dementia in later life (Rovia et al., 2005). A large longitudinal study has also suggested obesity and overweight as an independent risk factor for cognitive impairment, even after controlling for cardiovascular disease and diabetes (other risk factors for cognitive impairment) (Whitmer, 2005) however, these authors did not control for physical activity. Gustafson et al., (2004) showed a longitudinal (24 year follow up) relationship between BMI and temporal lobe atrophy in women (Gustafson et al., (2004) even after controlling for a number of physical, demographic and lifestyle factors, including self reported physical activity (Gustafson et al., 2004). Adiposity related inflammation has been suggested as a potential hypothesis (Knecht et al., 2008[R]); C reactive protein is elevated in adiposity (Das, 2001), and also associated with cognitive decline and dementia (Yaffe et al., 2004). Mid life adiposity (skin fold thickness) has also been associated with Parkinson's disease (Abbot et al., 2003). It is unclear at present how, or if, these associations are related to, or mediated by, physical activity.

The bulk of the existing data suggest that modest levels of physical activity and exercise can have beneficial effects on several cognitive processes of middle-aged and older individuals, and studies also suggest a reduced risk of Alzheimer's disease with physical activity. Although these studies are valuable in establishing a reliable association between exercise and cognition, conclusions are limited by the prospective, observational design (self selection into exercise levels, limited assessments of cognition and fitness). It is important to examine the relationship between fitness, cognition and brain function in randomised clinical trials in order to confirm causality and to understand the 'dose-response' relationship between physical activity and cognition (Etnier et al., 2006).

Colcombe and Kramer (2003) carried out a meta-analysis of all experimental studies published between 1966 and 2001 examining the effect of cardiovascular fitness training on cognitive function carried out in adults over 55 years of age. These authors found a clear and significant effect of aerobic training on cognitive function. A further finding was that, although exercise effects were seen across a wide range of tasks and cognitive processes, the effects were largest for those that involved **executive control** processes (i.e. planning, scheduling, working memory, interference control, task coordination) (Colcombe& Kramer, 2003). Executive control processes, and the brain structures that support them, have been shown to decline substantially with age (Raz, 2000). Therefore, the results of the meta-analysis by Colcombe & Kramer (2003) suggest that even processes that are quite susceptible to ageing appear to be amenable to intervention (Kramer et al., 2005).

Colcombe et al., (2004a) carried out a cross-sectional fMRI study on 41 older adults (aged 55-77 years). These adults were split depending on their cardiovascular fitness (Rockport 1 mile walk test). The participants were examined using functional magnetic resonance imageing, while performing a modified version of the Ericksen Flanker test (Eriksen & Erisken, 1974. Consistent with the author's predictions, older adults who tested high in cardiovascular fitness, demonstrated significantly greater activation in several cortical regions associated with attentional control. In support, recent evidence has shown that individual differences in cardiovascular fitness affect regional cortical density (Colcome et al., 2003).

Kramer et al., (1999) demonstrated the first clear evidence that aerobic exercise (versus stretching and toning) has *selective* positive effects on cognition; with the benefits being seen in tasks involving executive control (planning, scheduling, working memory). In a randomised controlled trial by the same authors (Colcombe et al., 2004b) a separate sample of 29 sedentary older adults aged 58-

77 years were randomly assigned to either a cardiovascular training group (aerobic) which involved walking groups 3 times per week for 6 months with increasing length and intensity (heart rate), implemented by exercise training personnel, or a stretching and toning group (control). After 6 months the aerobic group showed a significantly greater level of task-related activity (measured by functional magnetic resonance imageing (fMRI) while performing the Flanker task as above) in attentional control areas (middle frontal gyrus, superior frontal gyrus, and the superior parietal lobe) and, interestingly, a reduction in activity in the anterior cingulate cortex (Colcombe et al., 2004).

As noted by the authors, fMRI measures used in these studies are sensitive to changes in blood flow. Therefore, it may be suggested that the results of these studies may be due to changes in fitness-related blood flow rather than changes in neural recruitment. However, as noted, in these studies, high-fit or cardiovascular trained participants show a *decrease* in activity in the anterior cingulate cortex (a region associated with the presence of behavioural conflict and the need to adapt attentional control processes). If increased fitness leads to increases in task-related blood flow, it should be seen in all areas therefore these data likely relate to changes in cortical function (Colcombe et al., 2003). The result of the adult studies described above support the hypothesis that aerobic exercise is associated with better performance on tests of executive function in older adults.

Suggested mechanisms for the effect of exercise in prevention of cognitive decline are mediation of risk factors (hypertension, high cholesterol, diabetes, overweight) (Kivipelto et al., 2001; Launer et al., 2002), however, Ravo et al. (2005) controlled for these factors and found a protective effect of exercise against dementia and Alzheimer's disease (Ravo et al., 2005). Other potential mechanisms may be alleviation of the amyloid burden (Ravo et al., (2005), increasing cognitive reserve, improvement or maintenance of vascular health (although evidence suggests that exercise-related reduction in vascular dementia are less likely; (Podewils et al., 2005) and neurobiological mechanisms. Neurobiological mechanisms are discussed in more detail in **section 1.6.**

Data from animal models, human behavioural paradigms and neuroanatomical models all suggest that exercise positively affects cognitive functioning in ageing humans (Colcombe et al., 2004).

1.4. Physical activity and cognitive function in children

Children's executive function

If the observed relationship between aerobic exercise and enhanced executive function performance were to exist in children, this may have a positive impact on school readiness and school performance (Bull et al., 2008), which in turn, may aid in the promotion of physical activity (in educational establishments, and by parents), and aid in the public health campaign to reduce the growing epidemic of childhood obesity (Wooford et al., 2008; Sharma, 2006; DeMattia et al., 2006; Reilly at al., 2006). Physical activity and play behaviours are thought to have important roles in the normal maturation of children's executive function processes (Hughes, 1995; Johnston, Christie and Yawkey, 1987; Panksepp, Sivity & Normasell, 1984). Indeed restrictive environments which limit children's access to time to engage in free play, rough and tumble play, and physical activity may retard frontal lobe structures resulting in core deficits present in ADHD (Panksepp, 1998).

Physical activity and cognitive function: child studies: for detailed descriptions of studies see Table 1. 6.

A meta-analysis of 44 studies on the effect of chronic exercise studies on cognition in children conducted by Sibley & Etnier (2003) suggested that chronic exercise is positively related to cognitive function in children. A significant overall effect size of 0.32 was obtained, providing further support for the effect sizes demonstrated in the adult meta-analyses (Etnier, 1997; Colcombe & Kramber, 2003; Etnier., 2006). Sibley & Etnier (2003) suggest however that their analysis is weakened by a number of factors. Firstly an insufficient number of studies (only 9 peer-reviewed studies using true experimental designs have been published) and the methodology and outcome measures in these studies vary dramatically. As noted by the authors, the little existing data support the hypothesis that exercise *causes* improvement in cognition, but that the limited number of studies, and potential confounding variables make it hard to draw conclusions, and randomised controlled trials are required (Sibley & Etnier, 2003).

It is unclear to what extent the observed effect of exercise on executive function in adults exists in children. In an attempt to address this issue, Davis et al. (2007) carried out the first ever RCT designed to examine the relationship between aerobic exercise and executive function in children. The trial involved 94 overweight (BMI >85th centile) 7-11 year old children in Georgia, USA. These authors examined pre and post scores from the Cognitive Assessment System (CAS); a standardized cognitive assessment containing a subscale measuring executive function (the Planning scale) and three other subscales measuring other aspects of cognition (the CAS is described in detail in **Chapter 4** of this thesis) after a 15 week intervention (aerobic games designed to elicit HR of >150 bpm). Children were assigned to a Control, a Low-Dose exercise (20 minutes 5 x per week) or High-Dose exercise (40 minutes 5 x per week) group. Significant improvements were seen in post-test CAS scores in the High-Dose group relative to the other groups. The improvements were seen in the Planning scale only, supporting the executive function hypothesis (Davis et al., 2007). Interestingly, similar improvements in fitness were seen in the High and Low-Dose exercise groups; this does not support the cardiovascular fitness hypothesis (that exercise-related cognitive gains are directly related to improvement in cardiovascular fitness). The results in this study may apply only to sedentary, overweight children from low socio-economic background, who may respond better to intervention (Davis et al., 2007). It is important to carry out research to determine whether these results can be applied to more typically developing children over a wider range of ages. It should be noted, that at the time of designing the protocol for the pilot study described in **Chapter 6,** the data from Davis et al. were not available. It was unclear what exercise ‘dose’ was necessary to elicit a change in cognitive function in children.

Physical activity and behaviour

There has been very little evidence on the effects of physical activity (chronically or acutely) in typically developing children. A meta-analysis by Allison et al. (1995) revealed 16 studies (some single participant studies) examining the effects of 'antecedent exercise'; defined as 'any increased physical exertion applied with the intent of reducing disruptive behaviour', on disruptive behaviour. A significant effect size of 0.33 was reported. It is unclear whether this is generalisable, as it possible that children with behavioural disorders may response better to intervention (Allison et al., (1995), and this is an area for further research.

Physical activity and academic achievement: see table 1.5.

Educators have suggested that physical activity contributes to academic performance (Sibley & Etnier, 2003). Physical activity is thought to be associated with improvements in attitude, discipline, behaviour and creativity (Keays & Allison, 1995). Cross-sectional studies tend to find a positive relationship between physical activity level and academic achievement (e.g. Castelli et al., 2007; Nelson & Gordon-Larson, 2006; Linder, 2002; Field et al., 2001). However, findings are equivocal; some cross-sectional studies have suggested no relationship (Dollman et al., 2006), or even an inverse relationship between physical activity and academic achievement (Tremblay et al., 2000). The large majority of existing studies have been cross-sectional in nature, and therefore give no information on the direction of the relationship, have used self reported physical activity, and sometimes self reported achievement scores (child participants asked to provide average grades) and may be confounded by numerous other health-related, demographic or environmental variables **(see summary Table 1. 5).**

For example, in a large-scale descriptive study on California school children, Winger & Thomas (2002) reported data obtained from 353,000 5th grade, 322,000 7th grade and 279,000 9th grade were associated with children's fitness scores on the Stanford Achievement Test (Winger & Thomas, 2002). In each age group higher academic achievement scores, particularly in maths and reading, were related with higher levels of physical fitness (Winger & Thomas, 2002). Castelli et al., (2007) found that aerobic fitness has a small, significant positive relationship to academic achievement (Castelli et al., 2007). These data do not attribute a causal relationship between children's physical activity and learning as the data are cross-sectional.

To date there is only one randomised controlled trial that has examining the effects of physical activity (increased physical education (PE) time) in schools on academic achievement (Ahamed et al., 2007). In a 16 month cluster RCT, ten schools were randomised to intervention or control (usual practice). The intervention consisted of the AS! BC model, which is a school health framework designed to promote physical activity in schools incorporating school, home and environment elements, and teacher training (Ahamed et al, 2007). In this intervention study, 15 minutes extra physical education per day was provided by teachers. There was no significant difference in achievement scores after 16 month intervention (Ahamed et al., 2007). Although this study is the only existing RCT to examine the effects of exercise on achievement, there are notable limitations; physical activity was assessed by questionnaire, which is prone to bias, especially in children (Trost, 2005). There were no objective measures of either habitual physical activity or the intensity of the PE intervention. 15 minutes a day extra PE time only amounts to around an extra 75 minutes per week, which may not be enough to be a high enough ‘dose’ of physical activity to influence cognition (Davis et al, 2007), and the practicalities of carrying out such an intervention in school time make it probable that a large proportion of the supposed ‘enhanced’ PE was actually spent organising and instructing children, and warming up / cooling down. Although randomised, the control group had significantly higher baseline achievement scores than the intervention group (Ahmed, et al., 2007) while this may have been unavoidable, it suggests that there may have been inherent differences between the children in the intervention and the control group. Another major limitation was the failure to control for socio-economic status (SES), which is a know predictor of academic achievement (Noble, 2005; Blair, 2005).

Only four large-scale studies (included in the Sibley and Etnier meta-anlaysis) have been conducted and published examining the effect of exercise and academic achievement; the Vanves project (not published in English, but mentioned as quoted consistently), the Trois Riveries study (Shephard et al, 1984), the South Australian study (Dwyer et al., 1978), and Project SPARK (Sallis et al., 1999). In each of these studies time in physical education (PE) was increased dramatically and time spent in academic subjects was reduced. In three of the studies there was a significant improvement in academic performance with increased PE, and in one (the South Australian study) there was no difference in academic performance between increased PE and standard curriculum **(see Table 1. 5).** This finding is also important as, although time spent in PE was increased by approximately 15%-20%, there was no detriment to more 'academic' subjects.

The mechanisms by which physical activity may positively influence academic achievement are unclear. It has been suggested that exercise may exert its positive effect on cognitive function in children by providing a 'break' from the classroom (Shephard, 1996). While it would seem natural that this would be the case, this does not appear to be supported in the literature; there is evidence that there may a threshold level of activity that has to be reached in order for children to benefit academically from exercise within school physical education (PE) time. Coe et al., (2006) randomly assigned 214 children to either enrolment in school PE or non-enrolment, and found that, even within the PE group, only those children who achieved a level of activity set by the US Healthy People 2010 Guidelines (US Surgeon Generals Report, 1996); at least 5 or more session of 30 minutes moderate PA per week, and 3 or more 20 minute sessions of vigorous activity (Coe et al., 2006).

Of note in the study by Coe et al., (2006) is that there were no significant differences in the grades of children in the PE group in general versus the non-PE group, despite substantially less 'academic' classroom time. While there is very limited data on the effect of enhanced school PE on academic grades, and the results of existing studies are equivocal, the literature is consistent in it's finding that increased physical education time, and it's consequent reduction in classroom time, does not have a detrimental effect on academic performance

(Trudea & Shephard, 2008[R]; Coe et al., 2006; Dwyer, et al., 2001; Daley & Ryan, 2000). It is important to establish which aspects of physical activity impact which aspects of cognitive function, and also how changes in cognitive function relate to academic achievement, before attempting to determine whether physical education in schools can influence academic performance. School-based physical education also tends to have a large motor skill development component and emphasis with limited evidence of the impact of aerobic exercise. Based on the adult & animal data it is likely that aerobic exercise has the greatest impact on cognition, and none of the existing studies looking at the effects of PE on academic achievement take this into account.

It is important to try and understand the interaction between physical activity, motor and cognitive development, in order to attempt to understand how they may influence school performance

1.5. Physical activity and cognitive function: potential mechanisms

It is clear that exercise can positively influence cognitive function (Etnier et al., 2006; Colcombe & Kramer, 2003; Sibley & Etnier, 2003). Possible mechanisms by which exercise may exert its effects on cognition are discussed.

Acute exercise effects on cognition

Acute (a single session) of exercise is thought to have a facilitating effect on mental functioning, but previous studies in humans have been inconclusive, likely due to lack of consistency in the methods of testing (Magnie et al., 2000;

Tomporwksi & Ellis 1986). Several studies in adults have reported numerous benefits of acute exercise sessions such as reduction in anxiety (Roth,1989), feelings of well-being and clarity of thought (Tuson & Sinyor 1993), and increased speed of information processing. It is likely that the mechanism by which acute (a single) exercise session may influence cognition will be different to brain adaptations observed following chronic (longer term) exercise. Therefore, the potential mechanisms will be discussed separately (where possible).

Neurophysiological Data

Research on the neuroelectric system has greatly advanced the understanding of cognitive processing (Nelson & Monk, 2001; Thomas & Nelson, 1996). Event-related potentials (ERPS's) reflect changing voltage patterns in brain activity that occurs in response to a stimulus. The P3 is a component of the ERP that occurs around 300-800ms after the onset of a stimulus, which is elicited when participants attend to, and discriminate between stimuli (Hillman et al., 2005; Polish, 1991). The P3 is thought to be involved in the allocation of working memory and attention resources (Hillman et al., 2005) (For supporting literature see Polish, 1995).

Few studies have examined the possible relationship between exercise and electrophysiological changes in the brain. Van Praag et al., (2000) found that postsynaptic potential (EPSP) slopes were higher in the hippocampus of rats living in enriched environments (van Praag et al., 2000).

Both physical activity participation and aerobic fitness have been associated with behavioural performance using cross-sectional (Polich & Lardon, 1997) and randomised controlled-trials (Dustman et al., 1990; Kramer, 1999) designs in adults, but there is a gap in the literature examining the effects of exercise on neuroelectric activity in children. The direct measurement of the neurolectric response to exercise may be particularly beneficial in children, as there are a number of other factors, such as socioeconomic status, that may influence children's activity participation (Duncan et al., 2004) and cognition (Blair, 2005; Noble, 2005), making it particularly problematic to determine the influence of fitness on cognitive function during the early life span (Hillman et al., 2005).

In an attempt to address this Hillman et al., (2005) investigated the relationship between age, aerobic fitness, and cognitive function by comparing high fit and low fit preadolescent children and adults (Hillman et al., 2005). 51 adults and children were placed into either high fit or low fit (child) groups, or high fit or low fit (adult) groups, based on their scores on the Fitnessgram, which is a valid and reliable assessment of fitness for both adults and children (Hillman et al., 2005). P3 amplitude was measured by electroencephalogram (EEG) in participants whilst performing the visual oddball paradigm (a stimulus discrimination task). The results of this study indicated that high-fit preadolescent children had greater P3 amplitude than low-fit children and than both adult groups. This suggests that high-fit children had higher neural recruitment for the stimulus discrimination task. Additionally, high-fit children and adults had faster P3 latency than their low-fit counterparts, indicating faster neurocognitive processing (Hillman et al., 2005). The overall suggestion from this study is that higher-fit children have greater allocation of attention and working memory resources in response to stimulus processing, which supports previous research on physical activity and cognitive function (Hillman et al., 2004). There are notable limitations of the study by Hillman et al., (2005). Firstly, the study is cross-sectional in design; therefore it is plausible that selection bias may account for the findings that were attributed to fitness. Although participants were carefully matched; it is possible that high and low fit participants may differ in other factors that were not controlled for (e.g. genetics, personality traits, and skull thickness) (Hillman et al., 2005). There were a relatively small number of participants in each group also. The authors suggest that similar studies be carried out with larger numbers of participants (Hillman et al., 2005).

To date, only three studies have examined the influence of an acute bout of exercise on cognitive processing using event-related potentials (ERP), but these have yielded promising results. Nakamura et al., (1999) examined variations in P3 amplitude using an acoustic oddball paradigm in trained joggers after an acute bout of jogging and found increased amplitude in the Cz and Pz electrode sites, and no difference at Fz, when compared to baseline. A limitation of this study however was the small sample size (n= 7) (Nakamura et al., 1999).

Magnie et al., (2000) measured changes in the P3 and N4 components before and after maximal graded exercise tests. These authors reported increased P3 amplitude and decreased latency for P3 during the post-exercise compared to the pre-exercise testing sessions, and suggested that the exercise induced differences in P3 were indicative of an overall increase in central nervous system arousal (Magnie et al., 2000). Hillman et al., (2003) examined P3 amplitude of 20 college students while performing the Eriksen Flanker task (Eriksen & Erisken, 1974) before and after a 30 minute treadmill run. A larger P3 amplitude was observed in these students post-exercise compared to baseline. At baseline a shorter P3 latency was observed during neutral (i.e. HH**H**HH) versus incongruent conditions (HH**S**HH), but this difference was not observed after acute exercise. Overall, the findings of this study support the hypothesis that acute exercise can influence the neuroelectric activity underlying executive control processes (Hillman et al., 2003).

Functional MRI (fMRI) studies support the notion the exercise-related improvement in cognitive function is greatest on tasks that require greater amounts of executive control (Hillman et al., 2006). Older adult fMRI studies suggest that cross-sectionally fitness, and longitudinally, aerobic exercise is associated with a decrease in activity in the anterior cingulate cortex (Colcombe et al., 2004), and an improvement in a task involving executive control (Colcombe et al., 2004). Brain imaging (fMRI) studies have indicated that reading is associated with an activation of the prefrontal cortex (PFC), and parietal posterior cingulate cortex, and maths comprehension with an area of the brain called the intraparietal sulcus (which is located on the surface of the parietal lobe) in adults and children, but also an area of the PFC in children (Hillman et al. 2008[R]) It has been demonstrated that exercise is related to the prefrontal network of the brain in older adults, therefore it is feasible that children may benefit academically from exercise (Hillman et al. 2008).

Changes in molecular brain systems

There is evidence to suggest that some of the beneficial aspects of exercise arise from direct effects on the molecular brain systems (Cotman and Berchtold, 2002). Evidence from animal studies has suggested that aerobic exercise can enhance brain-derived neurotrophic factor (BDNF) gene expression and increase BDNF production in the hippocampus, cerebellum and cortex both acutely, and chronically, enhancing learning, and possibly reducing risk of age-related cognitive decline (Cotman and Berchtold, 2002; Cotman and Engesser-Cesar, 2002). Although other trophic factors, including nerve growth factor (NGF) (Neeper, 1996) and fibroblast growth factor (Gomex-Pinilla, 2001) were also induced in the hippocampus in respond to exercise, their upregulation was transient and less robust than that of BDNF, suggesting BDNF is a better candidate for mediating the effect of exercise on the brain (Cotman and Berchtold, 2002). Exercise training in ageing animals has also been shown to increase levels of other key neurochemicals that improve plasticity and neuronal survival such as insulin-like growth factors (IGF-1) and serotonin (Kramer et al., 2005).

The increase in BDNF, and other neurotrophic factors, associated with aerobic exercise may then increase the number of synapses, capillaries and cell bodies, as is seen in rats (Neeper et al., 2002; Churchill et al., 2002; van Praag et al., 1999). One possibility is then that aerobic exercise increases the number of synapses in frontal and parietal grey matter allowing for greater recruitment of these under high cognitive load (Colcome et al., 2004).

Evidence for the exercise induced benefit of BDNF in humans?

As noted above, it is becoming increasingly evident that (at least some) of the benefit of exercise on the brain is mediated via a brain derived neurotrophic factor (BDNF) mechanism (Ferris et al., 2007). Adequate BDNF is essential for healthy brain function (Ferris et al., 2007). The animal evidence is highly supportive of the notion that physical exercise enhances BDNF gene expression, especially in areas of the hippocampus susceptible to plasticity, and promotes learning and memory (Vaynman et al., 2004; also see **summary Table 1.** 2) but at present there are limited data in humans. In older adult studies, Colcombe & Kramer (2004a & b) saw a reduction in the age-based decline in tissue density in frontal, parietal and temporal cortices of the brain as a function of introduction of an aerobic walking programme these outcomes would be consistent with neurotrophic and neurogenic action of BDNF, however assays for BDNF were not performed.

Certainly BDNF is essential for ‘normal’ human cognitive functioning (Ferris et al., 2007). The important of BDNF in healthy brain function can be demonstrated by examining related disorders brain function that may be mediated by BDNF, for example chronic stress (Dunman et al., 2006), depression (Martinowich et al., 2007[R]), Parkinson’s disease, and Alzheimer’s disease. What is striking about each of these cognitive disorders is that there is (some) evidence that aerobic exercise may be able to prevent, or alleviate each of these conditions (Dishman et al., 2006[R]; Thorsen et al., 2005; Cassidy et al., 2004; Cotman & Berchtold, 2003[R]; Smith & Zigmond, 2003). There is also a suggestion that the mechanisms may be related; for example stress has been demonstrated to decrease hippocampal BDNF mRNA (Dunman & Monteggia et al., 2006; Smith et al., 1995), whereas animal data suggest that exercise can increase it (

Table 1. 2). Conventional treatments for depression (i.e. antidepressants) increase BDNF mRNA gene expression in the hippocampus and prefrontal cortex (Martinowich et al., 2007[R]). New research also suggests that stress and depression impair long term potentiation (LTP) (Martinowich et al., 2007) and BDNF is a mediator of LTP in the hippocampus (Lu et al., 2005[R]). There is some (limited) evidence that serum BDNF levels may be elevated following acute exercise in adults (Rojas Vega et al., 2007), the research on direct links between BNDF and exercise in human are understudied, and this is an area for future research.

The results of Colcombe and Kramers (2003) meta-analysis revealed several moderator variables that may support the notion that aspects of exercise act directly on the brain. For example, aerobic exercise training programmes combined with strength and flexibility training had a greater positive effect on cognition than aerobic alone. This effect may result from increases in insulin-like growth factor (IGF-1) in response to strength training (Kramer et al., 2005). IGF-1 is involved in neuronal growth and differentiation (Carro et al., 2001). Exercise training programs also had a larger impact on cognition if the study samples had greater than 50% females. This effect may be due, in part, to the positive influence of oestrogen on both BDNF and increased exercise participation (Cotman and Berchtold, 2002). It has been demonstrated that oestrogen up-regulates BDNF mRNA in much the same way as exercise, and that BDNF and oestrogren are important for hippocampal synatopgenesis and neurogenesis

(Kramer et al., 2005; Berchtold et al., 2001). Dysfunction of the BDNF system is also implicated in schizophrenia (Weickert et al., 2003) and traumatic brain injury (Horsfield et al., 2002). There is some evidence that exercise may aid recovery and improve functioning following traumatic brain injury (Grealy et al., 1999), and improve psychiatric symptoms in schizophrenic patients (Humphrey et al. 2005) although, likely due to the nature of these disorders, the evidence base is limited, and existing studies are small. Genetic BDNF system dysfunction is also implicated in obsessive compulsive disorder (OCD) and Tourette's syndrome (Klaffke et al., 2006). Whether these conditions can be influenced positively by exercise, or whether inactivity is a risk factor for any of the conditions previously mentioned (with the exception of TBI) are areas for future research.

Another possibility is that increases in fitness lead to increase capillary supply in the regions necessary to carry out executive functions, which, in turn, provides the metabolic resource necessary to coherently respond during task performance (Colcombe et al., 2003) and as mentioned before, cholinergic function is enhanced following aerobic exercise in rats, which leads to better spatial learning performance (Fordyce & Farrar, 1991).

A cardiovascular fitness hypothesis?

While meta-anlayses examing the effect of exercise on cognitive function in adults (Etnier, et al, 1997; Colcombe & Kramer et al, 2003) indicated a significant positive effect of exercise on cognitive function, with overall effect sizes of 0.25 and 0.48 respectively, they did not provide direct support for the hypothesis that an increase in cardiovascular fitness was related to a relative increase in cognitive function; for example, Colcombe & Kramer (2003) categorised 18 studies into no change in VO_2 max, a 5-11% increase, or a 12-25% increase. There was no significant difference in the effect size on cognitive function between these groups (Colcombe & Kramer, 2003; Etnier et al., 2006). Etnier et al., (2006) published a meta-regression analysis with the aim of testing the cardiovascular fitness hypothesis. Regression analysis was carried out on 211 effect sizes. The analysis revealed a significant positive effect size of exercise on cognition of 0.35; the similarity of this to the other meta-analysis effect sizes is important, because, as noted by Etnier et al., (2006), only 11% of the studies in this analysis were used in the 1997 meta-analysis. This suggests a real, and fairly consistent, effect size of exercise on cognitive function in adults (Etnier et al., 1997; Colcombe & Kramer et al., 2003; Etnier et al., 2006) and in children (Sibley & Etnier, 2003). However, while the study supports an effect of exercise on cognitive function, it does not support the hypothesis that this exercise-related improvement in cognition is mediated or facilitated by an improvement in cardiovascular fitness.

Results of the regression analysis of cross-sectional studies suggest there was a significant interaction of age and aerobic fitness on cognitive performance, so age groups were reanalysed separately to clarify the nature of this interaction (Etnier et al., 2006). The results revealed that aerobic fitness was a significant *negative* predictor of cognitive performance for children and young adults, was a significant positive predictor of cognitive performance for adults, and a was not a significant predictor in older adults (Etnier et al., 2006). For pre-post test comparisons, cardiovascular fitness was negatively predictive of cognitive performance for older adults, and not a significant predictor in either adults, or children (Etnier, et al., 2006). The inconsistency of these results makes interpretation difficult.

Overall however, the results of this meta-analytic review indicated large gains in cognitive function in groups with small gains in fitness, and clearly do not support a cardiovascular fitness hypothesis. Limitations to this meta-analysis should be noted; firstly, as a meta-analytic study, summary statistics are combined, with inconsistent study designs, exercise interventions and cognitive tests employed. It is unclear how generalisable these results are to children, as the majority of the existing work has been done in older adults (63% of studies), with a very small percentage of the data coming from child studies (1%) (Etnier et al, 2006). The RCT in older adults by Colcombe et al., (2004) (previously discussed) indicated a reduction in conflict in incongruent tasks (see glossary) of around 11% in the aerobic fitness group versus around 2% in the stretching toning group, which is markedly similar to the improvement in cardiovascular fitness in each group (10% and 3% increase in maximal VO_2 uptake) (Colcombe et al., 2004). The results of this study do appear, on the surface, to support the cardiovascular fitness hypothesis.

As is noted by Etnier et al., (2006) empirical studies designed to test a dose response relationship between cardiovascular fitness are needed, and empirical trials involving children are required.

1.6. Physical activity and motor development

The relationship between motor development and cognitive development

While it was previously though that motor development and cognitive development were two separate constructs, it is now suggested that they are ‘’fundamentally intertwined’’ (Diamond, 2000 pp 44). The prefrontal cortex of the brain was thought to be essential for more complex human cognitive functions, and the cerebellum, traditionally, thought to be the critical site for motor skills (Diamond, 2000). However, more recent evidence has suggested that the cerebellum is also critical for complex cognitive functions (Raichle, 1994), and that there is a relationship between cognitive and motor performance in young children (Wassenber et al., 2005). There is also a wealth of evidence suggesting that the majority of children who have a cognitive developmental disorder (e.g. dyslexia; ADHD) also have impaired movement skills (Wassenberg et al., 2005). Exercise or habitual physical activity in young children is mainly gross locomotor movement during ‘play’ (Pelligrinini & Smith, 1998). It begins around the first year of life, and peaks around 4-5 years. It is thought to serve an important developmental purpose (Gabbard, 2004). There is a rapid growth and development of neurons around this period (from birth to 5 years) – the ‘brain growth spurt’ (Gabbard, 2004), and active ‘play’ may positively influence synapse formation, and motor maturation (Pelligrini & Smith, 1998). This period also coincides with the ‘window of opportunity’ for optimal motor development (Gabbard, 2004).Measurement of movement (motor) skills will be discussed in more detail in **chapter 2**.

Physical activity and motor development in children: see table 1.6.

Despite the emphasis put on movement skills development in schools particularly during physical education (McMurray et al., 2002) there is a lack of data examining the relationship between any type of physical activity and movement skills (see **Table 1. 6** for details of existing literature). Okely et al., (2004) found a significant cross-sectional associ ation between body mass index (BMI) and 6 fundamental movement skills in 5518 4th to 10th grade Australian adolescents (Okely et al, (2004). There is no measure of physical activity reported in this study, and the cross-sectional design gives no information about the direction of the relationship. The same authors (Okely et al., 2001) found a small, but significant relationship between physical activity and participation in organised sports; in a regression model containing gender, geographic location & movements skills, movement skills accounted for only 3% of the variance in time spent in organised physical activity (Okely, et al. 2001). As noted by the authors, the use of self-reported physical activity may limit the results, however, in the only study examining the relationship between physical activity and movement skills in preschoolers (Fisher et al, (2005) a similar amount of the variance (3%) of time spent in objectively measured moderate and vigorous physical activity (MVPA) was explained by movement skills score. This study (Fisher et al., 2005) forms chapter 3 of this thesis, so will be discussed in more detail. The existing literature in this area is shown in **Table 1. 6** Studies examining the relationship between physical activity and movement skills., and will be discussed in more detail in **Chapter 3**. Extreme lack of research in the area, differences in research design, assessment of and agreement on what constitutes a ‘movement skill’, and differing method of assessing physical activity have made findings equivocal.

1.7. Researching the relationship between physical activity and motor or cognitive function: design issues.

Age group

There are reasons to suspect that exercise-induced benefits on cognition may be more pronounced in young children than in older children and adolescents (Davis et al., 2007). Younger children may be more susceptible to the effects of exercise as their brains are more ‘plastic’, and going through periods of rapid growth and development (Gabbard, 2004; Diamond, 2000). The average weight of a newborns brain is around 450g, and an adult’s brain is 1400g. Human brain growth tends to be in ‘spurts’ followed by ‘quiet’ periods (Harris & Butterworth, pp72-73). (Perry, 2002). Children are still in a state of neural differentiation, and their central nervous systems may adapt more rapidly in response to environmental stimulus (e.g. exercise) (Davis et al., 2007; Cabeza, 2001) whereas older adults are in a state of de-differentiation (Cabeza, 2001). Evidence suggests that better scores on tests of digit span and executive function in preschool (4 years) are predictors of maths and reading in primary school and the benefit is evident for at least 3 years (Bull et al., 2008).

A considerable body of evidence suggests a ‘critical period’ for wiring of neural circuits and optimal brain growth (Fontaine et al 2006). It appears that, while the timing of the growth spurt cannot be altered, the extent of brain development is activity dependent (Harris & Butterworth, 2004). Around 10 years of age the brain selectively eliminates (prunes) connections that are infrequently or never used (Gabbard, 2004). Supporting data suggests that there is a rapid rise in brain glucose utilisation between birth and four years, a plateau from 4 – 9 years, then a gradual decline into adulthood (Chugani et al 1998; Diamond 2000; Gabbard 2004). Some researchers have suggested 'windows of opportunity' for optimal cognitive and motor development (Gabbard, 2004). It seems likely that physical activity interventions to enhance cognitive or motor functions should be implemented as early as possible.

Educators believe that the process of movement, particularly in very young children, stimulates cognitive development (Leppo *et al.,* 2000; Pica 1997). Burdette & Whittaker (2005) describe the need to 'resurrect free play' in children, especially outdoors, not only as an intervention to reduce obesity, but also for normal development of cognition and social and emotional domains. If animal data are to be considered, it appears that motor learning and aerobic exercise can independently influence brain development. In younger children it has also been shown that environment can influence cognitive and socio-emotional development, and later school readiness (Casey, 2000).

Potential confounders

There is some evidence suggesting that body mass index (BMI) may be inversely related to academic performance (Castelli et al., 2005; Huang et al., 2006; Datar et al., 2004; Mikkila et al., 2003; Mo-Suwan et al., 1999). However, these results are cross-sectional and likely confounded by other variables that may impact independently on BMI, and academic achievement (e.g. socio-economic status).

Indeed, when other variables have been controlled for in these studies, often the significant relationship between BMI and academic achievement disappears (e.g. Hung et al., 2006; Dartar et al., 2004).

Previous research has indicated that socio-economic status (SES), parental education, handedness (i.e. left or right), and gender may influence cognitive and/or motor development (Noble et al 2005; Casey et al 2005; Okely et al., 2004; Gabbard, 2004). There is also evidence for an effect of diet on cognitive function and behaviour (Stevenson, 2006[R]; Rogers, 2001[R]). Therefore, where possible, to examine the relationship between physical activity and cognitive or motor development, these should be controlled for.

1.8. Summary

The animal and older adult data provide convincing evidence that aerobic exercise can positively influence executive control. There is support for the notion that this is true in older, overweight children (Davis et al., 2007), but randomised controlled trials are required to determine whether exercise can influence executive function in younger children.

There is emphasis on the development of movement skills in the school physical education curriculum, and relationship between physical activity and movement skills has been highlighted as a research area. However, it is unclear whether habitual physical activity and movement skills are related in young children.

Aims

The aims of this thesis are;

To examine the relationship between movement skills and physical activity in young children.

To carry out pilot and exploratory work to examine the relationship between exercise and cognitive function in young children.

Table 1. 1 Key reviews and meta-analyses examining the effect of exercise on cognitive function

Author	Title	Brief Summary of Conclusions
Tomporowski et al., (2008) Review: *Child data.*	Exercise and children's intelligence, cognition and academic achievement.	Exercise appears to facilitate children's executive functions.
Trudeau & Shephard, (2008) Review: *Child data.*	PE, school PE, school sports & academic performance.	PA can be added to the school curriculum by taking time from other subjects without the risk of hindering student academic achievement. Taking time away from physical education time and adding time to academic or curricular subjects does not enhance grades, and may be detrimental to health.
Angevaran, Aufdemkampe & Verhaar, (2008) Review*: Older adult data.*	Physical activity and enhanced fitness to improve cognitive function in older people.	11 studies fulfilled the inclusion criteria; RCT's involving older adults (>55 years) with an aerobic exercise intervention. There is evidence that aerobic physical activities that improve cardiovascular fitness are beneficial for cognitive function, however the data are insufficient to show that the improvements in cognitive function can be attributed to improvement in fitness.
Cotman & Berchtold (2007) Review: *Animal data*.	Physical activity and the maintenance of cognition: Learning from animal models.	Work in animal models has identified several key responses in including up-regulation of growth factors, increased neurogenesis, and improved learning and memory, which might be the key to improved cognition in response to exercise.
Rockwood & Middleton (2007) Review: *Adult data.*	Physical activity and the maintenance of cognitive function.	The available epidemiologic support the concept that physical activity might prevent or delay the onset of cognitive decline. Whether that will translate to a reduction in dementia in unknown.
Hillman, Erickson & Kramer, (2008) Review: *Animal, adult, child data.*	Be smart, exercise your heart: exercise effects on brain and cognition.	Human and non-human studies have shown that aerobic exercise can improve cognitive performance. A growing number of studies support the idea that physical exercise might lead to increased physical and mental health throughout life.
Dishman et al. (2006) Review: *Animal, adult, child data.*	Neurobiology of Exercise	Voluntary exercise can influence brain plasticity by enhancing neurogenerative, neuroadaptive, and neuroprotective processes. Motor skills training and regular exercise enhance executive function of cognition, and some times of learning (including motor learning).
Etnier et al., (2006) Meta-regression analysis: *Child and adult data.*	A meta-regression analysis to examine the relationship between aerobic fitness and cognitive performance.	There was a significant negative relationship between aerobic fitness and cognitive performance. The results do not support the cardiovascular fitness hypothesis for the effect of exercise on cognitive function. Future studies should employ dose-response relationships to confirm these findings, and examine other physiological and psychological variables that may mediate the relationship between exercise and cognition.

Kramer et al., (2005)	Fitness, ageing and neurocognitive function.	In general, the results are promising and suggest fitness may serve a neuroprotective function for ageing humans.
McAualey, Kramer & Colcombe (2003) Review:	Cardiovascular fitness and neurocognitive function in older adults: A brief review.	Animal data and older adult data are reviewed, and future research directions assessed.
Colcombe & Kramer (2003) Meta-analysis: *Older adult data.*	Fitness effects on the cognitive function of older adults, A meta-analytic study.	18 intervention studies (1966-2001) were included. Fitness training was found to have a robust but selective effects on cognitive function, with the largest being fitness-induced benefits on executive control.
Sibley & Etnier (2003) Meta-analysis: *Child data discussed.*	The relationship between physical activity and cognition in children: a meta-analysis.	There is a significant positive relationship between physical activity and cognition in children, however, more research is needed. Statistically powerful intervention studies, both acute and chronic, that include valid and reliable measures, and control for potential confounders are needed.
Cotman & Engesser-Cesar (2002) Review: *Animal data.*	Exercise Enhances & Protects Brain Function	Exercise induces gene expression in the brain, increasing BDNF, a molecule that increases neuronal survival, enhances learning, and protects against cognitive decline.
Etnier, et al, (1997) Meta-analyis.	The influence of physical fitness and exercise upon cognitive functioning: a meta-analysis.	From the existing 200 studies examining the effects of exercise on cognition, 135 had sufficient data to calculate an effect size. The overall effect size was 0.25 suggesting a small positive effect of exercise on cognition. Characteristics of the exercise, participants, the cognitive tests and quality of the study design all influenced effect size. As experimental rigour decreased, the effect size increased, emphasising the importance of a rigorous study design.
Allison, Faith & Franklyn (1995)	Antecendent exercise in the treatment of disruptive behaviour.	Meta-analysis of 16 studies suggested a significant positive effect of antecedent exercise on disruptive behaviour. Effect size 0.33.
Kavale & Mattson (1983) Meta-analysis; *child data.*	One jumped off the balance beam: meta-analysis of perceptual-motor training.	Meta-analysis of 180 studies suggest that perceptual motor training is not an effective for improving academic, cognitive or perceptual-motor training.

Table 1. 2 Overview of key animal studies examining effects of exercise or environmental enrichment on brain structure and cognition. Animal data will be presented in chronological order to represent developments in the field.

Author	Aim / Design	Findings
MacRae et al., (1987)	Ageing and young rats Comparison between rats Trained (exercised on treadmill 12 weeks; endurance) And 'Untrained'	Endurance training may slow down the negative effects of ageing on dopamine neurons and receptors.
Black et al., (1990)	To examine the different effects on the cerebellar cortex (an area associated with motor learning and neural plasticity) of motor activity, aerobic exercise and inactivity. 38 rats in 4 conditions Acrobatic (motor learning); Forced Exercise (aerobic); Voluntary Exercise; Inactive.	Animals keep in acrobatic condition had greater number of synapses per Purkinjie cell than animals from exercise or inactive groups. No significant difference in number of synapses between exercise groups & inactive group. Exercise group animals had greater number of density of blood vessels in the molecular layer. Conculsion: Motor *learning* increases synaptogenesis, *Physical activity* (exercise) increases angiogenesis in cerebellar cortex.
Fordyce & Farrar (1991)	To examine hippocampal and parietal cortical cholinergic function (areas and system associated with learning and memory) in F344 rats. 5 conditions: Control (n=8) Acute treadmill run (n=12) Chronic treadmill run (n=12) Control spatial-memory tested (n=6) and Chronic run spatial memory tested (n=6) *Spatial memory test Whishaw Test (version of the Morris Water Maze)*	Daily physical activity (chronic) enhanced performance on the spatial memory test. Enhanced performance appeared to be associated with running-induced alterations in the hippocampal not parietal cortical area (increased high-affinity choline uptake (HACU) and muscanaric receptor density. HACU was *increased* after acute exercise, and *decreased* after chronic exercise coupled with an upregulation of musinaric receptors in the chronic condition. These findings are indicative of a *reduction* in neural activity after chronic exercise – an adaptation to repeat stimulation - coupled with an improvement in performance. HACU was increased in the Control Spatial Memory tested rats, and is generally increased after a learning experience.

		Chronic-run rats may possess ability for enhanced cholinergic synaptic communication.
Isaacs et al., (1992)	To compare the morphology of cerebellar cortex in adult female rats exposed for 1 month to: Repetitive Exercise (treadmill / running wheel) Motor Learning Inactive Condition	Promotion of brain vascularisation in the exercise group (increased angiogenesis associated with metabolic demands) as compared to Motor Learning or Inactive rats. Motor Learning rats displayed increased volume of molecular layer per Purkinje neuron and increased blood vessel number. Different types of angiogenesis in motor learning and exercised rats.
Neeper et al., (1995 & 1996)	BNDF mRNA was measured following 0 (control) 2, 4 or 7 nights voluntary wheel running.	BDNF mRNA levels in the hippocampus were correlated with distance run. Exercise effects on BDNF were greatest in areas of high brain plasticity.
Van Pragg et al., (1999)	To examine the contribution of learning and physical activity to growth of new cells in the dentate gyrus (a region of the hippocampus associated with memory formation) . Mice divided into Learner (water-maze learner) Swimmer, Runner (Voluntary Wheel Runner) Enriched and Control.	Both Enriched and Runner groups showed enhanced Brdu (a marker that indicates replication of DNA in cells) increased cell proliferation, cell survival and neurogenesis in hippocampus. In both groups, more cells became neurons (enhanced differentiation) than in control groups
Neeper et al.,. (1995 ; 1996)	Exploration of the effect of exercise on gene expression in rat hippocampus. 3 month old rats; 3 weeks of wheel running compared to sedentary controls.	Increased hippocampal BDNF gene expression in rats. Increased BDNF and nerve growth factor in cortex, cerebellum and hippocampus. AP180 genes (and others) was induces in hippocampus of running rats.

Tong et al., (2001)	To examine the effects of exercise on acute gene expression in the rat hippocampus. Rats voluntary running for 3 weeks vs sedentary controls.	Exercise leads to enhanced BDNF gene expression. Exercise enhanced expression of numerous genes known to be associated with neuronal activity, synaptic structure and neuronal plasticity.
Radak et al., (2001)	Young (4 weeks old) and middle aged (14 month old) rats assigned to: Young Exercised & Control Middle-aged Exercise and Control Exercise – swimming 1 hours day, 5 days per week for 9 weeks. Passive avoidance test (memory test) Conditioned pole-jumping avoidance (learning).	Middle-aged Exercised rats had better short (24 hours) and long term (72 hour) memory than controls (Controls reduced significantly; the age-related decline was prevented by exercise). Learning was improved in Young and Middle-Aged Exercise groups compared to controls. Exercise decreased the accumulation of reactive carbonyl derivatives (RCD) in rat brain.
Vaynman, et al., (2004)	Rats randomly assigned to: Sedentary: hippocampal cytochrome C (cytC) injection Exercise: hippocampal cytC injection) Sedentary: hippocampal Trk/B-IgG injection) Exercise: hippocampal Trk/B-IgG injection) *Trk/B-IgG blocks the action of BDNF by binding to the BDNF receptor (TrkB)* Morris Water Maze	Exercise significantly increased the mRNA levels of CREB and synapsin I (neural plasticity markers) in the Exercise cytC group. Blocking action of BDNF was enough to prevent the exercise induced increase in CREB (cAMP response-element-binding) and synapsin. Escape latencies from the Morris Water Maze were significantly negatively associated with hippocampal BDNF levels (i.e. less hippocampal BDNF, slower escape, reduced spatial memory performance). Cognitive enhancement seen in exercise in BDNF dependant.

	Exercise: Voluntary running wheel 1 week.	BDNF might enhance memory by augmenting CREB expression.
Garza et al., (2004)	To examine whether antidepressant treatment may enhance BDNF in the hippocampus of ageing rats, and whether this can be accelerated by voluntary exercise (voluntary wheel running).	In aged rats (22 month old) antidepressant treatment, voluntary physical exercise, or the two interventions combined resulted in significant increases in hippocampal BDNF mRNA expression after 2, 7 or 20 days. Areas affected appeared to differ between younger and older rats.

Table 1. 3 Randomised controlled trials & meta-analytic studies examining effect of exercise on cognitive function in adults; key references.

Reference	Sample	Methods	Findings	Limitations
Ravia et al., (2005)	1448 adults examined at midlife (50 years) and later life (70 years)	Midlife: Leisure time PA questionnaire; BP; BMI; Serum cholesterol; history of locomotive disorders. Later life: Incidence of dementia or Alzheimer's disease, alcohol, smoking, stroke, history of diabetes, heart attack.	Leisure time PA at least twice per week is associated with reduced risk of dementia and Alzheimer's disease in later life. The associated were more pronounced in APOE e4 allele carriers.	Physical activity assess by questionnaire. Unreliable / prone to bias.
Colcombe et al., (2004a)	41 older adults Rockport 1 mile walk fitness test (Kline et al, 1987)	Cross sectional Brains scanned with fMRI scanner while carrying out a Flanker task of incongruent << > << and congruent >>>>> stimuli	Groups spilt by fitness level. Higher fit group more efficient at dealing with incongruent (conflicting) stimuli. (18% interference) than lower fit (26% interference). fMRI revealed greater activation in cortical regions related to selective attentional control ; the right middle-frontal gyrus (MFG); superior frontal gyrus (SFG) ; superior parietal lobe (SPL) and reduced activity in anterior cingulated cortex (ACC).	Cross sectional – potential confounders. Possible that social stimulation is responsible for cognitive benefits of exercise (although this is controlled for in Colcombe et al. 2004b) Small sample (although large for a brain imageing study).
Colcombe et al., (2004b)	29 58-77 year olds (11 males) Cardiorespiratory fitness assessed by Parvo Medics TrueMAx 2400 (maximal oxygen & indirect calorimetry)	RCT – Aerobic group (walking; 10-15 mins + 1 minute per session; 40-50% HR initially, then 60-70% HR. 3x week for 6 months) Control (stretching and toning; 3x week for 6 months)	Aerobic group – significant increase in cardiovascular fitness relative to control (maximal vo2 uptake 10.2% vs 2.9%) Aerobic group significant (11%) reduction in conflict. Control group 2% reduction (non-significant). fMRI revealed greater activation in cortical regions related to selective attentional control ; the right MFG; SFG;	All males, not generalisable to females, especially as oestrogen know to impact cognitive decline. Small sample in each group. Fairly wide age-range.

		Brains scanned with fMRI scanner while carrying out a Flanker task of incongruent << > << and congruent >>>>> stimuli at baseline, and 6 month follow-up.	SPL and reduced activity in ACC.	
Colcombe & Kramer (2003)	18 intervention studies published between 1966-2001	Meta-analysis Inclusion criteria; RCT's involving a fitness programme over time vs a control, in adults aged 55-80 years. 4 theoretical hypotheses based on previous adult research. *Speed hypothesis* (tasks requiring low-level neuropsychological functioning e.g SRT; finger tapping) *Visiospatial hypothesis* (tasks requiring remembering visual or spatial information). *Controlled-process hypothesis* (tasks that initially require effortful control, then becomes automatic e.g. choice reaction time). *Executive control hypothesis* (tasks that do no become	Exercise had greatest effect on executive processes, significantly greater that any other task EF 0.68, however, improvements relative to controls were seen in *controlled processes* 0.426 *spatial* 0.426 and *speed* 0.274. Participants in strength plus aerobic improved significantly more that aerobic alone (0.59 vs 0.41). Participation in brief (1-3 months) programs provided as much benefit as moderate (4-6) , but not as much as long term (6+). Acute bouts / 30 minutes had no significant effect. Group as a whole seemed to benefit more if >50% females. Participants in the mid-old (66-70 yrs) category seemed to benefit most. Clinical populations and non-clinical populations seemed to benefit equally. *Fitness training increased cognitive*	N/A

		automatic over time, and require a central executor. Relating to planning, inhibition and scheduling of a mental procedure, e.g. Erikson Flanker Task).	*performance on average 0.5 SD regardless of type of task, exercise or participants characteristics.*	
Bakken, (2001)	15 72-91 year olds.	RCT - Aerobic exercise (marching, side-stepping, boxing, cycling, walking 1 hours 3 x week vs Control (waiting list) for 8 weeks. Finger-movement tracking test (of pattern on computer screen). Test of visual attention / information processing. GXT.	Performance on tracking test improved with aerobic performance. No aerobic training effect. *Note: does not support the aerobic fitness hypothesis.*	Only 5 participants in each group available for final analysis (study was a pilot study). Control, no intervention, possible 'Hawthorn effect'.
Kramer et al. (1999)	124 60-75 year olds	RCT aerobic (walking) or anaerobic (stretching and toning). Executive control tasks; task switching. Non executive control tasks.	Walking group showed significant improvements in rate of oxygen consumption (5.1% compared to -2.8% in the toning group) and performance on tests of executive control. No difference in non-executive control tasks.	
Blumenthal et al.,, (1988)	30 men aged 30-58 years.	RCT – 3 x per week for 12 weeks. Aerobic (jogging) (n=15) 15 strength training (n=15) VO^2 max. Reaction time (Steinberg 1969 memory search	Aerobic group 15% increase in VO^2 Strength group 3% increase in VO^2 Both groups showed improvements in RT, but not	Small sample, all men – not generalisable. Wide age-range.

		paradigm).	related to type of exercise or improvement in aerobic fitness. *Does not support aerobic fitness hypothesis.*	
Dustman et al., (1984)	55-70 years.	RCT- 4 months of aerobic training	Improvement in SRT and Stroop test, but not in choice RT.	Abstract only. Mentioned due to consistent citation in other papers.
Blumenthal et al.,, (1989)	101 men aged 60-83 years.	RCT 4 months aerobic training (n=33). Yoga & flexibility (n=34). Waiting list control (n=34). Peak oxygen consumption & anaerobic threshold. Mood, psychiatric symptoms & neuropsychological function.	Aerobic group: 11% improvement in VO2-sub-2. 13% increase in anaerobic threshold. Lowered cholesterol and diastolic BP.	Abstract only. Mentioned due to consistent citation in other papers..

Table 1. 4 Prospective & cross sectional studies examining the effects of exercise and cognitive function / cognitive impairment in adults.

Reference	Sample	Methods	Findings	Limitations
Ravo et al., (2006)	1449 65-79 year olds.	Midlife (50 years) Leisure time PA (questionnaire) BP, BMI, serum cholesterol, history of locomotor disorders. Later life (70 years) Incidence of dementia History of diabetes, stroke, heart attack, smoking, alcohol.	Leisure time PA (at least twice a week) was associated with a reduced risk of dementia and Alzheimer's. The relationship was more pronounced in genetically susceptible individuals (carriers of APOE e4 allele).	Other potential lifestyle confounders that may not have been controlled for (e.g. diet, SES).
Hillman et al., (2006) *PA and cognitive function (accuracy and RT on Flanker task).*	241 15-71 year olds, USA.	Cross-sectional examination of relationship of PA to executive control (planning, scheduling, working memory, interference control, task coordination). Erikkson Flanker Task. Multiple regression controlling for age, gender, IQ.	Age related slowing of RT across flanker conditions. Physical activity was associated with faster RT regardless of age. Physical activity was related with response Accuracy during the incongruent trials for the older cohort only.	Self reported physical activity, prone to bias / unreliable. Wide age-range; from adolescents to older adults.
Podewils et al., (2005)	3375 adults >65 years, USA. Cardiovascular Health Study.	Cerebral magnetic resonance imagine (MRI). Physical activity – Minnesota Leisure time questionnaire. Blood samples (APOE genotyping), social network. SES, age, gender, education level, ethnicity, smoking, alcohol, HRT. MMSE	Those who developed dementia (n=408) were more likely to have lower education level, were more likely t carry the APOE e4 allele, had poorer cognitive performance at baseline, and were more likely to show white-matter disease on MRI. More likely to have history of stroke or hypertension. Leisure time PA was inversely	The interaction between PA and APOE e4 in this study was limited to only 28 participants - possibly underpowered.

			associated with Alzheimer's disease risk, but non-significant for vascular dementia. Leisure time PA was inversely associated with PA only in non APOE e4 carriers.	
Lytle et al., (2004) *PA and incidence of cognitive impairment.*	1146 men and women >65 years.	MMSE every 2 years. Self reported PA.	Higher levels of self reported PA associated with reduced incidence of cognitive decline 2 years later.	Self report focussed on structured exercise, no report of habitual physical activity.
Weuve et al., (2004)	18766 women aged 70-81 years (Nurses Health Study), USA.	Self reported leisure time physical activity (converted to METS). TICS (telephone assessment modelled on MMSE). East Boston Memory Test Digit Span Backwards Administered at twice, 2 years apart.	Regular physical activity associated with less cognitive decline across all cognitive measures. 20% lower risk of cognitive impairment in women in the highest quintile of activity. Indicative of a dose-response relationship.	Reverse causation, predisposition or existing mental impairment may reduce participation in PA.
Barnes et al.,(2003)	349 >55 year olds (Participants of health outcome study, Sonomia, California).	Cardiorespiratory fitness measure (standard treadmill exercise test). Modified MMSE at baseline and 6 year follow-up. Trail Making Test Stroop Test. Digit Symbol Test *(measure of executive function/attention at 6 year follow-up only)* California Verbal Learning Test (verbal memory). Test of verbal fluency.	Participants with lower CV fitness showed greater cognitive decline on the MMSE over 6 years. Participants with lower CV fitness at baseline performed worse on the 6 year tests of executive function and attention. Maintenance of high levels of CV function may protect against cognitive decline.	No longitudinal measures of attention/executive function. Predominantly white participants. Non representative.

Dik et al., (2003)	1241 62-85 year olds, Holland.	MMSE Alphabet coding task (information processing speed) Physical activity by questionnaire. Confounders: age, gender, lifestyle factors & health indicators.	Early life physical activity associated with information processing speed but not score on MMSE. Association only significant in men.	Cross-sectional design. Early life PA was asked retrospectively with only 1 questions. Self reported PA unreliable in general, especially in those prone to cognitive decline. No control for HRT, which is associated with cognitive decline in women.
Yaffe et al.,, (2001) *PA and incidence of cognitive impairment.*	5925 women >65 years. (Participants of Study of Osteoporotic Fractures).	Prospective study; baseline and 6-8 year follow up. Self reported PA (city blocks walked). MMSE	Women who reported greater levels of PA were less likely to show symptoms of cognitive decline at 6-8 year follow-up (17% impairment in the highest quartile for physical activity and 24% in the lowest quartile). This significant trend remained after adjusting for age, educational level, comorbid conditions, smoking status, oestrogen use, and functional limitation. Odds ratio 0.66 (95% CI 0.54-0.82)	Self report of physical activity. Prone to bias, possibly more pronounced in participants prone to impaired cognitive function. Participants who dropped out of study tended to have lower IQ & lower physical activity. Possibly link between subclinical cognitive function and lower participation in PA at baseline. No men in study, and majority of participants were caucasian.
Laurin et al., (2001)	4615 older adults (>65 years) Canada	Prospective study; baseline & five year follow-up. MMSE Self reported PA Confounders: age, education.	Women – risk of CIND, Alzheimer's disease & dementia were lower with higher levels of PA. Dose response evident. Men – risk of CIND, Alzheimer's disease & dementia were lower **(but non significant)** with higher	PA assessed by 2 questions. No adjustment for SES, HRT, health status. No control for pre-clinical cognitive decline at baseline.

			levels of PA.	Data excluded (non follow up data) tended to be older less active, less education participants .

MiniMental State Examination (MMSE) – screening tool for cognitive impairment.
Telephone Interview for Cognitive Status (TICS).
HRT Hormone replacement therapy. SES socio-economic status.

Table 1. 5 Studies examining effect of exercise on cognitive function or academic achievement in children.

Reference	Sample	Methods Used	Findings	Limitations
Buck, Hillman and Castelli (2007)	74 7-12 year olds, USA.	Age appropriate paper and pencil version of the Stroop task. Fitnessgram. IQ, health and demographics (coviariates).	Aerobic fitness was associated with better performance on all conditions of the Stroop test. Results indicated that relation between fitness and task performance was not greater on compoments requiring more interference control. (i.e. incongruent).	Cross-sectional. It is possible the differences seen in performance are related to another factor (e.g motivation or self esteem).
Davis et al., (2007)	94 overweight (BMI >85th centile) 7-11 year olds USA.	RCT Low dose aerobic exercise (20 minutes 5 x per week aerobic games to maintain HR >150 bpm) High dose (as above 40 minutes per week) Control (No intervention) Cognitive Assessment System (CAS)	Significant improvement in CAS (Planning scores only) in High exercise group relative to Low dose and control groups. Supportive of effect of aerobic exercise on executive functions. Suggestion of a threshold effect. Children in high and lose dose improved equally in fitness.	Limited to sedentary overweight children, so results not generalisable. Children and interventionists were not blinded to the condition. Control group should possibly have had an ‘intervention’ of some sort (i.e. non active, but similar time / attention from staff).
Castelli et al., (2007)	259 3rd and 5th grade children,	Fitness (aerobic, muscle strength	Field tests of physical fitness	Cross sectional.

	USA.	and body composition). Academic achievement.	related to global aspects of academic achievement (maths & reading). BMI inversely associated with academic achievement.	Other confounders (e.g. SES) could explain the relationship.
Ahamed et al., (2007)	396 9-11 year old school children, Canada.	16 month cluster RCT. BMI PA questionnaire Standardised test of achievement (Canadian Achievement Test).	No difference in achievement scores at follow up.	No objective measure of habitual PA or intensity of intervention. Despite randomisation baseline achievement scores were significantly higher at baseline. Average 50 minutes PA extra per week, possibly not high enough dose.
Sigfusdottir, Kristjansson & Allegrante, (2007)	5810 14-15 year old school children, Iceland.	Cross-sectional Self reported academic achievement (asked to report average grades). BMI from self-reported height & weight. Self reported fruit and vegetable & other dietary data.	BMI most strongly correlated with academic achievement. Diet and PA weaker significant correlations (24% of variance combined). Parental education, absenteeism, and self esteem all stronger	Cross sectional design. Relationship between BMI and academic achievement may be

		Depressive symptoms (Symptom Distress Checklist). Self esteem (Rosenberg self esteem scale).	correlates of academic achievement than health behaviours.	overstated, as no control for SES, which has been shown to be related to BMI & academic achievement.
Dollman, Boshoff & Dodd (2006)	117 schools (no individual child data presented)	Cross-sectional Schools surveyed on average time spent on PE and demographic characteristics Average child literacy and number scores. Regression assessed the relationship between PE, academic scores and demographics.	The only predictors of language and numeracy scores were SES and number of staff. No relationship between time spent on PE and language and numeracy scores.	Quality & intensity of PE lessons not considered. It is feasible that less frequent, high quality and intensity PE would impact cognition more than frequent low quality/intensity PE lessons. PE lessons likely have a large skill-based element, adult data suggests aerobic exercise may have biggest impact on cognitive function. Habitual or physical activity outside school

				not considered.
Huang et al., (2006)	666 11-14 year olds, USA.	Self reported grades Actual grades Age, gender, ethnicity BMI Body fat (Tanita) Previous Day PA recall		Mostly Latino and Asian-American children. Non representative. Adiposity & BMI were not related to actual grades, but were to self reported grades. Provides evidence of unreliability of self reported grades. MVPA related to self reported and actual grades inof adiposity & BMI.
Nelson & Gordon-Larsen, (2006)	5979 males; 5978 females mean age 15.8 (SD 11.6 years) National Longitudinal Study of Adolescent Health	Cross-sectional 7 day standard recall of physical activity; MET values calculated.	Active teenagers (>5 bouts of MVPA per week) were significantly more likely to have higher grades (adjusted risk ratio 1.20).	Self reported PA and grades. Possible confounders (e.g. higher PA= lower truancy=better grades simply as a factor of being in class more often?; higher PA= higher self esteem= between

				school performance?).
Yu et al, (2006)	333 8-12 year olds, Hong Kong.	Exam and test results Self esteem (questionnaire) Self reported PA 'School conduct' grades (no elaboration in paper as to what these are).	Girls had higher academic scores than boys. PA not significantly related to academic achievement. PA significantly related to school conduct.	Cross-sectional, correlation results, don't give information about the direction of the relationship,. Teacher 'school conduct grades' highly subjective. Self reported physical activity unreliable, especially in children.
Field, Diego & Sanders (2001)	89 high school children (age-range not provided in paper) USA.	Cross-sectional Questionnaire based assessment of physical activity.	Children with higher levels of activity group had higher grade point averages, spent less time depressed, more time in sports and better relationships with their parents.	Small sample, questionnaire based physical activity. Difficult to tease out the interaction between family relationships (a correlated of achievement) PA, and achievement. No control for SES, which can

				influence achievement, and possibly family relationship.
Coe et al., (2006)	214 10-13 year old children, Michigan, USA.	Cross-sectional Random assignment to PE enrolment vs not enrolled in PE. Habitual PA 3-d physical activity recall. MET values SOFIT direct observation of PE classes. School grades.	PE enrolment did not influence academic grades. When examining percentiles, Students who achieved Healthy People Guidelines achieved higher grades.	Possibly not high enough dose of activity in PE group (estimated mean 19% time in MVPA in 50 minute session). Quality / intensity of PE classes (only 4 observed in a semester). Unreliable measure of habitual activity. Possible evidence that there may be a 'threshold' level of activity that has to be reached to benefit cognition.
Dwyer et al., (2001)	7961 7-15 year old school children, Australia.	Cross sectional Scholastic achievement as rated on a Likert scale by principle or teacher. Measures of BMI and muscular	Scholastic ratings higher in boys, and higher for older than younger children. Scholastic ratings positively associated with fitness, capacity	Cross sectional design, likely confounders, and direction of relationship can't be inferred.

		power, muscular force & endurance, joint mobility, skin folds, lung function, cardiorespiratory endurance (1.6km run).	and activity and weakly with muscular force, endurance and power (all significantly).	
Tremblay, Inman & Williams (2000)	6923 6th grade (9-12 year old) children, Canada	Cross-sectional Maths & Reading Scores Items from Self-description questionnaire (self esteem measure) Physical activity assessed by questionnaire. SES	Physical activity & SES were related to self-esteem PA levels were weakly negatively related to achievement. PA negative relationship with BMI. SES & self esteem significantly related to math and reading score. SES negatively associated with BMI.	Measure of physical activity was only based on 4 questions; 2 about exercise and 2 about stretching toning. Unreliable, especially in younger children and questions not necessarily relevant to the age group (would a child 'stretch and tone?') No assessment of habitual activity. The weak measure of PA was sensitive enough to show a negative relationship with BMI though) Cross sectional design, can't infer causality

				(e.g. self esteem may lead to increased PA participation).
Linder (2002)	1447 13-17 year old students, Hong Kong.	Cross-sectional Objective measure of scholastic achievement (records from schools) and the effect of academic banding - whole schools 'banded' in terms of overall performance. Physical activity questionnaire	Physical activity School band was a significant predictor of PA participation time. Children from higher band schools greater participation.	Cross-sectional study design can't imply causal relationship. Higher band school may have had benefits (e.g. more funding, opportunity for PA, quality of teaching, staff). There may have been differences between SES groups in low and high band schools.
Linder (1999)	4690 9-18 year old school children, Hong Kong.	Cross-sectional Self reported sport participation and perceived 'self reported' academic achievement.	Weak significant positive correlations between sport participation and perceived achievement.	Self reported sports participation and perceived academic achievement in children, with cross-sectional design. Too many potential confounders to draw any

				conclusion.
Caterino & Polack (1999) †	177 9-11 years	15 mins stretching and walking Woodcock-Johnstone Test of Concentration	9 & 10 : no detriment to concentration 11 yrs : improvement in concentration	No control group.
Corder (1996) †	24 "mentally retarded" boys	4 weeks daily PE	Improvement in intellectual/social development	Small sample. Not generalisable.
Klein & Deffenbacher (1977) †	30 hyperactive males	3 weeks circuit training, 2 x per week Continuous performance task, Matching Familiar figures task	Improvement in Matching Familiar figures task in hyperactive exercise group	Small sample. Not generalisable
McCormick et al., (1968) †		7 weeks – PE 2 x weeks (perceptual motor training)	Improvement reading achievement	Cant find abstract / paper (extracted from Sibley & Etnier, 2003)
Sallis et al.,. (1999) † (Project SPARK)	754 Californian school children	2 years specialist-taught PE 3 x week	No harmful effect on academic test scores despite greatly increased time in PE (intervention 28% more per week than controls) 2 year follow-up significantly less decline in score in Intervention vs Control	Non randomised.
Zervas et al., (1991) †	9 pairs of monozygotic twin boys 11 – 14 years	6 months 20 mins treadmill running Matching a comparison design	Significant pre and post test improvement in decision making in exercise groups	
Shephard et al., (1984) † (Trois Rivieres Experiment)	546 school children, grades 1-6	1 additional hour per day of specialist instructed PE Goodenough & WISC tests	At baseline controls significantly higher academic grades, grades 2-6 experimental students higher grades (significantly in 2, 3, 5)	
Dwyer et al., (1978) † (SHAPE, South Australian Study	519 10 year old Australian school children	14 weeks: Fitness (75 mins high	No significant differences in academic performance between	

		intensity PE 5 x week) , Skill (75 mins curriculum PE /week) Control (3 x 30 mins PE wk)	groups.	

† Experimental studies highlighted in Sibley & Etniers (2003) review
SOFIT – system for observing fitness instruction time.
SES – socioeconomic status

Table 1. 6 Studies examining the relationship between physical activity and movement skills.

Reference	Sample	Methods Used	Findings	Limitations
Cliff et al. (2007)	13 overweight children	Community based motor development programme. BMI, motor development, perceived athletic competence, perceived global self-worth. Objectively measured PA.	Decline in MVPA at follow up and post treatment. Perceived athletic competence and global self-worth increased.	Small sample size (was a feasibility study though). Does an increase in movement skill time have a detrimental effects on time spent in MVPA?
Fisher et al., (2005)	392 3-5 year old children, UK.	See chapter 4 of thesis.	See chapter 4 of thesis.	See chapter 4 of thesis.
Lela & Toivo (2002)	294 6 year olds, Tartu.	Parent & teacher reported PA . Motor ability evaluated using tests from Eurofit test battery & 3 minute endurance shuttle run test. Controlled drawing observation test as a measure of school readiness.	Indoor physical activity predicted 19-25% of variance in motor scores. Motor ability tests significantly related to school readiness.	Subjective measure of PA. Construct validity of the other measures (i.e. do they measure what they propose to?)
Okely, Booth & Chey (2004)	5518 8th to 10th grade Australian adolescents	BMI & waist circumference Six fundamental movement skills (run, vertical jump, catch, overhand throw, forehand strike, kick)	Inverse linear relationship between FMS and overweight/waist circumference in both sexes. Overweight children were twice as likely to be in the lowest quintile for FMS.	No measure of physical activity, so interactions can only be implied.
Okely, Booth & Patterson (2001)	982 8th (mean age 13.3 yrs) grade & 862 10th grade (mean age 15.3 years) Australian children.	Physical activity – self report of time in organised and non-organised physical activity. Six fundamental movement skills (run, vertical jump, catch, overhand throw, forehand strike,	A regression analysis revealed that movement skills, gender, grade and SES all had a significant effect on time in organised PA (whole model 4.3% of	Use of self reported PA unreliable.

		kick)	variance). Movement skills only explained 3% of the variance	
Butch & Eaton (1989)			Relationship between running speed and agility & participation in vigorous PA.	Use of 'product' oriented assessment (i.e. a yes or no') as opposed to a process oriented (each part of the movement process is scored).
Ulrich (1987)	Kindergarten to 4th grade.		Significant relationship between movement competence & PA (organised sports participation)	

Chapter 2: Methods I – Movement assessment

2.1 Movement skill assessment in young children

Introduction

A literature search revealed no recent papers reviewing tests of movement skills for use in research in young children. Therefore, the aim of this review was to describe widely used tests of movement skills in terms of practical considerations for use in research: age range, cost, training required and psychometric properties.

For a test of movement skills to be widely adopted it must be easy to administer, standardised, reliable and valid and practical for it's intended use (Greenwood et al., 2002), The following review discusses the practical utility, and validity / reliability and use in research of tests of movement skills in preschool (3-5 years – the age to be studied in **Chapter 3** of the thesis).

Assessing fundamental movement skills in preschool children

Four of the most widely used tests for the measurement of movement skills in preschool children are: the Bruininks Oteresky Test of Motor Proficiency (BOTMP) (Bruininks, 1978) (the most widely used in the USA), the Movement Assessment Battery for Children (MABC) (Hendersen & Sugden, 1992), Test of Gross Motor Development (TGMD) (there is now an updated version TDMD-2, Ulrich, 2000) and Peabody Developmental Motor Scales (Folio & Fewell, 2000). Practical considerations of these tests and psychometric properties of these tests are highlighted in **Table 2. 1.**

Movement Assessment Battery (Movement ABC; MABC)

The Movement ABC was developed by Henderson & Sugden (1992) as a method of assessing those at risk of motor impairment. It is the single most used tool for assessment of developmental coordination disorder (Geuze et. al, 2001). Applicability of the US norms published in the test manual have been examined in Europe (Smits-Engelsman et al. 1998; Rosblad & Gard, 1998) Asia (Miyahara et al., 1998; Chow et al., 2001, Wright et al., 1994) and Australasia (Livesey, Coleman and Piek, 2007). These studies (on the whole) suggest generalisability, but with some cultural differences between the Asian data and US norms (for example Miyahara et al. (1998) found their Japanese sample performed better on dynamic balance, but poorer on drawing tasks than the US normative sample (Miyahara et al., 1998). Although the normative data begins at 4 years, there is some evidence that the MABC can be used in successfully in children as young as 3 (Livesey et al., 2007).

There are two components of the Movement Assessment Battery: a Performance Test (previously the Test of Motor Impairment, then Test of Movement Impairment – Henderson Revision TOMI-HI) and Checklist. The MABC is well structured, and division of tests into age bands with similar skills sets allows comparison of skills through a child's development. Although the most widely used test of developmental coordination disorder (DCD), the psychometric properties of the MABC Performance test and Checklist require further investigation; use in children under 4 may be feasible, but normative data does not exist in this age group, and cultural differences between some Asian countries as compared to US norms suggests a normative database must be developed for these countries.

The Test of Gross Motor Development-2 (TGMD-2)

The Test of Gross Motor Development (TGMD) (Ulrich, 2000) was published as a criterion referenced test for programme planning (Wiart et al., 2001). The authors suggest that the TGMD will assess the movement skills generally taught in physical education. The 12 movement skills tested by the TGMD are divided into Locomotion and Object control skills.

The TGMD-2 is a useful, practical and cost effective tool that has been successfully used in research in children and adolescents (Okely et al., 2001) however it's usefulness in preschool children is limited, as most items in the object control test are too difficult for 3-4 year olds (Burton & Miller, 1998, p242).

Peabody Developmental Motor Scales (PDMS-2) (Folio & Feldwell, 2000)

The Peabody Developmental Motor Scales is a standardised test with components to evaluate gross, and fine motor scales. The test can be used in children from birth – 71 months. Acceptable reliability has been demonstrated in both the gross and fine motor scales (Folio & Feldwell, 2000; Van Hartingsveldt, 2005) Psychometric properties of the PDMS-2 are shown in **Table 2. 1.** There are some noteworthy limitations of the PDMS-2 – a relatively large amount of equipment is required, and would have to be purchased to ensure standardisation and transported by car to test sites. The test is relatively time consuming (20-30 minutes for each scale), therefore the numbers to be tested could

Additional outcome measures of movement skills

Ages and stages Questionnaire

The Ages and Stages Questionnaire (Bricker et al., 1995) is a multi-domain, parent assessment. Parents complete the simple, illustrated 30-item questionnaires at designated intervals, assessing children in their natural environments. Each questionnaire can be completed in just 10-15 minutes and covers five key developmental areas: communication, gross motor, fine motor, problem solving, and personal-social. The Ages & Stages Questionnaire is standardised, low cost (can be photocopied by purchasing a one off licence) and can be used up to age 5. The Ages and Stages Questionnaire has good reliability: 2 week test retest reliability in 175 children 0.94 (Standard Error of the Mean (SEM) = 0.10). Inter-rater reliability in 112 children was reported to be 0.91 (SEM 0.12) (Squires et al., 1997).

Concurrent validity of the Ages and Stages Questionnaire with a number of standardized tests (Gessell & Armatruda Developmental and Neurological Examination; Bayley Scale of Infant Development (Infants), The Stanford-Binet Intelligence Test and McCarthy Scales of Children's Abilities (preschoolers) has been carried out. The sensitivity and specificity across all age categories was 75% and 85% respectively (Lee & Harris, 2005).

Limitations

While the Ages & Stages Questionnaire has great potential for large scale evaluations of motor skills, it is well known that the response rate to postal questionnaires is low. Therefore, measures must be taken to ensure a reasonable response rate: electronic / online version, telephone follow-ups, face-to-face administration by an interviewer. The preferred level for sensitivity of a motor skills test is at least 80%, and specificity at least 90% (Glascoe et al., 1992), whereas the Ages & Stages Questionnaire has a sensitivity of 75% and 85% respectively (Bricker et al. , 1995), and these factors must be taken into consideration.

Affordances in the Home Environment for Motor Development (AHEMD-SR; Gabbard et al., 2008)

The AHEMD-SR is a parent report of the quality and quantity of factors in the home that may influence motor development. The AHEMD-SR shows good reliability and validity in children aged 18/42 months (Rodrigues et al., 2005; Gabbard et al., 2008) and the authors are currently validating the tool for use in younger children.

Limitations

Validity data for the AHEMD-SR is only available in a small sample, and no normative data exists at present. However, normative data, and reliability data in other samples and settings needs to be established. The test cannot be used after 3 years, so may not be appropriate for the requirements of the current study.

Table 2. 1 Movement skill assessments for Preschoolers (3-5 years); psychometric properties & practical utility

Test	Age	Normative Data	Admin. Time	Items	Cost (£)	Abilities Tested	Psychometric Properties	Intended Purposes stated in Manual	Equipment Required
BOTMP (Bruininks, R.H. 1979)	4.5-14.5 yrs	765 typically developing 4-14 yr olds, USA.	LF: 45-60 SF: 15-20	LF: 46 (8 subtests) SF: 14	250	FM GM	Validity: Reliability Test Retest n=63 7-9.3 yr olds Adjusted ICC = 0.77 GM = 0.89 CB n= 63 11-13 yr olds Adjusted ICC = 0.85 GM = 0.86 CB Moore et al (1986) N=32 5 yrs old ICC = 0.76 (reliability of subtest items ranged from 0-0.76 median 0.39)	Screening, evaluation, research, programme planning, placement decisions.	Mat, stopwatch, chairs, clipboard, test kit

Test of Gross Motor Development (TGMD)	3 – 10 yrs	909 3-9 year olds, USA.	15-20	32	47	GM (To assess MS typically taught in PE)	Validity: Evidence that scores increase with age (Wiart & Darrah, 2001) Reliability: Test Retest >0.80	Screening, programme planning, evaluation, research. Limited info on preschool children.	Masking tape, chalk, traffic cones, 3 different sized balls, bat, tape measure
Movement Assessment Battery for Children (MABC) Performance Test (Originally TOMI)	4 – 12 yrs	1234 4-12 year olds. USA	20-30	32 (divided into 4 age bands)	260		Validity: Concurrent, with the BOTMP (Croce et al, 2001) Reliability in n=360 Test Retest TOMI-H >0.75 Interrater: >0.75 In n=76 4-6yrs olds (Chow et al, 2001) Interrater = 0.96 Test retest = 0.77 Test retest=106 n=5-12 yrs >0.90 (Croce et al, 2001)	Screening, intervention planning, programme evaluation, research.	Stopwatch, clipboard, test kit.
PDMS (Folio & Fewell, 2000)	Birth – 7 yrs	617 typically developing 0-6.11 yrs.	20-30	10 at each age level.	123	GM FM	Validity*: Content* Concurrent 0.73-0.86 (manual) 0.78 -0.95 with BSID (Palisano, 1986) Reliability: n=38 GM=0.99 FM=0.99 Inter-rate= 0.99 FM=0.99	Identification, screening research, evaluation for children suspected difficulties	Tape, rattle, stopwatch, string attached to a toy, 2 chairs, stairs with railing, ball, tennis ball, table objects of differing heights, tape measure, trike, wall target, mat, two cans.

Note the MABC Checklist (Hendersen & Sugden, 1992) age limits are 5-11 yrs, therefore are not included. BOTMP- Bruininks Oteresky Test of Motor Proficiency; TGMD – Test of Gross Motor Development; MABC – Movement Assessment Battery; LF – Long form; SF – Short Form; MS – Movement Skills; MA – Motor Abilities; EMM – Early Movement Milestones; FMS – Fundamental Movement Skills . Psychometric properties are from the test manual (unless otherwise stated).

2.2 Measurement of physical activity in children

Physical activity has been recognised as a leading health indicator (US Dept, Health: Healthy People 2010). The growing epidemic of childhood obesity is almost certainly due in part to a lack of physical activity in modern children. Levels of physical activity may be particularly important in young children (Kelly et al., 2004), as these children are at a critical period for the development of obesity. In order to quantify levels of physical activity in young children, the best method of measurement must be identified. To date there is a lack of studies examining 'best practice' for the measurement of physical activity (Oliver et al., 2007). As a result of their short bursts of spontaneous physical activity and cognitive-ability and recall limitations, only direct observation or objective measures of physical activity should be used in children under 10 years (Cardon & De Bourdeaudhuij, 2007).

The aim of the current section is to provide a brief review the methods of measuring / assessing physical activity in young children, with the aim of selecting an appropriate measure for the studies in this thesis.

Methods

Search terms CHILDREN or YOUNG PEOPLE and PRESCHOOL and PHYSICAL ACTIVITY or EXERCISE or PLAY and EVALUATION or ASSESSMENT or MEASURE$ were used.

Computer searches were made in English language journals through Medline, Embase, PsychInfo, general internet searches and review articles.

There are a number of excellent existing reviews on the measurement of physical activity in children / adolescents. These are highlighted in **Table 2.2**.

Criterion methods

Doubly labelled water (energy expenditure)

Doubly labelled water (DLW) is used in the assessment of free-living energy expenditure (Schoeller & van Santen, 1998; Ainslie, Reilly & Westerterp, 2003). DLW data are usually collected from 4-20 days, to give a representation of free living energy expenditure. The participant takes a dose of water orally, containing a known amount of stable isotopes of hydrogen (^{2}H) and oxygen (^{18}O). The isotopes mix with the normal hydrogen and oxygen in the body water. As energy is expended, CO_2 and water are produced. The CO_2 is lost in breath, and water in urine, sweat and breath (Ainslie, Reilly & Westerterp, 2003, p9). ^{18}O is lost more rapidly (as it is contained in both CO^2 and water). ^{2}H is only contained in CO_2 (Ainslie, Reilly & Westerterp, 2003, p9). The difference between the rate of loss of 18O and ^{2}H reflects the bodies CO_2 production rate, and can be used to estimate energy expenditure (EE). To make the calculation more reliable, an estimate of CO_2 production to VO_2 can be calculated by calculating a respiratory quotient or collecting data on energy intake. Indirect calorimetery can also be used to measure CO_2 production in relation to VO_2. The doubly labelled water method is often considered the ‘gold standard’ for measurement of free living energy expenditure (Mann et al, 2007), and can be used in babies, children, adults, and the elderly. DLW can be used as a criterion to assess validity of measure to assess (for example) physical activity, or energy intake (Ainslie, Reilly & Westerterp, 2003) however, energy expenditure and physical activity are separate constructs and this may limit attempts to validate measures of physical activity (Sirard & Pate, 2001). While the DLW technique demonstrates excellent validity (Schoeller & Hnilicka,), there are some clear limitations to its usefulness in large scale studies. Primarily the cost: more than £500 per adult participant at present, and specialist expertise required for analysis. A recent study in 9 adult males (Mann et al., 2007) has indicated that a one-tenth dose of doubly labelled water may provide a reliable measure of energy expenditure at a lower cost (Mann et al., 2007), but this would require further investigation in the intended populations, and would still prove too expensive for a population based study.

Direct Observation

Direct observation is the most appropriate criterion measure of physical activity for children (Sirard & Pate, 2001). Methods of direct observation are summarised in **Table 2.3.**While direct observation is often considered the 'criterion' method for measurement of physical activity in young children, it has limitations. It is fairly expensive and labour intensive, and cannot be used to assess habitual physical activity. It is a subjective measure, and as such, is dependent on how accurately data are observed, interpreted and recorded. Some studies have demonstrated inter-observer agreement to be poor. Direct observation has been validated against methods which in themselves are dependent on factors other than physical activity level (heart rate and oxygen consumption). However, it remains the most appropriate criterion measure of physical activity for use in children, and it may be feasible, and advisable, to validate the intended method (e.g. motion sensor) against direct observation in sub-sample of the intended population.

Objective Measures

Objective measures of physical activity have the advantage that they are free from researcher bias, are affordable compared to criterion methods, reduce bias in data as a result of self report or parent (proxy) report. Of the objective measures used in paediatric research, accelerometers are the most common. Some studies have also investigated the use of pedometers in preschoolers: these motion sensors will be discussed in more detail.

Pedometers

Pedometers are small devices containing mechanical motion sensors that measure physical activity in steps, and can be worn around the hip, ankle or waist. They are generally relatively cheap, easy to use (no researcher training required) and the step count can be easily understood by adults and children. The step count is also potentially motivational. Adult studies have suggested that the Yamax Digiwalker DW/SW 200 is the most reliable commercially available pedometer (Schneider et al., 2004; Schneider et al., 2003). There are very few studies examining the use and validity of pedometers in children: Kilawnowski et al. (1999) compared output of the Yamax Digiwalker SW 200, Tritrac Accelerometer and the Children's Activity Ratings Scales (CARS) in 10 7-12 year old children (Buffalo USA) during classroom and recreational periods. Correlations between all measures were significant for recreational and classroom periods combined, and for recreational time alone ($r > 0.90$, $p < 0.001$).

Correlations between pedometer and accelerometer were significantly lower for classroom time alone ($r = 0.50$, $p<0.05$), the authors suggest this may be due to the pedometer being sensitive to vertical movement only (Kilanowski et al., 1999). However the results indicate that the pedometer had a higher correlation coefficient with the Children's Activity Rating Scale (CARS) (Puhl et al., 1990) (r 0.80, $p<0.02$) than the Tritrac accelerometer ($r = 0.70$, $p<0.01$) (Kilanowski et al., 1999). The small number of subjects in this study (7 boys; 3 girls) mean that the results are not generalisable. Rowe et al. (2004) examined reliability and reactivity (alteration in behaviour to wearing the monitor) of 299 10-14 year old children in North Carolina USA (Rowe et al., 2004). These authors found no evidence of reactivity, and this finding is supported by Vincent & Pangranzi, (2002a) who found no evidence of reactivity when using sealed pedometers that were sealed so that the wearer couldn't see the screen. Cardon & De Bourdeaudhuij (2004) used Yamax Digiwalker SW-200 pedometers to measure the step-count of 92 Belgian school children aged 6-13 years, and compared physical activity to reported MVPA (parent / child diary). There was a weak significant correlation ($r=0.39$, $p<0.001$) between pedometer counts and self reported MVPA. This correlation is similar to studies comparing accelerometer data to self reported physical activity. Eisenmann et al (2007) examined the utility of physical activity measured by pedometer (Digiwalker 200 SW) in predicting overweight in 608 (mean age 9.6 years) children, Midwest USA. The results indicated that children not meeting the pedometer recommendations: 11000-12000 steps/ day for girls, 15000 steps/day for boys (Vincent & Pangranzi 2002b; Cardon & De Bourdeaudhuij, 2004; Tudor-Lock et al., 2004) were two times more likely to be overweight / obese than those meeting recommendations.

Although the Yamax Digiwalker 200 shows promise in adults and older children, to our knowledge there are only 3 studies examining the use of pedometers in younger children (Oliver et al., 2007[R]).

Limitations of the pedometer

Pedometers have several limitations. They provide only estimates of cumulative activity, and do not store activity data by time. It is not possible to determine intensity or duration of activity. The one dimensional nature may be problematic when measuring physical activity in children, as children may engage in play behaviours that involve a greater range of movements than adult movement. They are better suited to higher intensity activities (Kilawnowski, 1999), and therefore would not be suitable for the measurement of sedentary behaviours and may mask lower intensity activity. There is some suggestion that the ability of the pedometer to accurately measure free living physical activity is questionable (Oliver et al., 2007). They are, however, correlated with physical activity in children and provide an inexpensive method for measuring physical activity in large samples of children.

Accelerometers

Both volume and intensity of activity are needed in physical activity research in order to understand the dose-response relationship between physical activity and the outcome being measured (Freedson, Pober & Janz, 2005). An alternative motion sensor, widely used in paediatric physical activity research, is the accelerometer. Acclerometers measure ‘acceleration’ (the change in velocity over time) and can therefore be used to measure the volume and intensity of movement. The internal mechanics of the accelerometer are beyond this scope of this thesis, but for a comprehensive description see Chen & Bassett, (2005). Intensity of activity can be quantified by applying cut points to define sedentary, light, and moderate and vigorous (MVPA) activity, or using equations to transform raw data to heart rate, or energy expenditure. The use of regression equations to transform data is problematic in children however, as associations are confounded by growth (Freedson, Pober & Janz, 2005). The bulk of the paediatric accelerometer literature involves 3 models: the Actigraph (CSA / MTI) Actical & Actiwatch (Mini Mitter, or the RT3 Triaxial Research Tracker (Tritrac-R3D) for a summary of the specification of these models see **Table 2. 4**. For details of validation studies in children see **Table 2. 5.**

Which accelerometer?

Uniaxial or triaxial

Children generally have a range of activities in a variety of directions, so it would seem logical that triaxial accelerometers may provide a more reliable measure of physical activity. However, little empirical evidence exists to support the use of a triaxial over uniaxial monitor (Freedson, Pober & Janz, 2005).

Model

Selection of the model should be based on practicality of use, intended population / sample size, software available for analysis, comparability to other studies and availability of a reliable method to quantify intensity of activity (Trost et al, 2005). Recent reviews (Reilly et al., 2008; De Vries et al., 2007) recommend use of the Actigraph (www.theactrigraph.com) accelerometer, based on the fact that is the most widely used in paediatric research, and has the largest body and evidence to support its validity, reliability and use in children (Reilly et al., 2008 p 615; De Vries et al., 2007). Based on these criteria, the Actigraph accelerometer may be the best of the currently available motion sensors for use in children. It has been validated for use in children, is small & lightweight, rechargeable, waterproof (the most recent Actigraph model, GT1M) easy to initialise and download and has a wide range of possible epoch lengths (www.theactigraph.com). Existing large birth cohorts; Avon Longitudinal Study of Parents & Children; ALSPAC (Riddoch et al., 2007; Ness et al., 2007) and new research (*Millenium Birth Cohort – MRC Institute of Child Health, Personal Communication*) in large population based studies have selected this as an outcome for the measurement of physical activity. The Actigraph accelerometer has been used and validated in children against doubly labelled water and direct observation (Fairweather et al., 1999). There are also published paediatric cut points for Actigraph output to quantify sedentary behaviour (Reilly et al., (2003), light activity and moderate and vigorous activity (MVPA) (Puyau et al., 2002). The Actigraph accelerometer has been used successfully in very large samples of children: n= 6329, Trioano et al., 2007 National Health and Nutrition Examination Survery (NHANES) www.cdc.gov/nchs/nhanes; n = >5000 Avon Longitudinal Study of Parents and Children (ALSPAC) www.alspac.bristol.ac.uk (Mattocks et al., 2008).

Practical considerations

Time sampling frequency (epoch)

Most studies use a 1 minute epoch, but there is some evidence that at very high intensity activities a shorter epoch would provide more representative information (Nilsson et al., 2002). However, in reality, even in children, epoch length used does not appear to greatly impact the overall data in sedentary behaviour, light and moderate physical activity (Reilly et al., 2008). Epoch length appears to only be important only at high levels of physical activity (Reilly et al., 2008; Rowlands et al., 2006; Nilsson et al., 2002).

Length of measurement period

The number of days and hours need to be determined for each sample and setting (Reilly et al., 2008), however in young children it appears the most reliable measure is obtained from 10 hours per day over 7 days (Penpraze et al., 2006). Representative data can be obtained from as little as 3 days of monitoring (Reilly et al., 2008; Penpraze et al., 2006). Based on this, accelerometer inclusion criteria for the studies in this thesis were at least 9 hours of data on at least 3 days. This provides reliability of 62%. The optimum monitoring period is 10 hours for 7 days, representing reliability of 80% (Penpraze et al., 2006).

Monitor placement

The bulk of the literature using accelerometers in children indicates the placement on the *right hip* is valid, and tolerated well by children. In an accerlometer calibration study by Puyau et al. (2002) hip or leg placement of monitor did not significantly influence physical activity output. However, placement around the waist is generally recommended (Reilly et al., 2008).

Cut-points

Analysis of child Actigraph data in 72 4-7 year old children (Reilly et al., 2008) comparing the most commonly used cut-points to quantify sedentary behaviour and moderate and vigorous physical activity (MVPA) (Treuth et al., 2004; Reilly et al., 2003; Puyau et al., 2002; Freedson et al., 1997) indicate that the most plausible cut-points to use are 1100 per minute to define sedentary behaviour (Reilly et al., 2003) and between 3000-3600 counts per minute to quantify MVPA (Reilly et al., 2008). For consistency, the cut point to define MVPA in this thesis is based on the study by Puyau et al. (2002) (> 3200 counts per minute). Vigorous physical activity, as measured by acceleromtery, in young children is defined as > 8200 counts per minute, based on the cut point provided by Puyau et al. (2002).

Old versus new Actigraph (GT1M) Model

In 2005 a new Actigraph model was launched; the GT1M. This replaced the Actigraph 7164, which forms the bulk of the literature on accelerometery, but which is no longer in use. Corder et al. (2007) suggest that the new GT1M systematically records physical activity around 9% lower than the old Actigraph model (Model 7164). The authors suggest a correction factor of 0.91 should be used when comparing data from the GT1M and the 7164. These authors suggest that the increased memory, and improved inter-monitor reliability of the GT1M should "produce more accurate and standardized data than the 7164" (Corder et al., 2007).

Limitations of Accelerometers

At present there is no clear consensus on which cut points should be used to quantify sedentary behaviour or which epoch length to use in young children – some researchers suggest that 1 minute epochs may not capture the short spontaneous bursts of activity seen in young children; however recent evidence comparing epoch lengths does not support this (Reilly et al., 2008). If lower epochs are to be used, this in itself is problematic – the lower the epoch, the shorter the possible data collection period possible. Previous cut points have been validated for on minute epochs, but its unclear whether these can be applied to shorter epochs lengths and, if so, how? Although the manufacturers claim that the technology is the same, as noted above, there are new data suggesting the new model of Actigraph (GT1M) reports activity counts around 7-10% lower than the older model (Corer et al., 2007) – this is problematic when applying cut-points that have been developed using the old model and comparison with studies that have used the old model, or have combined both old and new model. Ongoing research is being carried out to determine this in adults http://clinicaltrials.gov/ct2/show/NCT00342212 and in children.

To our knowledge, to date, no-one has published data on how data from an individual monitor may change over time, and especially in the case of the new Actigraph GT1M which is proposed as 'self-calibrating', this is potentially important.

Heart rate

The "Flex Heart Rate" (Flex HR) has become a standard method for assessing energy expenditure in human populations (for detailed review see Leonard, 2003). Reliability of the Flex HR as a proxy for energy expenditure, against criterion methods of doubly labelled water, and whole body indirect calorimtery, have been demonstrated in adults (see Leonard et al., 2003 pp 481 for summary of adult validation studies), and in children (Leonard et al., 2003 pp 483).

Limitations of use of the flex-HR method in children

Previous validation studies in children are relatively limited (Leonard et al. (2003). Existing data suggests that Flex HR is good for assessing group total energy expenditure (TEE), but may lack precision when providing individual estimates (Livingstone et al., 2000). HR calibration studies in children have tended to include only one type of exercise, generally treadmill or cycle ergometer, and this may not be representative of the daily activity patterns of children (Livingstone et al. (2000). Previous experience in our group suggested that there was lower compliance to use of HR monitors in young children as compared to acclerometers (unpublished pilot data from the 'SPARKLE' study). The combination of heart rate and accelerometery has been suggested as a promising measure of energy expenditure and physicial activity in children, for example the 'ActiHeart', www.camntech.com/cntactiheart.htm however further research in children is required.

Proxy (parental) assessments of physical activity

Questionnaires and activity diaries have a clear advantage in large population based or epidemiological studies. However, as a result of their cognitive-ability and recall limitations, it is recommended that direct observation or objective measures of physical activity should be used in this age-group (Cardon & De Bourdeaudhuij, 2007; Burdette, 2004). This, however, is not necessarily feasible for large-scale epidemiological studies. There are very few proxy measures of physical activity for children. Burdette et al. (2004) examined the validity of an Outdoor Time Checklist and parent recall of outdoor playtime in 250 children (Cincinnati, USA) against the RT3 accelerometer. The Checklist is based on the premise that children accumulate the majority of their physical activity outdoors (Burdette et al., 2004). Time spent outdoors (as recorded by parents on the checklist) was significantly, but weakly, correlated ($r=0.33$, $p<.001$) with the levels of physical activity measured by the accelerometer, as was outdoor playtime recall (0.20, $p=<0.001$). The 2 parent measures of outdoor time were correlated with one another ($r=0.57$, $p=<0.001$) (Burdette et al, 2004). While the checklist and recall may have merit in determining the proportion of overall physical activity accumulated by time spent outside in these children, it is not viewed as a precise enough measure of physical activity for many research applications. The differences in climate between the USA and UK (colder/wetter climate – less time outside) mean that it is unlikely that the results would translate. In their review, Sirard and Pate (2001) conclude that there is little evidence for the validity of proxy reports of physical activity by parents and teachers (Sirad & Pate, 2001).

A parent diary or proxy measure of physical activity may be considered to complement an objective measure may be considered. If a proxy measure of physical activity is the only feasible outcome measure, it must at the very least be validated in the proposed population against a criterion measure (direct observation), or a reliable objective measure (accelerometer), and reliability (test retest and inter-rater) data must be collected.

Conclusion: the existing research, expert reviews and recommendations suggest that the best outcome measure for objectively measuring physical activity in young children is the **Actigraph accelerometer**, placed on the **right hip**, with an attempt to collect data for 7-10 hours per day for 3-7 days (inclusion criteria at least 3 days containing at least 9 hours of activity.

2.3. Anthropometric measures

For descriptive purposes**,** we measured height to 0.1 cm, and body mass (to 0.1kg) in all children. Body mass index (BMI) was calculated as mass (kg) / height (m^2).Body mass index (BMI) was calculated (kg/m^2), and converted to BMI SD scores based on the UK 1990 reference data, using an Excel file and macro from the Child Growth Foundation (Cole et al., 1995).

Table 2. 2 Published reviews of measurement of physical activity in children / adolescents.

Reference	Title / Topic
Reilly et al. (2008)	Objective measurement of physical activity and sedentary behaviour: review with new data.
De Vries et al. (2006)	Clinimetric review of motion sensors in children and adolescents.
Rowlands (2007)	Accelerometer assessment of physical activity in children: an update.
Trost, S.G. (2007)	State of the Art Reviews: Measurement of physical activity in Children and Adolescents.
Oliver, Schofield & Kolt, (2007	Assessment of Physical Activity in Preschoolers
Trost, McIver & Pate, (2005)	Conducting Accelerometer based activity assessments in field based research.
Freedson, Pober & Yanz, (2005)	Calibration of Accelerometer output in children.
Chen & Basset, , (2005)	The technology of accelerometery-based activity monitors: current & future use.
Sirard, J.R. & Pate, R.R. (2001)	Physical Activity Assessments in Children & Adolescents.
Sallis, F.J. & Saelens, B.E. (2001)	Assessment of Physical Activity by Self Report: Status, Limitations and Future Directions. †

† Includes adult studies, but included for relevance.

Table 2. 3 Summary of scales for direct observation of physical activity in children

Scale	Description	Reliability Studies in Children	Concurrent Validity	Intended setting for use.	Limitations
CARS (Child Activity Rating Scale) (Puhl et al, 1990)	10 seconds of observation followed by 10 seconds of recording. Most commonly used. Coding of activity in 5 categories (resting, low, medium-to-high, vigorous)	Assessment of practicality and inter-observer reliability over a 12 month period in 491 3-4 year olds. Interrater reliability 0.74-0.94 in n=192 3-4 yr olds.	V_{02} & HR	Various.	Validation against V_{02}.
OSRAC-P (Observational System for Recording Physical Activity in Children-Preschool Version) (Brown et al, 2006).	5 seconds of observation followed by 25 seconds of coding. Modified version of CARS. Developed with preschool children.	Inter rater kappa = 0.79-0.99		Preschool (Indoor, outdoor, social).	Broad range of agreement for physical activity level and type (0.10-1.00) and 0.500-1.00).
BEACHES (Behaviours of Eating and Activity for Children's Health Evaluation System) (McKenzie et al,	1 minute momentary time sampling with 5 categories during various conditions**.**	Interrater 19 4-9yr olds K=0.71-1.0	HR	Various. Wide range of social and environmental influences. Home.	Time: four observations of 60 minutes recommended to characterised child behaviour.

1991)					Complex coding system & 10 hours of practice require for administrator (McKenzie et al, 1991).
SOPLAY (System for Observing Play and Leisure Activity in Youth) (McKenzie et al, 2000).	Incorporates aspects of SOFIT/ BEACHES & CARS. Planned activity check recording.	Intrerrater correlations 0.75 (0.76-0.98 lower in more active girls).	Self Reported Physical Activity**.** (before school 0.74; lunchtime 0.73; after 0.35) Coding validated with HR.	Various: Groups of children. Behavioural settings / target areas in schools / communities coded as 'sedentary', 'activity or 'very active.'	Aimed at older (school aged) children, no evidence of use in preschool. Low correlation for after-school activities (possibly relating to comparison with self-report).
Children's Physical Activity Form (CPAF)	1 minute time sampling in 4 categories.	Interrater reliability in 18 8-10 yrs 0.96-0.98	Correlation with HR 0.61-0.72 Actigraph accelerometer in 3-4 year olds (Fairweather et al, 1999; Kelly et al, 2004).	Structured class.	Moderate correlation with HR.
FATS (Fargo Activity Time sampling Survey)	10 second time sampling in 8 categories.	Interrater reliability in =14 aged 2-4 years 0.91-0.99	LSI r=0.78-0.90	Various.	Validation against LSI. Studies have suggested low correlations (albeit against self report) r = 0.16 to r = 0.40 (LaPorte et al (1981)

					and Klesges et al 1985).

LSI: Large-scale integrated physical activity monitor.

Table 2. 4 Specifications of the 3 most commonly used accelerometers in paediatric research.

Accelerometer	**Actigraph (MTI/CSA)**	**RT3**	**Actical / Actiwatch †**
Manufacturer	MTI	Stay Healthy	Mini Mitter
Dimensions	51x41x15mm, 43g	71 x 56 x 28 mm, 65g	
Battery Type **Battery Life (1 min epoch)**	Coin cell (rechargeable by USB in the GT1M) 22 days (14 days in GT1M)	1 x AAA 8.5 days	Coin cell 45 days
Epoch	1 second – 10 mins	1 second or 1 minute	15 seconds – 15 minutes
Axes	Uniaxial (vertical place)	Triaxial	Uniaxial
Manufacturers calibrator available for purchase	√ (not for GT1M)	**X**	√
Waterproof	√ (GT1M 'self calibrating')	**X**	√

†usually used in sleep research

Table 2. 5 Accelerometer validation studies in children.

Reference	Sample	Aim / Method	Summary Findings
Corder et al., (2007)	15 boys and 15 girls aged 15.8 years SD 0.6.	Comparison of old (7164) and new (GT1M) Actigraph models.	Correlation between models r=0.95 (p <0.0001) GT1M averaged 9% lower than 7164. A correction factor of 0.91 is suggested. GT1M showed more time sedentary, and less in light intensity activity. GT1M cut points should be 10% lower than existing (in this age-group).
Reilly et al. (2008)	32 5-6 year olds.	Analysis of Actigraph applying 15, 30, 54 and 60 second epochs.	Differences between epochs for sedentary behaviour were not significant. Epoch differences for MVPA were significant but small.
Mattocks et al., (2007)	83 12 year olds.	To develop population-specific cut points for definition MVPA. Cosmed K4b2 Actigraph 7164	Lower threshold for MVPA was 3581 counts per minute.
Penpraze et al., (2006)	76 mean age 5.36 years SD 0.4.	To identify the optimal montoring period for use of the Actigraph in preschool children.	The most reliable physical activity was a monitoring period of 10 hours per day for 7 days.
McLain et al. (2006)	31 children mean age 10.2 SD 0.4 years.	Comparison of Kenz Lifecorder (pedometer) Yamax Digiwalker pedometer and Actigraph	The 2 pedometers recorded a similar number of steps, but a significantly lower number

		accelerometer step counter.	that the Actigraph.
Pate et al., (2006)	30 3-5 year olds	Actigraph and Cosmed during rest and structured physical activity . activity	Correlation between accelerometer counts and VO^2 was 0.82.
Sirard et al., (2005)	16 3-5 year olds. 281 3-5 year olds	To establish cut points and evaluate the Actigaph as a measure of activity in preschools.	Abstract only, need paper.
Kelly et al,(2004) *Pediatr. Exerc. Sci 16*; 324-333.	78 3-4 year olds	CSA/MTI WAM-7164 and Actiwatch accelerometers simultaneously measured activity during structured-play classes in 3- to 4-year olds	Correlation between Actigraph & D.O. (r=0.72) Actiwatch & D.O. (r=16) Between monitors (r=0.36)
Treuth et al., (2004)	74 13-14 year old girls	Accelerometer and oxygen consumption (VO^2) (Cosmed K4b2) for 10 sedentary (e.g. TV viewing) and vigorous (e.g running) activities.	Sedentary cut point 0-50 Light 51-1499 Moderate 1500-2600 Vigorous >2600 Counts per 30 seconds.
Reilly et al., (2003)	30 3-4 year olds (n=52 cross validation)	Comparison of Actigraph accelerometer to direct observation (CPAF)	Optimal sensitivity and specificity for sedentary behaviour at 1100 counts per minute cut point. Mean specificity in cross-validation was 82 SD 11% (79-86%)
Chu et al, (2003) *Pediatri. Exerc. Sci*. 15; 55-56.	34 Vietnamese 11-15 year olds.	Validation of the Actigraph to predict energy expenditure.	Activity counts from Actigraph significantly correlated with oxygen consumption (r 0.88)(Cardiopulmonary

			diagnostic system) and HR (r=0.73). Prediction equations should be used in groups rather than individuals.
Nilsson et al., (2002)	16 7 year olds	To examine Actigraph data using different time sampling intervals (epochs) and different monitor placements.	There was so significant difference in time spent in moderate activity between epochs. A significant epoch effect was seen at high and very high intensity activity levels ($p<0.1$). There was no significant effect of monitor placement.
Puyau et al, (2002) *Obes. Res*. 10:150-157..	26 6-16 year olds	Relationship activity counts from Actigraph & Actiwatch to whole body calorimetry.	Stronger correlations with Actical (r=0.85) than Actiwatch (r=0.82). Correlation between monitors (0.93).
Ott et al, (2000) *Ped. Exerc. Sci.* 12:360-370.	28 9-11 year olds	Ability of Actigraph and Tritrac-RD3 to measure free play in children. Compared to HR / observation.	Both monitors significantly correlated with HR / obs across activities (video games, stepping, hopscotch, basketball, dancing, running). Tritrac-RD3 (r 0.66-0.73) Actigraph (r 0.53-0.64) Correlation between monitors (r=0.86) suggest similar data from uniaxial / triaxial.
Finn & Specker, *Med. & Sci in*	40 3-4 year olds.	Comparison of Actiwatch and	Correlations between

Sport & Exerc. 32; 10; 1794-1979, 2000.		Children's Activity Rating Scale (CARS).	Actiwatch and CARS ranged from r=0.03 – 0.92 (median 0.74) Higher correlations in more active children.
Fairweather et al, (1999) *Pediatr. Exerc. Sci*. 11 413-420.	11 3 – 4 year olds	To assess the ability of the actigraph (CSA) to measure physical activity in preschool children against Children's Physical Activity Form (CPAF).	Correlation between Actigraph and CPAF r = 0.87, p < .001.
Eston et al, *J. Appl. Physio*. 84:362-371, 1998.		Relationship between oxygen consumption , Actigraph & Tritrac RD3 during running / walking and play.	Tritrac-RD3 = r=0.91 Actigraph = 0.78
Coleman et al, (1997) *Med. Sci in Sport & Exercise.* 29; 11: 1535-1542.	Obese 8-12 year olds	Validity of Tritrac-RD3 and HR	
Welk & Corbin, *Res Q Exerc.* Sport 66:202-209, 1995.		Comparison of triaxial TriTrac-RD3 & uniaxial Caltrac to HR	Correlation RD3 & HR = r=0.58 Caltrac & HR = 0.52 Caltrac & RD3 = 0.88

Chapter 3. The relationship between fundamental movement skills and physical activity in young children.

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Contributions

Study design, all movement skills and physical activity data collection, downloading and accelerometer physical activity data reduction, and statistical analysis were all carried out by the thesis author under the supervision of Professor John Reilly.

Data were collected as the baseline of a large RCT; the MAGIC (Movement Activity Glasgow Intervention in Children) Study, therefore the study presented in this chapter would not have been possible without the input of the MAGIC research team; Professor John Reilly (PI) , Dr Louise Kelly, Dr Collette Montogomery, Dr James Paton and John McColl.

3.1 Introduction

There is increasing evidence that modern pre-school children might be less physically active than expected (Reilly et al., 2004; Jackson et al., 2003;Kelly et al., 2003), and there is increasing emphasis on early childhood lifestyle as a determinant of later disease risk (Reilly et al., 2003; Janz et al., 2002; Fulton et al., 2001). It is widely believed that fundamental movement skills and habitual physical activity are related in childhood and adolescence (McKenzie et al., 2004; Fulton et al., 2001; Okely et al., 2001; Pate et al., 2001), and elucidating relationships between these two variables was highlighted as a research priority by the Centre for Disease Control (CDC) in 2001 (Fulton et al., 2001). However, Pate (2001) questioned the premise that these two variables are related and asked whether the degree of emphasis being placed on motor skills in the paediatric physical activity community was excessive.

Very few studies have examined the relationship between habitual physical activity and fundamental movement skills (basic motor skills) in children. Okely et al (2001) found a significant relationship between fundamental movement skills and self-reported participation in organised physical activity in adolescents, although only a small proportion (3%) of participation in organised physical activity was explained by fundamental movement skills score. Butcher and Eaton (1989) reported a significant positive relationship between fundamental movement skills and participation in vigorous activity in pre-school children. However these authors used free play behaviour as their single measure of physical activity and running speed and agility were the only movement skills assessed. Ulrich et al (2004) found a significant relationship between parent-reported ‘movement competence’ and participation in organised sport in 5 to 10 year old children.

There is, therefore, no consensus in the literature on the methods that should be used to assess/ report physical activity, or the definition of fundamental movement skills, and measurement of both variables present practical problems, particularly in young children. Consequently, studies in this area have been scarce. We are not aware of any published studies that have tested empirically whether or not there are relationships between objectively measured habitual physical activity and global fundamental movement skills in young children.

A pilot study in 60 pre-school children (Reilly et al., 2003) found a significant positive correlation (r 0.30, $p<0.05$) between habitual physical activity, as measured by CSA accelerometer over two days, and fundamental movement skills test score in pre-school children. The aim of the current study was therefore to test whether there was any significant relationship between these two variables in a larger and more socio-economically representative sample of contemporary pre-school children in which physical activity was measured over a longer period (6 days).

3.2 Participants and methods

We aimed to study pre-school children recruited for baseline measurements (pre-intervention) of the Movement and Activity Intervention in Glasgow Children (MAGIC) randomised controlled trial (Reilly et al., 2006). For inclusion in the current study (for analysis purposes) children had to be apparently healthy, having no chronic disease relating to energy expenditure or physical activity. The children all lived in urban or suburban settings in and around Glasgow, Scotland. The study was approved by the Yorkhill Hospital Ethics Committee. Informed written consent was obtained from the parent/ guardian of each child.

The 'MAGIC' randomised controlled trial entered 545 children. Insufficient numbers of accelerometers and research staff during the study period meant that a pragmatic decision was taken to measure habitual physical activity (a secondary outcome measure in the trial) in 482 of these 545, and we selected these 482 children randomly (using a computer generated random number sequence) from the entire sample of 545. Of these 482, 58 children were excluded due to insufficient accelerometry data to meet our reliability criteria established before the study began; a minimum of 9 hours per day over at least three days (Penpraze et al., 2006). Physical activity was therefore measured successfully in 424/482 children. A further 30 of these 424 children were excluded from analysis due to: absence from nursery school on day of movement skills test (n=27) or inability/unwillingness to perform the movement skills test (n = 3). This left data from 394 children for analysis in the present study.

Physical activity measurements

Habitual physical activity was measured using the Actigraph Model 7164 accelerometer (MTI, Fort Walton Beach, FL). This is a small, lightweight, uniaxial device (measures movement largely in the vertical plane) which was worn on the right hip under clothing as previously described (Reilly et al., 2006; Jackson et al., 2003; Reilly et al., 2003; Fairweather et al., 1999; Chapter 2 of thesis). A number of studies have reported favourably on the validity of the Actigraph in children, by comparisons against direct observation of behaviour or energy expenditure (Reilly et al., 2003; Puyau et al., 2002; Finn & Specker et al., 2000; Fairweather et al., 1999; Eston et al., 1999; Trost et al., 1998) .The CSA/MTI produces output in activity counts per unit time. This output can be considered in 'raw' form (counts per minute, cpm) as a valid index of total 'volume' of physical activity (Puyau et al., 2002; Nilsson et al., 2000; Fairweather et al., 1999). Alternatively, output can be interpreted using cut-points which define different intensities of physical activity (Reilly et al., 2003; Nillson et al., 2002; Puyau et al., 2002). Paediatric cut-points have been published which have been validated for young children carrying out unrestricted activities based on both of the criterion measures for physical activity, i.e. energy expenditure (Puyau et al., 2002) and direct observation of behaviour (Reilly et al., 2003). We applied these cut-points in the present study: sedentary behaviour <1100 counts per minute (Reilly et al., 2003); light intensity physical activity 1100-3200 counts per minute (Puyau et al., 2002); moderate and vigorous physical activity (MVPA) >3200 counts per minute (Puyau et al., 2002). Alternative cut-points are less suitable for paediatric use at present because they do not meet a number of criteria are unpublished; involve extrapolations from adult studies which may be questionable; involve extrapolation from treadmill exercise which does not necessarily represent the types of activities carried out by young children (Reilly et al., 2008).

We aimed to measure habitual physical activity in participating children by asking families to fit the accelerometers in the early morning and remove them at night (before bedtime) for a period of 6 consecutive days. Parents and nursery staff were asked to record when accelerometers were fitted and removed, and why they were removed (e.g. for swimming).

Fundamental movement skills assessment

Fundamental movement skills were measured using 15 tasks based on the Movement Assessment Battery (Henderson & Sugden, 2002). Reliability and concurrent validity of the Movement Assessment Battery in young children has been documented previously by Croce et al: intra-class correlations for test-retest reliability over a 1 week period for children aged 5 - 6 ranged from 0.92 to 0.98. (Croce et al., 2001). The measurements in the current study were carried out by the same trained observer (the thesis author), positioned to allow full view of the tests, but far enough away to avoid obstructing or distracting children. The test involved a set of 15 tasks: jumps (vertical jump, running jump and standing jump from measured distance of 33 inches); balance, standing on one foot for exactly 1 second and standing on one foot for exactly 6 seconds-timed by stopwatch; skips (4 different forms of skipping); ball exercises, kicking rolled ball from 72”, catching ball from 33” (overarm throw), catching bounced ball from 72”; throwing beanbag into a target from 72”. These tasks were selected because they have been successfully measured in other studies (Butcher & Eaton, 1989), are age appropriate for the children in our study (Gabbard, 2004), and, as a set, favoured neither boys nor girls (Garcia et al., 1994).

A member of staff from each participating nursery was shown how to perform/ demonstrate each task. To make the children feel more comfortable they were taken out of class for testing in groups of 4-5 children (distraction caused by interactions between children is common in larger groups) but each child was tested and scored individually. Each group was given a single demonstration of the exercise. Children then attempted each task individually and the single trained observer (the author) checked a box YES (if the task was performed correctly), or NO (if the task was not carried out / carried out incorrectly). The test was scored YES = 1, NO = 0. Each child was therefore given a total score from 0-15. This single measure of overall movement skills was used for analysis, though analysis by subsets of tasks (locomotive, manipulative, and balance) was also carried out and these results are discussed below.

Anthropometry

For descriptive purposes**,** we measured height to 0.1 cm, and body mass (to 0.1kg) in all children. Body mass index (BMI) was calculated as mass (kg) / height (m^2). BMI was expressed as a standard deviation score (SDS) relative to 1990 UK reference data.

Statistical analyses

We first tested for associations between fundamental movement skills score and various indices of habitual physical activity (total physical activity summarised as accelerometry count per minute; % of monitored time spent in light intensity physical activity; % of monitored time spent in MVPA) using correlations. We also tested for differences in these indices of habitual physical activity by quartiles of movement skills score using Kruskal-Wallis tests. To compare activity levels in different quartiles for movement skills a Kruskall Wallis test was carried out using data from boys only, girls only, and both sexes combined. Where Kruskal-Wallis tests were significant, we used Mann-Whitney tests to assess the significance of differences in physical activity between the upper and lower quartiles for movement skills score. Statistical significance was set at $p < 0.05$.

3.3. Results

Full data were available from 394 children, mean age 4.2 SD 0.5 years (209 boys; 185 girls). The mean duration of accelerometry in the 394 children studied was 56.0 hours (SD 13.3). Physical characteristics, and summary data for total physical activity, percentage time spent sedentary, in light intensity physical activity, MVPA, and fundamental movement skills are shown in **table 3.1**. Total physical activity and percentage monitored time spent in light activity and in MVPA were slightly but significantly higher in boys than in girls (Mann-Whitney U test $p < 0.001$). Percentage time spent in sedentary behaviour was slightly, but significantly, lower in boys than in girls (Mann Whitney U test $p<0.001$). There was no difference in fundamental movement skills score between boys (median 8: min 0 max 14) and girls (median 8: min 0 max 14) (Mann Whitney U test p 0.56).

Relationship between fundamental movement skills and physical activity
Correlations in the entire sample

Total movement skills score was weakly but significantly positively correlated with total physical activity (accelerometry output in cpm): r 0.10, p 0.039. Total fundamental movement skills score was not significantly correlated with % time spent in light intensity activity: r 0.02, p 0.625. Total movement skills score was weakly but significantly positively correlated with % of monitored time spent in *MVPA*: r 0.18, p <0.001.

Table 3. 1 Physical characteristics and physical activity of children

Variable	Mean / Median	SD	Range
Age (y)	4.2 / 4.2	0.5	3.6, 5.0
Height (m)	1.03 / 1.03	0.04	0.92, 1.16
BMI	16.37 / 16.16	1.44	13.00, 24.94
BMI SDS	0.43 / 0.38	0.94	-2.23, 4.45
Mean accelerometer counts/min	769 / 747 †	192	365, 1480
% time inactive	76.3 / 77.0 †	6.8	53.6 , 92.9
% time in light intensity activity	20.3 / 19.9 †	5.3	6.3 , 34.9
% time in MVPA	3.3 / 2.9†	2.2	0.3, 13.0
Fundamental movement skills score	8 / 8	3	0 , 14

n=394; 209 boys, 185 girls

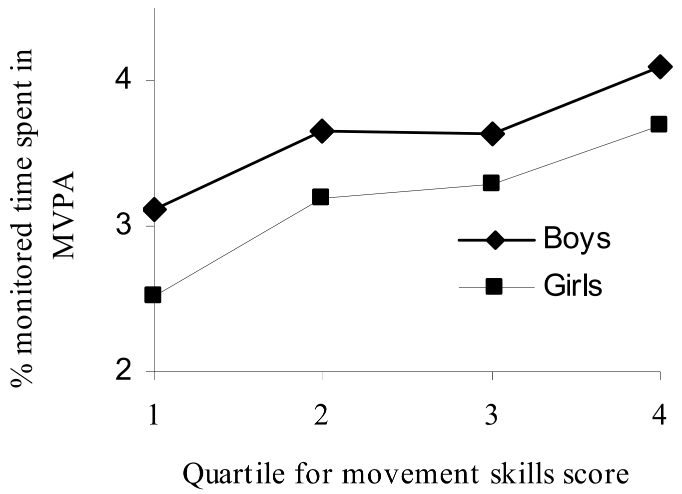
† significantly higher in boys than girls by Mann Whitney U test

Relationships between quartiles for movement skills score and habitual physical activity

We found no significant association between quartiles of movement skills score and *total* physical activity (accelerometry count in cpm; Kruskal-Wallis, p=0.16), or time spent in *light* intensity physical activity (p=0.54). These observations were essentially the same whether analysed for the entire sample or by treating the sexes separately in the analysis (boys p=0.21; girls p=0.49).

There was a significant association with quartiles of movement skills score and percentage of monitored time spent in MVPA (p=0.001). Comparison of percentage time spent in MVPA by quartiles for fundamental movement skills score are summarised in **figure 3.1**. In the girls time spent in MVPA was significantly higher in the upper quartile (Q4) quartile for fundamental movement skills than the lower quartile (Q1) (median difference 0.9%: 95% CI 0.2-1.6% p 0.01). In boys time spent in the upper quartile (Q4) for fundamental movement skills score was significantly higher by Mann-Whitney test than the lower quartile (Q1) (median difference 0.9% 95% CI 0.0-0.2% p 0.04).

Figure 3. 1 Lower, middle and upper quartiles for time spent in moderate and vigorous physical (MVPA) activity in boys and girls



% monitored time spent in MVPA as measured by the Actigraph GT1M accelerometer, using >3200 cut point by Puyau et al., (2002). Boys and girls in the upper quartile spent significantly more time in MVPA than boys and girls in the lower quartile ($p<0.05$).

3.5 Discussion

Main findings in context

The present study suggests that there are significant but weak cross-sectional relationships between habitual physical activity (specifically time spent in moderate and vigorous physical activity and total physical activity) and fundamental movement skills in modern pre-school children. Children who spent more time in MVPA tended to have higher fundamental movement skills scores, but each explained only a small amount of variation in the other variable in the present study. Our observations tend to support the view expressed by Pate (2001) that habitual physical activity and movement skills may not be closely associated in childhood. However, our observation of marked differences between time spent in MVPA and motor skills in upper and lower quartiles (**figure 3.1**) perhaps suggests that, at the extremes of the distribution, these associations might be more important. This possibility should be explored in future research. For example, children with the most limited engagement in MVPA also had poorest performance in the motor skills assessment and it is possible that limited engagement in MVPA might hinder motor development, or that limited motor development might restrict participation in MVPA.

Our findings are also similar to those of Okely et al (2001) who found a weak, but statistically significant, relationship between time spent in organised physical activity and fundamental movement skills in Australian adolescents (Okely et al., 2001). The amount of variance in time spent in organised physical activity explained by fundamental movement skills in the Australian study was small

(3%). A recent study in 124 Australian 6-12 year olds using the Movement Assessment Battery reported only weak significant, or non-significant, correlations with pedometer counts (Zivani et al., 2008).

In children in the present study engagement in MVPA was relatively low and engagement in sedentary behaviour high. We have previously reported this observation in other samples of young Scottish children (Reilly et al., 2006; Reilly et al., 2004; Jackson et al., 2003). The relatively low levels of habitual physical activity and time spent in MVPA might have reduced our ability to detect associations with movement skills score.

It is possible that gender differences might exist in the relationships between physical activity and motor skills (Gabbard, 2004; McKenzie et al., 2004; Okely, et al., 2001; Garcia,1994). We did not find any marked gender differences in the main analyses described above: this observation might have been due to use of data reduction to a single global movement skills score. More subtle observations such as gender differences might have been detectable within categories of the movement skills score (for locomotive, manipulative or balancing tasks), but our subsequent analyses using these three components of the movement skills score failed to indicate any clear gender differences.

Limitations

Despite being the largest empirical investigation of relationships between movement skills and physical activity to date, the present study had a number of limitations. We used a uni-axial accelerometer which, in principle, should provide less accurate measurement than bi-or tri-axial instruments. However, in practice this might be relatively unimportant, so long as a valid uni-axial instrument is used. Empirical studies which have compared uni vs bi- or tri-axial accelerometers against reference methods have either reported little difference in accuracy or higher accuracy for the uni-axial systems (Finn & Specker, 2000; Kelly et al., 2003, Puyau et al., 2002; Welk & Corbin, 1995). Furthermore, the uni-axial Actigraph accelerometer which we used has been the subject of several pediatric studies which have reported high validity relative to direct observation of behavior or energy expenditure as criterion measures, (Pate et al., 2006; Kelly et al., 2003; Reilly et al., 2003; Finn et al., 2000; Fairweather et al., 1999; Eston et al., 1998; Trost et al., 1998) and validated pediatric cut-points for accelerometry output are available which are based on free-living activity and sedentary behavior (Puyau et al., 2002; Reilly et al., 2003). Alternative accelerometry cut-points are in pediatric use, but they have not yet been validated, are not published, are based on treadmill exercise rather than free-living activity, and are based on extrapolations from adult data (Reilly et al., 2004).

The use of a 1 minute accelerometry sampling interval (epoch) has been regarded by some as problematic, and it has been argued on theoretical grounds that shorter epochs might measure vigorous intensity activity more accurately. Again, the empirical evidence suggests that this is a relatively minor source of error, with the main practical consequence of using 1 minute epochs in children being a slight misclassification of some vigorous activity as moderate intensity activity (Reilly et al., 2008; Nillson et al., 2002).

The fundamental movement skills test has certain limitations. There may be gender differences in the ability to perform certain tasks within the test, and indeed this has been demonstrated previously in pre-school and in older children, with girls typically performing more successfully in balancing tasks, and boys being in tasks which involve running and jumping (Gabbard, 2004; Garcia, 1994). It is possible that relationships between movement skills and physical activity might have been stronger if these sub-categories of movement skills were considered, rather than reducing the data to a single global score. In an attempt to address this question we analysed using three components of the overall movement skills score separately, but in practice the results were very similar to those obtained when the overall combined score was considered.

Our use of a product oriented, rather than process oriented, assessment of fundamental movement skills may be viewed as a weakness (Okely et al., 2001); product oriented assessment means the child can either peform the movement or not (for example 'can the child catch a ball?' Yes or No) process oriented assessments score every process of the movement (for example, 'does the child track the ball with their eyes? 'Do they reach out for the ball?'). These limitations may have masked the relationship between physical activity and movement skills to some extent.

3.5. Conclusions

The present study questions whether there is relationship between movement skills and habitual physical activity in preschool children. Alternative study designs should be considered. In particular, longitudinal studies and intervention studies might provide greater ability to detect associations between these variables.

Chapters 4-6: General introduction

The following chapters relate to the relationship between exercise and cognitive function. The original aim of this thesis was to move from examining the relationship between physical activity and movement skills in preschoolers, to examining the relationship between exercise and cognitive function in preschoolers. For a variety of reasons: instability of psychological measures (as advised by our expert Education psychologist J Boyle, University of Strathclyde, and expert Cognitive Psychologist P Tomporowski) and practical issues such as difficulty in introducing an intense aerobic intervention into preschools, the decision was taken to attempt to carry out the following studies in primary school children (6 year olds) instead.

As the effects of exercise on cognition in children this age had never been carried out before, we had several aims (discussed in more details in each chapter), all built around designing a future RCT to examine the effects of exercise on cognitive function in primary school children.

We applied for and successfully received a separate grant from the Chief Scientist's Office (CSO) for this funding.

Scottish Executive Health Dept Chief Scientists Office (2006-2007; £14,768). Effect of exercise on cognitive function in children JJ Reilly (PI), J Boyle, JY Paton, **A Fisher.**

Chapter 4 - Methods II

Psychological outcome measures

4.1 Cognitive Assessment System (CAS)

4.2 Conner's Parents Rating Scale (CPRS:S)

This chapter describes standardised psychological outcome measures where reliability data already exists in our proposed age group.

4.1. Cognitive Assessment System

The Cognitive Assessment System (Naglieri & Das, 1997) is a psychological instrument that can be used to determine individual's levels of cognitive functioning (Das, 2002). The Cognitive Assessment System (CAS) was developed to assess 4 aspects of cognition: Planning, Attention, Simultaneous and Successive processes (PASS theory) (Luria, 1996, Posner, 1993) and consists of 12 subtests (described in more detail), and a total score (Full Scale). The test is designed for children and adolescents aged 5-17 years. PASS was developed from a combination of theory and applied psychology, and it has been suggested that PASS processes are essential elements of all human cognitive functioning (Das, 2002). The CAS has been shown in previous studies to be a useful tool for the diagnosis of learning difficulties, and a valid and reliable tool for intervention studies (Das, 2002; Naglieri, 1999; Naglieri & Das, 1997; Kranzler & Weng, 1991, Fein & Day, 2003). The CAS was selected for the study described in **Chapter 6,** as it is the main outcome in the only existing randomised controlled trial examining the effects of exercise on cognitive function (in older overweight children) (Davis et al., 2007) so would allow comparison of findings, has good reliability and validity in young children (discussed in more detail (Das & Naglieri, 1997), and has subscales that allow the aerobic exercise-executive function hypothesis (described in chapters 1 & 6) to be tested.

Test descriptions and validity data from Das & Naglieri (1997) Cognitive Assessment System Interpretative Handbook unless otherwise stated.

Planning

Planning is an element of executive functioning whereby the individual determines, selects, applies and evaluates a solution to problem, and also guides how people focus their attention (Das, 2002). Planning is associated with the frontal lobe of the brain (Das, 2002), and is the process by which a problem with no obvious solution is solved. The Planning subtest of the CAS requires the child to develop and apply strategies to novel tasks, devise a plan of action to solve a problem, evaluate and monitor the value of the strategy used to solve the problem, revise or reject any unsuccessful strategy, and control the impulse to act spontaneously. Planning is an essential component of problem solving activities, and therefore essential in the classroom, and everyday life (Das & Naglier, 1997). Subtests of the planning battery are Matching Numbers, Planned Codes, and Planned Connections (Planned Connections is not used in children under 7) (Das & Naglieri, 1997). **For examples of subtests see Appendix I.**

Attention

Attention is a cognitive process by which an individual selectively focuses on a particular stimuli while inhibiting responses to competing stimuli, for example focussing on the teacher in a classroom, while blocking out conflicting 'noise' e.g. the large amount of auditory and visual stimulus present in an everyday classroom. Neuroimaging research indicates that attention is divided into the engagement, maintenance, disengagement and shifting of attention (Posner, 1993, p. 644). The subtests of Attention in the CAS require attention to be focused (concentrated to a particular activity), selective (the inhibition or 'blocking out' of some stimuli while focusing on others) sustained (the variation of performance over time) and effortful (the varying amount of effort required to sustain attention over time). Subtests of the Attention scale are Expressive Attention, Number Detection, and Receptive Attention (Receptive Attention is not used in children under 7).

Simultaneous Processing

Simultaneous processing is thought to be associated with the occipital and parietal lobes of the posterior region of the cortex (Das, 2002). Simultaneous processing is a cognitive process where the individual integrates separate stimuli into a group or whole group. It has spatial and logical-grammatical components. The spatial aspect of simultaneous processing involves both the perception of stimuli as a group, and the internalized formation of complex visual images. The logical-grammatical dimension allows for the integration of words into ideas through the understanding of word relationships, prepositions, and inflections so the person can obtain meaning. Subtests of the simultaneous processing scale are Nonverbal Matrices, Verbal-Spatial Relations, and Figure Memory.

Successive Processing

Successive processing is a cognitive process where the individual puts stimuli into a specific order that forms a logical progression. This type of mental processing is needed when things follow one another in an order that should be strictly defined. Each element should be only related to the stimuli that precede it and there are strong serial and syntactic components. Successive processing subtests in the CAS require perception and reproduction of the serial nature of stimuli, understanding of sentences based around syntactic relationships, and the articulation of separate sounds in a consecutive series. The successive subtests are Word Series, Sentence Repetition and Speech Rate. Successive processing is associated with the frontal-temporal lobe of the cortex (Das, 2002).

The CAS can be used as a predictor of achievement: the full scale standard score is the best predictor of achievement, and the PASS subscale scores will relate to specific areas of achievement.

Outcomes of the CAS

A raw score can be obtained for each subtest, for some subtests this is the time to complete in seconds (Planned Connections and Speech Rate), for some (Figure Memory, Nonverbal Matrices, Verbal-spatial Relations, Word Series, Sentence Repetition, and Sentence Questions). The Planned Codes, Matching Numbers and Expressive Attention raw scores are obtained by developing a ratio for each item based on the number correct, and the time to complete in seconds. Raw scores for the Number Detection, and Receptive Attention subtests are calculated by developing a ratio based on the number of items correct: the number of incorrect items.

Standardisation of the CAS

The CAS has been standardized in, and normative data provided for, a sample of 2200 children from North America, aged 5-17 years: 300 children aged years, 5.00-5.11, 300 aged 6.00-6.11 years, and 300 children aged 7.0-7.11 years (Das & Naglieri, - the populations of interest in this thesis.

Reliability of the CAS

Reliability is defined as “the consistency of scores obtained by the same persons when re-examined with the same test on different occasions, or with different sets of equivalent items, or under variable examining conditions”(Anastasi, 1988 p.102: Das & Naglieri, p.43). Reliability can provide information about the internal consistency of a test, and can be used for calculation of statistics such as the standard error of the mean (SEM). Reliability coefficients for all subtests, were uniformly high, and the reliability of the PASS scale (0.89-0.93 in ages 5-7 years), and Full scale (0.95-0.96 in ages 5-7 years) were high.

Test-retest reliability data were obtained from 93 children aged 5-7 years, from a period of 9-73 days (median 21 days). Test retest reliability across all subtests was high, and from the Planning (r= 0.88), Simultaneous (r=0.77), Attention (r=0.80), Successive (0.85) and Full Scale (r=0.89).

The correlation coefficients achieved in the tests of reliability for the CAS fall in to the range deemed appropriate for use a psychological research tool (in or above the range 0.75-0.80 Coolican, 1994; Sattler, 2001).

Validity of the CAS

Content validity

Content validity refers to the extent that the items in a test represent the cognitive domains being assessed. The subtests and items of the CAS were developed using a combination of task analysis and experimental design, to reflect the processed described in PASS theory.

Construct Validity

Construct validity examines how well the test actually measures the construct, or trait of interest. A major criterion for construct validity is the progression of scores through ages groups, in the expected direction, for example, test involving time would be expected to decrease with age, tests involving number of correct scores would be expected to increase through age groups. This has been demonstrated with the CAS (Das & Naglieri, (1997) p.51).

Criterion-Related Validity

Criterion validity examines how well a test compares to a criterion method. This is demonstrated in the CAS using relationships to intelligence and achievement tests, the use of strategy, and the relationship with strategy use scores in the Planning subsets, the PASS performance of students from groups of children with cognitive disorders in comparison to 'normal' children. Performance on the CAS and Woodcock-Johnstone test of achievement were compared. Correlations were relatively high for the Full Scale (r=0.73), but only moderate for the PASS scale (r=0.50 to 0.67) (Naglieri & Das, 1997).

Limitations of the CAS

The CAS is only moderately correlated with other measures of achievement, so caution must be used if relating CAS scores to overall academic performance. At present the normative database has been obtained from North American Children, and therefore may not directly relate to other populations. However, Van Luit et al, 2005 examined CAS scores of 71 Dutch children with the American normative database and found scores similar (Van Luit et al, 2005).

with The CAS is a relatively expensive outcome measure for a research study, as must be administered and scored by a trained psychologist, and relatively lengthy to administer (40 – 60 minutes), so requires a large time commitment from schools if used as an outcome measure in a large sample of children.

4.2 Conner's Parents Rating Scale: short form

Based on the suggestion that exercise may positively influence the behaviour of children with behaviour problems (Allison et al., 1995), and the lack of data on effects of exercise on behaviour in typically developing children, the decision was made to include a behavioural measure as a secondary outcome in the study described in chapter 6. The Conner'**s** Rating Scale (CRS) is the most frequently used questionnaire in the assessment of attention deficit hyperactivity disorder (ADHD) (Huss et al 2002). The short form of the Connors Parents Rating Scale has 27 items examining Oppositional problems (6 items), Cognitive Problems/ Inattention (6 items), Hyperactivity (6 items), ADHD Index (12 items). Parents must rate their child's behaviour (in the past month) on a score of 0 'not at all – never, seldom', to 4 'very much true-very often, very frequent'. For an example of the short form Conner's Parent Rating Scale see **Appendix II.** The selection of this test was based the criteria that is the most widely used behavioural rating scale in research, can be administered by post, and has a valid short form. Raw scores from the CPRS:S are converted to age and gender related T scores; the items on the rating scale (1-27 see **Appendix IIa**) are added to give a total for each section. The score for each section corresponds with an age and gender related T score (on the reverse of the scoring form, see **Appendix IIb**).

Reliability of the Conner's Parents Rating Scale: Short Form

Test and retest reliability for the 5-7 years age group are for the Oppositional scale 0.62, Cognitive Problems and Innattention scale 0.73, Hyperactivity scale 0.85 and ADHD Index 0.85 (Conner's Technical Manual 2001). Internal consistency of the subscales were reported as all >0.85 (Conner's, 1997).

Validity of the Conner's Parents Rating Scale: Short Form (CPRS:S)

The factorial validity (to what extent the subscales are appropriate, and make sense empirically and theoretically) convergent validity (the extent to which the measure correlates with other instruments thought to measure the same construct and discriminant validity (the extent to which the instrument discriminates between groups e.g. ADHD versus non-ADHD) has been demonstrated (Conner's Technical Manual, 2001 p119-144).

Normative data

Normative data are available in 545 North American children aged 6-8 years (the age group in the proposed study) (Conner's Technical Manual, 2001). Benefits of the Conner's parents rating scale are that it is parent reported, and can be administered and scored by any trained administrator making it suitable for a large scale evaluation. A short form is available (which takes about 15 minutes to complete) and the form can be administered by post in instances where face to face evaluation in not feasible.

Limitations of the Conner's parents rating scale

Test retest reliability of the Oppositional scale in the CPRS: S is only moderate (r 0.62), so results from this subscale should be viewed with caution. The form is a subjective, parental measure of behaviour, and as such, may be prone to bias, but is also widely used and recommended by psychologists. Where postal administration is used, there is a likelihood of a lower response rate.

Finally, the Conner's parents rating scale should not be used as a diagnostic tool, unless administered by a trained psychologist. However, it is acceptable for a trained researcher to administer the form as a research tool (Conner's, 2004 p8-9).

Review of the literature indicated that the other proposed psychological outcome measures; the Cambridge Neuropsychological Test Battery (CANTAB) and Attention Network Test (ANT) revealed that there was no reliability data for in our proposed age group, therefore the following chapter describes the CANTAB and ANT and test retest reliability data collected by the thesis author.

Chapter 5. Reliability of psychological outcome measures

This chapter describes psychological outcome measures where no reliability data existed in our proposed age group.

Contributions:

Selection of outcome measures and study design were carried out by the thesis author in collaboration with expert psychologists Mr James Boyle and Dr Philip Tomporowski, under the supervision of Professor JJ Reilly.

Collection of all data was carried out by the thesis author, with assistance from Ms Catriona Pearson (collecting children from class, helping with carrying/ setting up equipment).

All data management and statistical analysis was carried out by the thesis author under the supervision of Professor John Reilly and with advice from collaborators; Mr James Boyle, Dr Philip Tomporowski, Dr James Paton, Professor John McColl.

5.1 Test retest reliability of the Cambridge Neuropsychological Test Battery (CANTAB)

5.1.1 Introduction

The Cambridge Neuropsychological Test Battery (CANTAB) (www.cantab.com) is a computerised neuropsychological assessment battery consisting of 19 computerised tasks. The test battery is designed to focus mainly on the measurement of the frontal & temporal lobes of the brain (Luciana & Nelson, 2002). CANTAB was originally designed to investigate impairment in executive functions associated with ageing (Hughes & Graham, 2002; Fray et al., 1996), particularly in adult clinical disorders (Robbins et al., 1994). However, there are features of the CANTAB that potentially make it attractive for research in children. All task stimuli in the CANTAB are non verbal, and consist of simple shapes and colours. Completing the tests requires no verbal responses and no reading ability, making it suitable for use even in young children. Furthermore, the graded nature of the CANTAB tasks reduces the likelihood of a ceiling effect. The CANTAB test is administered using a touch-screen and laptop, enabling standardised objective measurement, and each test has a standard script.

Studies support the validity and use of neuropsychological assessment by CANTAB in adults (Rahman et al.,1999; Elliott et al., 1997; Fowler et al.,1997; Owen et al, 1997; Lange et al., 1992) and more recently, the CANTAB system has been used in paediatric populations (Luciana & Nelson, 2003). Several studies have shown that CANTAB is sensitive to executive dysfunction (autism and attention deficity hyperactivity disorder) in children (Hughes & Graham, 2002; Hughes et al. 1994) and can detect age-related improvements in executive function (Luciana & Nelson, 1998). However, there is little published data on the use of CANTAB in normally developing children at present.

Luciana & Nelson (1998, 2003) were the first to assess the feasibility of using CANTAB in a large normative paediatric sample. These authors assessed the age limits of the assessment, and whether it could be administered to normally developing children from 4-12 year old children, without having to adapt the adult version of CANTAB (Luciana, et al., 2003). The authors found that 4 year old children had difficulty comprehending test instructions, were intimidated by and / or had difficulty using the touch screen technology, and lacked motivation to complete tasks in as many as 50% of cases (Luciana & Nelson, 2003). However, performance in 5 year olds was markedly better, and in 6-8 year olds was akin to testing young adults. (Luciana & Nelson, 2003).

Luciana (2003) also highlights the importance of establishing test-retest reliability data for CANTAB in children. At present, to our knowledge, test-retest data do not exist. The primary purpose of the current study was therefore to gather data on the test-retest reliability of the CANTAB in 6 year old children.

5.1.2 Participants & methods

Participants were 6 year old children recruited from volunteering Glasgow City Council primary schools, recruited as part of the LEAPFROG (Learning, Exercise and Activity a Pilot: Furthering Research Through Organised Games) pilot randomised controlled trial. Children were recruited by issuing letters and consent forms to all eligible children (attending primary 2 of mainstream schools). Informed, written consent was given from all parents of child participants. Verbal assent and an initialled consent form was provided by all children. Ethical approval for the study was given by the NHS Central Office for Research (COREC). Glasgow City Council also approved the study.

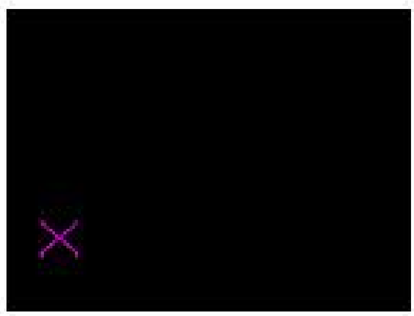
CANTAB test administration

The test was administered in the child's school in an available quiet area (empty classroom, medical room). The administration script was followed for each test used as per CANTAB manufacturers recommendation. The test was administered using a laptop computer and portable USB touch screen. Both instruments had the full system requirements for the administration of CANTAB (www.cantab.com). The tests were administered a baseline, and after 3 weeks (retest) in the same location. One child was tested at a time by the same researcher in every instance (AF). The touchscreen was set to calibrate automatically every time the system was switched on by a specialist psychological technitian at Strathclyde University. The children were seated exactly 53 cm from the screen (measure from 'nose to screen').

The CANTAB tests used in the present study were the following:

1. **Motor screening test (see Figure 5.1)** A pink cross appears on a black screen, and the participant must touch the centre of the cross with the dominant hand. There are two measurable outcomes of the Motor Screening Test, the Mean Latency (time taken for the participant to touch the cross) and Mean Error (the accuracy of the participants pointing – i.e. the distance between centre of cross and the exact location the screen was touched). This test is used as a screening test for visual, movement and comprehension problems, and to familiarise the participant with the touch-screen.

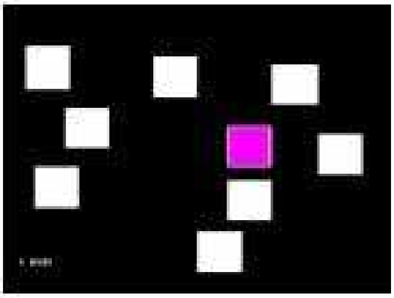
Figure 5. 1 The CANTAB Motor Screening subtest.



2. **Spatial Span (SSP) test (see Figure 5.2)** is a computerised version of the Corsi Blocks task (Milner, 1971) that tests Spatial Working Memory capacity (the number of items that can be held in working memory). The participants must observe as a pattern of boxes are lit up on the screen, then remember and replicate the pattern by touching the boxes that lit up, in the correct order. The test begins with two boxes, and gets progressively harder (to a maximum of

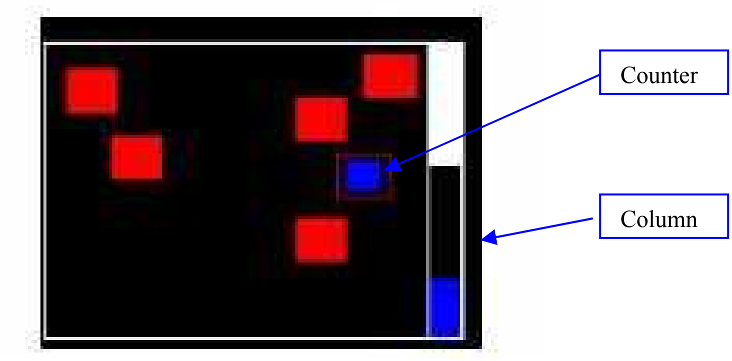
nine). If a participant touches the appropriate boxes in the right order, they move on to the next level of difficulty. After two failed attempts at a level, the test ends. The three outcomes measured in the Spatial Span Test are Span length –the longest sequence of coloured squares that can be remembered and copied by the participant; Total Errors - the number of times an incorrect box is selected; and Total Usage Errors - the number of times a participant selects a box out of sequence.

Figure 5.2 The CANTAB Motor Spatial Span Subtest



3. CANTAB test of **Spatial Working Memory (SWM) Strategy (see Figure 5.3)** assesses working memory & strategy use. A number (from 2 to 9) of red squares are visible on the screen, and blue tokens are hidden behind them. The participant must touch a red square to reveal whether there is token behind it and, if there is 'drag' (with finger) the token to fill up a column. The outcome measures from this test are Between Errors (the number of times a participant revisits a square where they had previously found a token; calculated with 4 + tokens only); Within Errors – (the number of times a participant revisits a box already found to be empty, Double Errors - an error categorised as Between and Within); and Strategy (whether a strategic search is used; Owen et al., 1990).

Figure 5. 3 The CANTAB Spatial Span subtest



Reliability
Test and retest reliability is a measure of the reproducibility of a measure when it is repeated. It is important to establish retest reliability prior to studies where repeat measures will be used. The standard error of measurement (SEM) is a measure of within subject variation (the within subject standard deviation), based on the likelihood that repeat measures in the same person will not produce exactly the same value each time. This within person variation can come from biological variation, and technical / equipment 'noise'. Limits of agreement (LOA) are another measure of within-subject variation devised by Bland & Altman.

Statistical analysis

Reliability

Reliability is an assessment of how reproducible a measure is. Reliability is assessed by taking repeat measurements in the same subjects. If a measure is unreliable, it cannot be used to successfully track changes in a research study that involves follow-up measurements (Hopkins, 2000).

It is unlikely that repeat measures in the same person will produce exactly the same value each time. The **standard error of measurement (SEM)** is the within-subject variation; the individuals standard deviation. It can also be called the 'typical error'. The error can come from biological difference, and / or equipment 'noise' or error (Hopkins, 2000). Another measure of within-subject variation is the **coefficient of variation**, which is the standard deviation (SD) expressed as a percentage of the mean (Hopkins, 2000).

Comparing repeat measures from a number of participants, the difference in mean from test 1 to test 2 can be calculated for each participant, and the mean of the differences in mean for the whole sample gives the **difference in mean** and **SD**. This SD divided by the √2 is the **SEM**. **'Limits of agreement' (LOA)** can be calculated by multiplying the SD of the difference in mean by 1.96. Technically, it can only be certain an observed change is 'real' (i.e. isn't due to measurement error) if it is greater than the LOA (Hopkins, 2000).

Another way to quantify how reliable a measure is, is to calculate the **intraclass correlation (ICC)** coefficient between repeat measures. A correlation of 1 represents perfect agreement between tests, and a correlation of 0 indicates no agreement. In psychological studies a measure should have a retest correlation coefficient of at least 0.75 (Coolican, 1994).

In test retest reliability for cognitive measures in children a retest timing of 3 weeks (+/- 1 week) was recommended by our expert educational psychologist

(JE Boyle) as this is a short enough period of time for no major developmental changes to take place, but long enough to minimise potential learning effect (JE Boyle, personal communication).

Statistical analyses were performed using SPSS software (www.spss.com), and the reliability spreadsheet www.sportsci.org/resource/stats/ (Hopkins, 2000). Intraclass correlations (ICC), Coefficient of Variation (COV), Standard Error of Measurement (SEM) and Limits of Agreement (LOA) between test and 3 week restest reliability data were computer. Statistical significance was set a $p<0.05$.

5.1.3 Results

Characteristics of study participants

71 children (mean age 6.2 yrs SD 0.3, 33 boys / 38 girls) were recruited for the study, 3 children were absent from school on the day of testing so baseline CANTAB data were collected from 68 children. At retest there were a further 4 children absent, giving available test and re-test data for analyses from 64 children (mean age 6.2 years SD 0.3 29 boys / 33 girls).

Practical utility of the tests

The individual administration times differed from the adult times published in the CANTAB manual. Overall, our experience was that the tests were quick and easy to administer, and were enjoyed by and engageing for children. In this age range, the range of completion times for each test as follows: Motor test 2-3mins; Spatial Span 3-6 minutes; Spatial Working Memory 10-15 minutes. No child tested refused to complete any of the testing, and the re-test measurement was met with a positive reaction from all children tested.

Test-retest results

For test retest correlations of CANTAB working memory tests see **Table 5. 1.** None of the tests examined fall into the acceptable level of stability (in or above the range 0.75- 0.80) required for use as a clinical research tool (Coolican,1994; Sattler, 2001).

Table 5. 1 Reliability of the CANTAB working memory battery in 6 year olds.

Outcome	Mean 1	SD	Mean 2	SD	ICC	SEM	CV	LOA
SSP Span	4	1	3	1	0.51**	1	20	2
SSP Total Errors	10	4	9	4	-0.1	4	15	12
SSP Usage Errors	3	2	3	2	0.1	2	51	5
SWM Strategy	40	3	39	3	0.03	3	8	8
SWM Within Errors	69	11	70	10	0.59**	7	8	20
SWM Total Errors	70	12	71	11	0.53**	8	10	22

SSP spatial span (number of items that can be held in short term memory), **SSP total errors** (the number of times an incorrect item is selected), **SSP usage errors**; the number of times an item is selected out of sequence. **SWM** spatial working memory; **SWM** Between Errors - the number of times participant revisits a square where they had previously found a token; Within Errors – the number of times a participant revisits a box already found to be empty, Strategy - whether a strategic search is used. **ICC** – intraclass correlation; **SEM** – standard error of measurement; **CV** – coefficient of variation; **LOA** – Limits of agreement.
**p<0.001 Mean 1 is baseline, Mean 2 is 3 week retest; n=64 mean age 6.2 SD 0.3 years.
The outcome measures from this test are).

5.1.4 Discussion

There is currently very little data on the feasibility, and no data on the reliability, of administering CANTAB to the paediatric population. Luciana et al.,(2003), describe the experience of administering CANTAB with 6 year old children as "tending to be highly motivated, intrigued by the computerised testing format." This was consistent with our experience in the current study: the children were all familiar with computer equipment, and the introduction of the touch-screen and bright colours and shapes, engaged their attention and curiosity, making the test instructions relatively easy to administer.

The test retest data suggest that the scores from the selected tests from the CANTAB working memory battery used in the current study may not be stable enough to use as a primary outcome measure for future research intervention studies on executive function in 6 year old children. However, it should be noted that the current study examined only tests from the Working Memory Battery (as data were collected as part of a pilot study for a future randomised controlled trial).

In their examination of adult CANTAB test retest reliability, Lowe & Rabbit (1998) found extreme variation in correlations between individual tests in the CANTAB battery, and indeed within individual outcomes in each test. These, and the results from the current study, suggest that data from CANTAB should not be used or interpreted with confidence unless test-retest reliability has been established in the intended population and age group (Lowe & Rabbit, 1998).

Lowe and Rabbit, in their examination of test retest reliability of the CANTAB and ISPOCD tests in 162 older adults (60-80 years) found that reliability in the Spatial Span and Spatial working memory tests in CANTAB did not fall into acceptable range for reliability as a research tool (correlations 0.68 & 0.64 respectively). These authors found, however, that reliability fell into acceptable levels in tests 'simpler' tasks, such as simple choice reaction time, and simpler search and recognition tasks (Lowe & Rabbit, 1998). It is suggested that tasks involving executive functions may only work when they are 'novel' to the participant, as a marked learning effect can be seen when an individual discovers an optimal strategy, but will improve less if no strategy is found, and deteriorate if a sub-optimal strategy is found (Lowe & Rabbit, 1998). If this is the case, then this further limits the value of these tests as a research tool. Young children, in an early stage of cognitive development, tend not to be able to form effective strategies for problem solving therefore this is a likely contributor to the low reliability of some of the CANTAB subtests.

Only a minority of children failed to complete the Spatial Span task (i.e. did not get a score of 2 or more) in the present study, at either at baseline (n= at 3 week re-test (n=7), or both. For the children who achieved a score in the spatial span task at baseline, then not at re-test it appears that de-motivation may be an issue, as it is clear the initial instructions were understood. For children who achieved no score at baseline, but a relatively high score at follow-up, it is unclear whether they did not initially comprehend the test instructions, were de-motivated at baseline, or had a learning effect at follow-up. These are issues that must be evaluated when using CANTAB in children in future. Researchers intending to use this system with children should be aware of these potential problems.

Limitations

For the present study reliability of tests from the CANTAB working memory battery were assessed only. The main reason for this was that we were specifically considering tests of working memory for a planned randomised controlled intervention trial. There is a need validate all tests from the CANTAB battery in children.

5.1.5 Conclusions

In the present study, Spatial Span and Spatial Working Memory tests, from the Cambridge Neuropsychological Test Battery (CANTAB) showed only modest test-retest reliability. The present study suggests that these tests within the CANTAB battery are not reliable enough in 6 year old children to be used as a research tool. The currently study also further highlights the need to gather test retest reliability data of the intended psychological outcome measures within the intended population prior to carrying out a full scale RCT.

Computerised neuropsychological testing has great potential as a measure of executive dysfunction in children. The current study suggests that the CANTAB is too variable to use as a primary outcome measure in psychological research in children.

5.2 Test retest reliability of the Attention Network Test

5.2.1 Introduction

It has been suggested that attention is divided into three distinct networks (Fan et al, 2002: Posner & Peterson, 1990). Alerting, which refers to the readiness of an individual to respond to any type of stimulus. Orienting, a process that refers to how and to what degree an individual is prepared for a specific stimulus and executive control, which refers to the process of resolving conflict when two responses are called for by a stimulus (Posner and Petersen, 1990; Fan et al, 2002). Numerous brain imaging studies support the existence of the alerting, orienting and executive control networks of attention (Corbetta et al, 2000; Corbetta & Shulman, 2002: Fan et al, 2003: Pardo et al, 1991; Posner & Petersen, 1990).

The Attentional Network Test (ANT) is an experimental paradigm designed to examine the three attentional networks (Fan et al, 2002). The ANT is a computerised test based on the Eriksen Flanker Task (Eriksen & Eriksen, 1974) providing reaction time (RT) and accuracy scores to congruent, incongruent and neutral flankers and incorporating cues (no cue, centre, double and spatial) to vary alertness and orienting (Fan et al, 2002, Reuda et al, 2004). Reaction times for networks of attention can be calculated by subtracting relevant cues and flankers: Alerting RT for No Cue – RT for Double Cue, Orienting: RT for Central Cue – RT for Spatial Cue, Conflict: RT for Incongruent – RT for Congruent trials (Reuda et al, 2004).

The ANT has promise for research in children, as a specific child version has been developed (using coloured fish as flankers), the test is simple, free to download from the test authors (www.sacklerinstitute.org/users/jin.fan/), inexpensive to run (approximately £450 ($900) for an E-Prime software licence (www.pstnet.com)) and fairly quick to administer (approximately 30 minutes). The ANT requires little verbal ability and little interaction with the test administrator, and has been used to demonstrate the existence of the attentional networks in previous studies involving even young children (Reuda et al, 2003; Reuda et al, 2005). The ANT can be administered by any trained researcher.

In previous studies, the ANT has been shown to be sensitive to disorders of cognition such as schizophrenia (Wang et al, 2005; Neuhaus et al, 2006) and depression (Gruber at al, 2007). Changes in reaction time and accuracy scores of the ANT have been shown to progress through age groups in adults and in children (Reuda et al, 2004). The ANT shows relatively high immediate test and retest reliability in adults (Fan e al 2002). Prior to using the ANT as a psychological research tool in children, it is important for test retest reliability data to be collected in the intended age group.

The aim of this study was therefore to determine the test-test reliability of the Attention Network Test in 6 year old children.

5.2.2 Participants and methods

Participants were 6 year old children involved in the LEAPFROG study (Learning, Exercise & Activity a Pilot: Furthering Research through Organised Games), who were recruited by sending recruitment information to all children in primary 2 of volunteering primary schools from the City of Glasgow, Scotland.

Children were eligible for inclusion in the study if they had no diagnosed disorder of cognitive or motor function. The study was approved by Central Office for Research Ethics Committee (COREC). Informed written consent was given by all parents of and child participants.

Test administration

The administration of the child ANT was followed as described by the test authors (Rueda et al., 2004). The test was administered in the child's school in an available quiet area (empty classroom, medical room). The test was administered using a DELL laptop and run on E-Prime Software (www.psnet.com). Two children were tested at a time and by the same administrator in every instance (AF). The children were seated approximately 53 cm away from the computer screen (measured using a tape measure from 'nose to screen', with the dominant hand resting on the mouse.

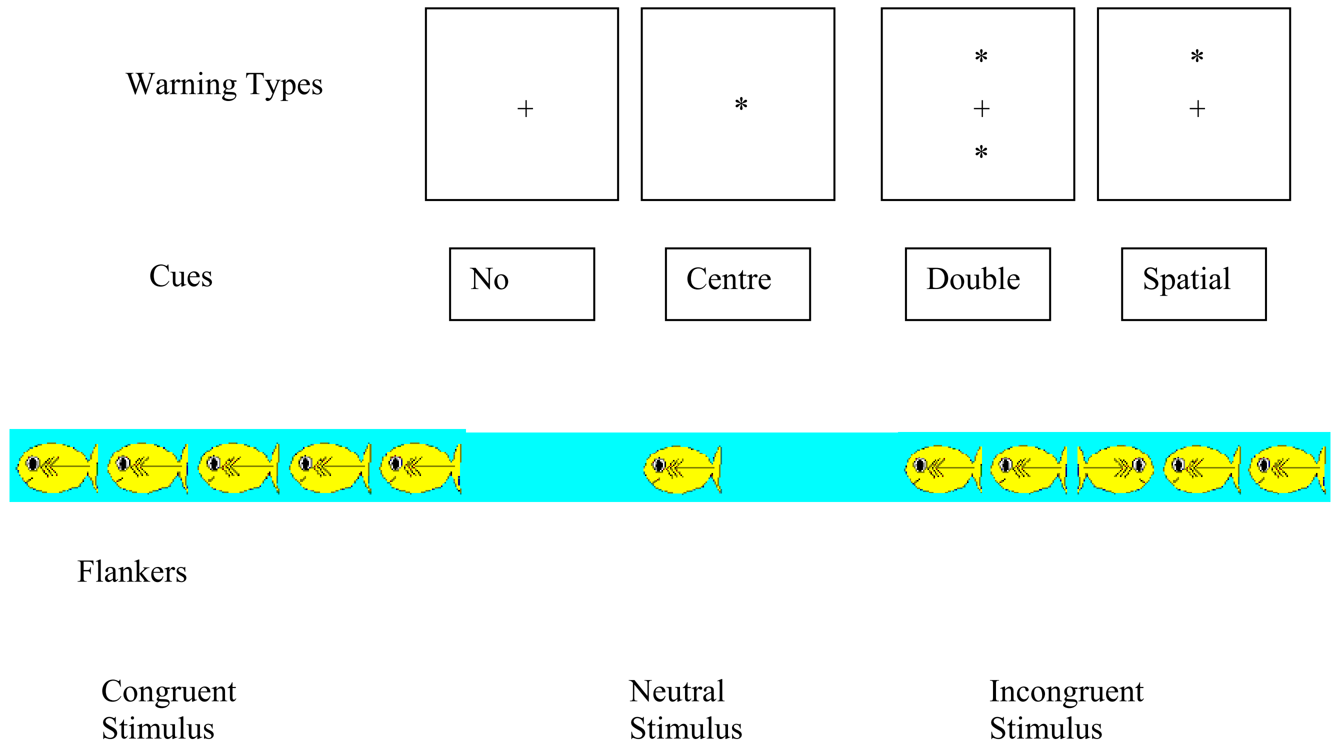
The ANT involved 4 blocks, each approximately 5 minutes long. The first block was a practice trial to ensure no visual or comprehension problems, so data were not included in analysis. There are 3 experimental blocks of 48 trials, each representing one of 12 potential conditions (congruent, incongruent and neutral) x (no cue, central cue, double cue, and spatial 'down or up' cue) (see **Figure 5.4)** The child must determine whether the flanker (fish) is pointing left or right, and click the corresponding mouse button. Reaction time (ms) following onset of the stimulus and accuracy (whether correct button selected) are recorded. Picture cards demonstrating a right pointing and left pointing fish (neutral condition), were used prior to the practice trial to ensure that children understood the instructions.

Statistical analysis

See reliability description in **Section 5.1**.

Statistical analyses were performed using SPSS software (www.spss.com), and the reliability spreadsheet www.sportsci.org/resource/stats/ (Hopkins, 2000). Intraclass correlations (ICC), Coefficient of Variation (COV), Standard Error of Measurement (SEM) and Limits of Agreement (LOA) between test and 3 week restest reliability data were computer. Statistical significance was set a $p<0.05$.

Figure 5. 4 Schematic representation of the Warning Types, Cue, Flankers and Stimuli in the Child Attention Network Test (ANT)



The children were told that they had to 'feed hungry fish' by pressing the mouse button that matched the way the fish was pointing (as described by Reuda et al, 2004).

5.2.3 Results

Characteristics of Study Participants and Practical Utility of the Test

We recruited 71 children for the study. 3 children refused to complete all blocks of the test at either baseline or retest, 4 were absent from school at either baseline or retest, and data were excluded from 2 as median reaction times were <200ms: these responses were thought to be 'anticipatory'. Data were available from 62 children at baseline and retest, mean age 6.2 SD 0.3 years (44% boys, 56% girls: 6.6% Left handed). The test took around 30 minutes to complete.

Test -retest reliability of the ANT

Correlations between test and retest reliability for flanker and warning types and for alerting, orienting and executive control were uniformly low (see **Appendix III**), therefore analyses were carried out on a composite reaction time and accuracy scores. Composite reaction time test and retest reliability coefficients were also relatively low, although statistically significant. Reliability data are presented in **Table 5. 1.**

Table 5. 2 Reliability data from the Attention Network Test (ANT) in 6 year olds

Outcome	Mean 1	SD	Mean 2	SD	ICC	SEM	CV	LOA
RT (ms)	960	138	856	123	0.35*	104	17	297
ACC	104	28	105	28	0.60**	18	84	52

RT - reaction time to stimulus in milliseconds (mean of median), stimulus is a fish appearing on screen (mouse button is pressed); ACC accuracy – total correct from 144 a 'correct' response is when the mouse button pressed corresponds with the direction the 'flanker' (fish) is pointing in; ICC – intraclass correlation
SEM – standard error of measurement; CV – coefficient of variation; LOA – Limits of agreement. Participants were n=62 children taking part in the LEAPFROG pilot study.
*p<0.05 **p<0.001 Mean 1 is baseline, Mean 2 is 3 week retest.

5.2.4 Discussion

Though test-retest correlations were statistically significant, the present study found that test-retest reliability of the ANT in the current sample and setting was relatively low. Our findings indicate that the ANT is unlikely to be sufficiently reliable in 6-7 year olds to serve as an appropriate outcome measure indicative of effects of biological significance in future intervention studies, unless the intervention to be tested in the trial yields large effects. However, the ANT may still have use as a moderator in a regression analyses.

In adults, the ANT showed relatively high immediate test and re-test reliability scores (Fan et al., 2002). At present no data exists (to our knowledge) on how reliable the test is in adults over time.

Although the ANT took a similar length of time to administer in children as for adults (30 minutes), it may have been fairly difficult for 6 year old children to maintain interest for this length of time, as the test itself is fairly repetitive. Indeed 3 children refused to complete the full test either at baseline or a 3 week retest as they indicated to the researcher that they were 'bored.'

In our experience children had to be watched very closely during the ANT in order to ensure they were not simply pressing the mouse button randomly, and were paying attention to the screen at all times, and there was a tendency for children to become distracted during the test. These methodological problems are likely to be related to the age of the children tested in the present study. Anticipatory responses (i.e. pressing the mouse button randomly in anticipation of the stimulus) were evident in the data (reaction time <200ms), but only in 2 children on one occasion each and these data were excluded as noted above.

Test and retest correlation coefficients were low when individual flankers and warnings were examined, and when subtractions were carried out to examine networks of attention **(Appendix III).** Therefore, composite reaction times and accuracy were used. None of the baseline and re-test correlations for individual flanker and warning types fell within the range deemed appropriate for use as a psychological research tool (Coolican, 1994). In light of the fact that the adult (Etnier et al., 1997; Colcombe and Cramer, 2003) and child (Sibley and Etnier, 2003) meta-analyses examining the effects of exercise on cognitive function find a fairly consistent significant effect size of less that 0.5, the Attention Network Test is arguably not a suitable primary outcome measure for future intervention requiring repeat measures in this age group.

5.2.5 Conclusions

We hoped in a future trial, to examine the effects of aerobic exercise on executive control specifically as previous data suggest that aerobic exercise (Colcombe et al., 2004 b) or, cross-sectionally, fitness (Hillman et al., 2005) may differentially influence the attentional networks. So the Attention Network Test was originally selected as a candidate outcome measure for this reason. However, the current study suggests that the ANT is not be reliable enough to used as a primary outcome measure in this way in 6-7 year old children.

Chapter 6. Chronic Effect of Aerobic Exercise on Executive Function: A Pilot Study

Contributions:

Some data in the present study could not be collected by the author; the Cognitive Assessment System (CAS) data were collected by Miss Elaine Beck and Miss Katy Brady, as the CAS must be administered by a trained psychologist. The psychologists were blinded to the nature of the study, and the allocation of the schools.

Design and implementation of the Intervention and Control PE sessions, Glasgow City Council was carried out by Glasgow City Council Primary PE specialists under Mrs Christine Watson (Head of Primary PE) in collaboration with thesis author (A Fisher) and Professor John Reilly.

Collection of habitual physical activity data, Attention Network Test and CANTAB – thesis author, with assistance from Miss Catriona Pearson.

Collection of data of intensity of intervention and control PE sessions was carried out by Miss Catriona Pearson under the supervision of the thesis author. Downloading, reducing and analysing this data was carried out by the thesis author.

Study design, data management and statistical analysis thesis author under the supervision of Professor John Reilly and with support from collaborators; Mr James Boyle, Dr Philip Tomporowski, Dr James Paton, Dr John McColl, and advice from Dr David Young.

6.1 Introduction

Regular physical activity improves brain health (Dishman et al., 2003), as noted in **chapter 1.** Exercise can improve depressive symptoms (Pertruzzello et al, 1991; Peluso Mam et al., 2005) quality of sleep (Elavsky & McAuley, 2007; Youngsted, 2005), and cognitive function in older adults (Colcombe & Kramer, 2003) and in children (Sibley & Etnier, 2003: Tomporowski, 2003).

There is substantial animal evidence to suggest that an enriched environment and / or increases in physical activity can enhance brain structure and function (Cotman & Berchtold, 2002; van Pragg, 2000; Young et al., 1999; Kempermann et al., 1997; Escorihuela et al., 1995). Evidence from animal data also suggests that voluntary exercise alone (such as wheel running and treadmill training) has similar effects on the rodent brain as environmental enrichment, such as enhanced learning and memory (van Pragg et al., 1999; 2000). In exercise studies comparing sedentary and active animals, the more marked differences were seen in more challenging cognitive tasks (van Pragg et al., 2000). Animal studies also indicate that aerobic exercise (such as wheel running in rats) can increase expression of the genes that encode brain growth factors, and thereby the expression of these growth factors, such as brain derived neurotrophic factors (BDNF) (Cotman & Engesser-Cesar, 2002; Dishman et al., 2006) which has emerged as a mediator of the efficiency of the brain synapses, neuronal connectivity, and use-dependent brain plasticity (Cotman & Berchtold, 2002) – key aspects in cognitive functions such as the formation of new memories, as noted in chapter 1. There is also evidence to suggest aerobic exercise can elevate neurotransmitter levels, and increase neurogenesis in the dentate gyrus of the rodent hippocampus (van Pragg et al., 2000; Dishman et al., 2006).

In recent human research, functional magnetic resonance imaging (fMRI) studies in older adults have suggested that cardiovascular fitness (Colcombe et al., 2004) can alter the activity of areas of the brain associated with attentional control (Colcombe et al. 2004: Colcombe & Kramer, 2003) and mediate age-related brain tissue loss (Colcombe et al. 2003). There is also some evidence that regular physical activity may maintain life-long brain health, and reduce incidence of age-related Alzheimer's disease (Laurin et al., 2001), and have neuroprotective effects, reducing incidence of neurodegenerative diseases such as Parkinson's disease (Smeyne et al., 2004: Thacker et al., 2007).

The mechanism(s) by which exercise impacts cognitive function in humans are unclear at present as described in chapter 1, but meta-analyses and well controlled studies in older adults point to the positive effects of aerobic exercise appear to impacting tasks involving *executive control* most strongly (Colcombe & Kramer, 2003). The selective effects of exercise on aspects of executive control have been demonstrated in well designed RCT's in both older adults (Kramer et al., 1999; Colcombe et al., 2004) and now in overweight children (Davis et al., 2007).

In a recent survey of 1200 parents and teachers in the USA, (www.rwjf.org) it was suggested that around 90% of participants surveyed believe that children who are physically active learn and behave better in the classroom (www.rwjf.org). Despite this, there has been very little research examining the relationship between physical activity and cognition in children (Burdette & Whittaker, 2005). Less than 1 % of all existing studies examining the relationship between physical activity and cognition with a true experimental design involve child participants (Etnier et al, 2007).

A cross-sectional electroenecephelogram (EEG) study in 51 high and low fit (as measured by the Fitnessgram) participants in Illinois, USA, suggests that higher fit children have faster neurocognitive processing, and recruit more neurons for attentional and working memory tasks that lower fit children (Hillman et al, 2005). Castelli et al. (2007) demonstrated a positive relationship (cross-sectionally) between fitness and academic grades (Castelli et al., (2007). A recent RCT in overweight children in Georgia, USA indicated that enhanced aerobic exercise improved performance on the Planning scale of the Cognitive Assessment System (CAS), a measure of executive function (Davis et al., 2007) (these studies are described in detail in **Chapter 1).**

There is a suggestion that any benefit of physical activity may be greater in younger children, in an early stage of brain development, with a higher degree of neural plasticity (Gabbard, 2004: Diamond, 2000). Any benefit of physical activity on cognitive function, and therefore school performance, would logically be more beneficial if implemented as early in life as possible. To our knowledge, however, there have been no studies examining the effect of a physical activity intervention on cognitive function in children under the age of 7 years.

The aim of the current pilot study was to examine the effect of increasing aerobic school–time physical education on executive functioning and behaviour in 6 year old children. The study was a pilot for a future full-scale RCT and so emphasis was placed on an assessment of the feasibility of the intervention and of the outcome measures.

6.2. Participants and methods

Participants were recruited from 6 volunteering primary schools in the City of Glasgow, Scotland. Recruitment packs were issued to all primary 2 classes of participating schools. Children were eligible for inclusion in the study if they had no known diagnosed disorder of cognition, and no condition affecting their ability to participate in a physical activity programme.

The study was approved by the Central Office of Research Ethics (COREC) and approved by Glasgow City Council. Informed written consent was provided by all parents of, and child, participants. The study was registered as a randomised controlled trial number ISRCTN70853932.

Schools were randomised, by a statistician independent of the study (Dr David Young, Yorkhill Hospital), to receive either the Intervention or Control condition for 10 weeks (September to December 2006).

The **Intervention** consisted of a series of specialist devised aerobic games, based around the aerobic components of the 'Basic Moves' programme (Jess et al., 2004), which a programme that already exists within the primary school curriculum.. The programme was adapted by Glasgow City Council primary PE specialists to include only the ‘travelling movement’ component.. The travelling movements are run, gallop, fast side step, skip (Jess et al., 2004 pp 25) and the PE specialists utilised these components, and included them in games that they deemed suitable for 6 year olds. The PE specialists were asked to make the sessions ‘as physically active’as possible (in our terms spending as much time ‘moving’; in moderate and vigorous physical activity (MVPA) assessed by the Actigraph accelerometer. In children the accelerometer cut point for MVPA corresponds to heart rate of >140 (Puhl et al. 1990). The PE specialists and teachers were also advised to ‘minimise instruction time’, and ‘minimise / avoid any time children were queuing for equipment, or standing around’. Two hour-long sessions were given per week; one delivered by a PE specialist, and one session by a trained teacher (the class teacher). Activity data was collected from PE sessions. The aim was for the children to spend at least 50% of the hour in MVPA. In practice, however, this proved difficult to achieve.

The **Control** schools received the standard curriculum, which between the September and December terms consists largely of movement skill development (e.g. object control – throwing and catching a ball, balance, gymnastics). In an attempt to examine the effect of increased aerobic activity only, and control for any improvement in psychological outcome measures by simply intervening (Hawthorn effect) physical education time was increased to two hours per week also, one specialist delivered, and one trained teacher session. Parents were fully informed that the study was a pilot aiming to see whether exercise with a specialist in increased school physical education time could influence learning and behaviour, but not which group were expected to see the greater change (i.e. aerobic or non-aerobic), to avoid any bias in parental ratings of behaviour.

Psychological Outcome Measures

The **Cognitive Assessment System (CAS)** was administered by a trained psychologist blinded to the allocation of the schools, once at baseline and once at 12 week follow-up. The CAS has high reliability and validity in 6 year old children, with test retest reliability coefficients for 96 5-7 year olds falling between 0.95-0.96 (Das & Naglieri). **The Attention Network Test** and **Cambridge Neuropsychological Test Battery (CANTAB)** working memory battery were administered to the children once at baseline, once at 3 week re-test (data presented elsewhere- Chapter 4), and once at 10 week follow-up by the same trained researcher in all instances (the author). As a secondary outcome, parental rating of behaviour was assessed using the **Connors Parents Rating scale: short-form (CPRS:S)** (Conners, 2001) discussed in **chapter 4.**

Physical Activity

We measured physical activity both habitually (6/7 day record) and during randomly selected Intervention and Control PE sessions, using the Actigraph GTM1 accelerometer (www.theactigraph.com). As described in chapter 2 the Actigraph is a small, uniaxial accelerometer that measures physical activity on the vertical plane. Validity of the Actigraph in children (Janz et al, 1994; Trost et al, 1998; Eston et al, 1998; Jackson et al, 2003; Kelly et al, 2004) has been demonstrated against criterion methods of doubly-labelled water and direct observation. Published, validated paediatric cut points exist for the Actigraph to quantify sedentary behaviour (Reilly et al, 2003), light and moderate-and-vigorous physical activity (MVPA) (Puyau et al, 2002). The Actigraph was placed on the right hip, under clothing (Jackson et al, 2003; Fairweather et al, 1999; Reilly et al, 2004).

Statistical Analysis

Analysis was carried out on Minitab software (www.minitab.com). All data were checked for normal distribution using graphical summary of data, skewness, descriptive statistics, and test of normality. For initial basic between group comparisons, t tests (or Mann Whitney Tests where appropriate) were carried out on the change (follow up score minus baseline score) over time. A General Linear Model was carried out on all psychological outcome measures with the follow up score as the Response variable, Group (Intervention or Control), socio-economic status (SES), Gender, School(with nested Group) as Factors and Age and Baseline score on the psychological outcome measure as Covariates.

The study was a pilot study aimed, in part, at gathering data to adequately power a full scale RCT, so as such was not powered, but based on the advice of our statistician (J McColl) 6-8 primary schools would allow to control for clustering and the advice of our psychologists (JE Boyle and P Tomporowski) an sample of around 60 was aimed for. Based on practical considerations, the aim was to recruit 10-15 children from each primary school.

The general linear model in more detail

The General Linear Model is a statistical analysis that is midway between analysis of variance and regression. The main purpose of the General Linear Model is to increase the precision of comparisons between groups by accounting for variation in important variables, or adjust comparisons between groups. The Response is the variable of interest (for example, change in CAS scores from baseline to follow up), and the other variables are entered into the Model. Continuous variables (e.g. age) are entered as covariates.

6.2 Results

Baseline descriptive data

For a CONSORT (www.consort-statement.org) flow diagram of the LEAPFROG study see **figure 6.3**

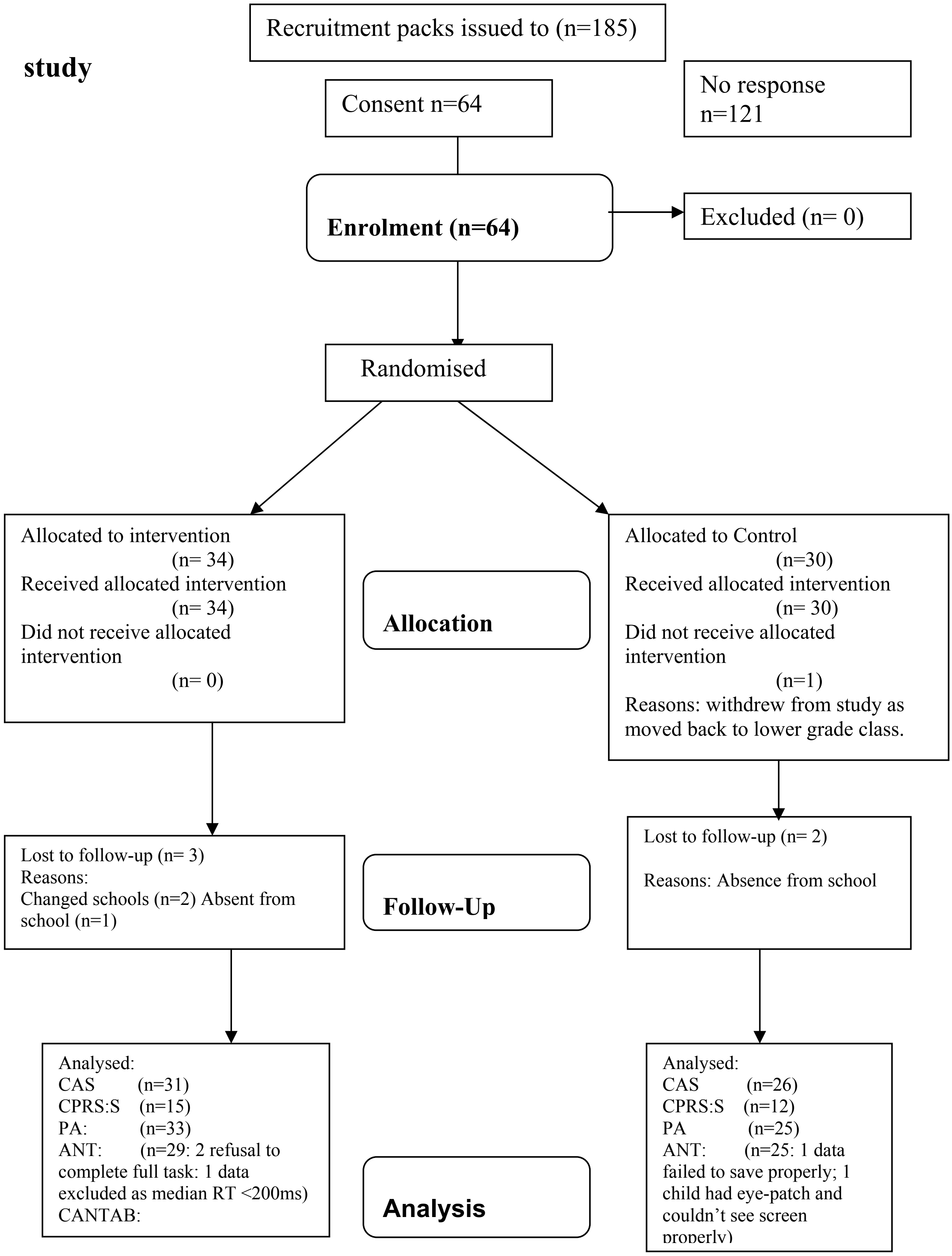
We recruited 64 children from 6 participating primary schools mean age 6.1 years SD 0.3. Participant baseline characteristics are shown in **Table 6.1.** There were no significant differences in any baseline anthropometric characteristics between Intervention and Control children ($p > 0.05$).

Table 6. 1 Baseline characteristics for LEAPFROG participants

	Whole sample (n=64)	SD	Intervention (n=34)	SD	Control (n=30)	SD
Mean age (years)	6.1	0.3	6.1	0.3	6.2	0.3
Mean BMI (kg/m^2)	16.4	1.7	16.2	1.7	16.7	2.6
Mean BMI SDS	0.4	1.2	0.3	1.0	0.5	1.4
% Overweight (BMI >89th centile)	24		24		24	
% Obese (BMI >95th centile)	10		10		10	
% boys	45		47		42	
% Left handed	9		12		8	
Mean birth weight (g)	3158	648	3205	738	3100	495
Median SES †	6	1	6	1	7	1

† Deprivation category score based on postcode McLoone et al. (2005)
BMI SDS (Body mass index standard deviation score) was calculated using the LMS method (1990 UK reference data) (Cole et al., 1995)

Results: **Figure 6. 1** CONSORT Flow Diagram for LEAPFROG **study**



Habitual physical activity and intensity of the physical education intervention

Physical activity data were available for analysis for n=58 children, from an attempted 62**.** Limited number of accelerometers prevented us from attempting to collect habitual data in all 64 children**.** Two children were absent from school, 1 accelerometer was lost and 1 data from 1 child was excluded as monitor was only worn for 2 days based on our exclusion criteria; at least 3 days of measurement with at least 9 hours of data (Penpraze et al., 2006).

Physical activity data are presented in **Table 6.2.** Means, standard deviations, medians and inter quartile ranges are presented, as some data were skewed. There were no significant differences in 6/7 day habitual physical activity between Intervention and Control groups at baseline ($p<0.05$) so habitual activity data were combined for presentation in table.

Total physical activity (mean accelerometer counts per minute: cpm) was significantly higher in Intervention than Control physical education (PE) sessions (median difference 628 cpm 95% CI 460, 786 p= <0.0001). Total physical activity in both Intervention and Control PE sessions were significantly higher than for habitual physical activity (p=<0.001). Percentage time spent in light intensity physical activity (above 1100 cpm, but less than 3200; Reilly et al., 2003; Puyau et al, 2002) was significantly higher in Intervention (36%) than Control (30%) PE sessions (mean difference 6 %, 95% CI 2, 11 p= <0.009). Time spent in light intensity physical activity in both Intervention and Control PE was significantly higher than habitual physical activity ($p<0.0001$).

Percentage time spent in moderate and vigorous intensity physical activity (MVPA) was significantly higher in Intervention (20 %) than Control (9 %) PE sessions (median difference 9 %, 95% CI 5, 13 p= <0.0001). Time spent inactive <1100 (Reilly et al, 2004) was significantly lower in Intervention PE sessions (44 %) than Control PE sessions (61 %) or during Habitual physical activity (78 %).

Table 6. 2 Habitual physical activity and physical activity intensity during intervention and control physical education (PE) sessions

	Habitual n=58				Intervention PE Sessions n=33				Control PE Sessions n=25			
	Mean	**SD**	**Median**	**IQ range**	**Mean**	**SD**	**Median**	**IQ Range**	**Mean**	**SD**	**Median**	**IQ Range**
Total physical activity (accelerometer cpm)	715	169	691	602, 799	1973	493	1801	1618, 2173	1280	305	1158	1057, 1501
% of monitored Time spent Inactive (<1100 cpm)	77	11	78	74, 81	43	12	44	36, 49	58	9	61	52, 65
% of monitored Time spent in Light intensity activity (1100 to 3200 cpm)	19	4	19	16, 22	36	10	36	30, 41	30	8	30	25, 35
% of monitored time spent in MVPA (>3200 cpm)	3	2	3	1.8, 5	21	8	20	14, 27	12	7	9	7, 15

Data are from waist-worn Actigraph GT1M accelerometer. Total physical activity: mean accelerometer counts per minute; MVPA moderate and vigorous physical activity. Inactive cut point <1100 cpm (counts per minute) from Reilly et al. (2003); Light and MVPA cut points from Puyau et al. (2002). Data are from n=58 children mean age 6.1 SD 0.3 years.

Effects of intervention versus control

Cognitive Assessment System (CAS)

Scores from the CAS are presented in **Table 6.3.** There were no significant differences in the changes in scores from baseline to follow up between the intervention and control group by 2 sample t test (see **Table 6.4** for 2 sample t test results). A general linear model to examine any effect of ‘Group’ (intervention or control) on difference in Planning scores (baseline minus follow up) and including gender, SES and school (for clustering) as potential covariates indicated no effect of Group on changes in CAS Planning scores (p 0.38), Full scale (p=0.78) see **Table 6.5** or any of the other CAS subscales (Attention p = 0.75; Simultaneous p = 0.91; Successive p=0.85). There was a significant effect of school on change in Planning scale only (p 0.001) i.e. the school attended appeared to have an effect on how much scores on the Planning scale changed over time, but this was not related to Group allocation (see **Table 6.5**). BMI SD scores were not included in the model as the degrees of freedom for error were negative and Minitab would not allow the calculation, but BMI SD score was not significantly correlated with Planning Score; correlation coefficient = 0.071 p = 0.636. See **Figure 6.4.** BMI was not significantly correlated with any of the baseline or follow up scales of the CAS (p >0.05).

Table 6. 3 Scores from the Cognitive Assessment System (CAS)

	Intervention Baseline		Intervention Follow up		Control Baseline		Control Follow-up	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Planning	106	17	113	17	118†	11	125†	10
Attention	103	13	106	10	108	15	110	14
Simultaneous	99	13	104	12	106	17	106	15
Successive	103	12	108	16	102	16	105	21
Full Scale	104	14	110	9	113	15	116	13

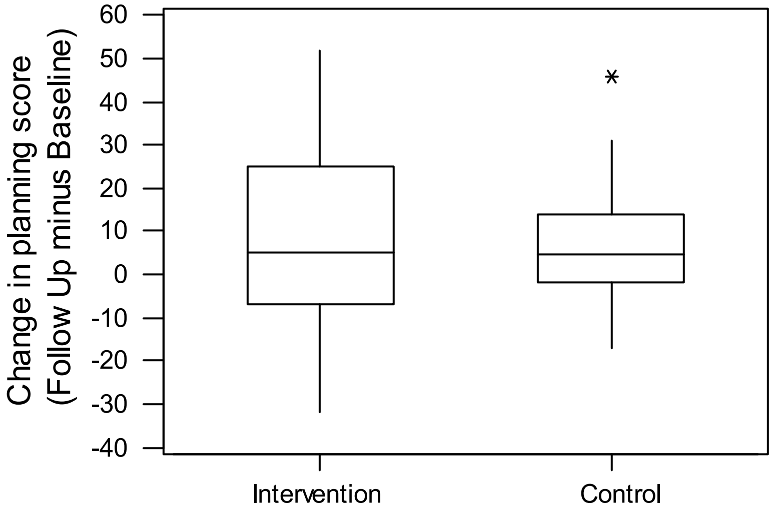
† Significantly higher than Intervention group by 2 sample t test ($p < 0.05$) ; CAS was performed in schools by trained psychologists at baseline, then after 10 week enhanced physical education intervention. Sample were n=school children mean age 6.1 SD 0.3 years.

Table 6. 4 Change in scores of from Cognitive Assessment System (CAS) in Intervention and Control groups

	Intervention		Control				
	Mean†	SD	Mean†	SD	Mean difference	95% CI	p-value
Planning	7	21	7	14	-0.1	-10,10	0.985
Attention	3	14	3	14	-0.7	- 9, 7	0.861
Simultaneous	4	15	0	16	-4.4	- 14, 5	0.334
Successive	3	14	3	14	-1.5	- 10, 6	0.709
Full Scale	6	10	5	8	-1.7	- 7, 4	0.516

† data are mean changes in scores. Data are from 2 sample t tests comparing change in mean between intervention and control groups Sample were n=school children mean age 6.2 SD 0.3 years. Statistical significance was set at $p<0.05$.

Figure 6. 2 Boxplot of changes in Cognitive Assessment System (CAS) score in LEAPFROG Intervention and Control groups



Changes in CAS scores in children participating in the LEAPFROG study by group (Intervention and Control). Sample were n=school children mean age 6.2 SD 0.3 years. Data are not signicantly difference by 2 sample t test p=0.985.

Figure 6. 3 Boxplot of changes in Cognitive Assessment System (CAS) score

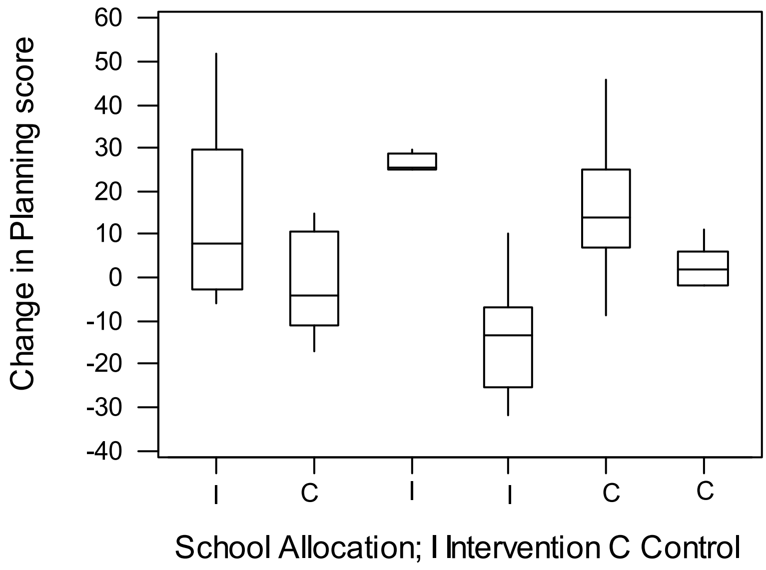


Fig 6.3. Change in Cognitive Assessment System Planning score from baseline and after 10 week intervention or control in n=58 children mean age 6.1 SD 0.3 years in schools participating in the LEAPFROG study; I – intervention C- control **.**

Figure 6. 4 Scatterplot of Cognitive Assessment System and BMI SDS

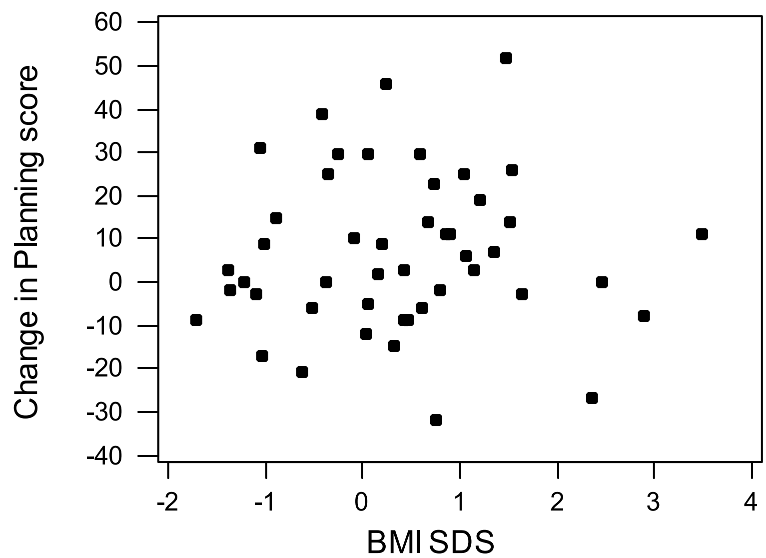


Fig 6.4 Scatterplot of BMI SDS calculated relative to 1990 UK reference data and CAS in n=58 n=58 children mean age 6.1 SD 0.3 years in schools participating in the LEAPFROG study.

Attention Network Test (ANT)

There were no significant differences in change in ANT reaction time scores by 2 sample t test (Intervention mean change -118 ms SD 121sm vs Control -107ms SD 175ms; estimate for difference -11.1ms, 95% CI 86, 108ms) p=0.816 see **Figure 6.5.** Change in reaction time data is negative, as reaction time was generally faster at follow up in both groups. A general linear model indicated that there was no effect of 'Group' on change in reaction time (see **Table 6.5**) but a significant effect of gender on reaction time at follow up (p=0.04) with boys having significantly fast reaction times than girls, data not presented. There was a significant difference in change in ANT Accuracy scores by 2 sample t test. With the Intervention group showing a significantly greater increase in ANT Accuracy scores than the Control (Intervention mean increase 18 SD 24 vs Control mean increase 2 SD 18; Estimate for difference 16, 95% CI 3, 29) p=0.02. See **Figure 6.8.** In the general linear model a trend remained for the change in Accuracy between groups (adjusted mean difference 13 p 0.063) **(see Table 6.6).**

Figure 6. 5 Change in Attention Network Test (ANT) reaction time.

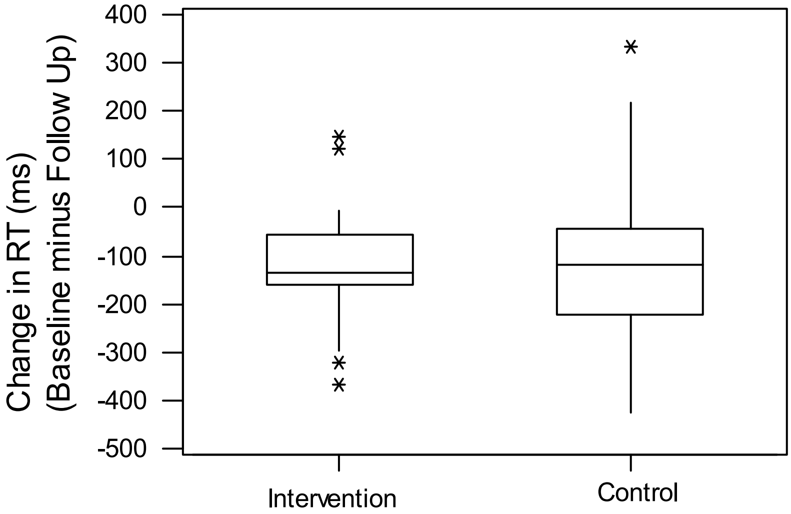


Fig 6.5. Change in ANT score from baseline to follow up (after 10 week intervention or control) in n=58 children mean age 6.1 SD 0.3 years in schools participating in the LEAPFROG study.

Figure 6. 6 Change in Attention Network Test (ANT) accuracy scores.

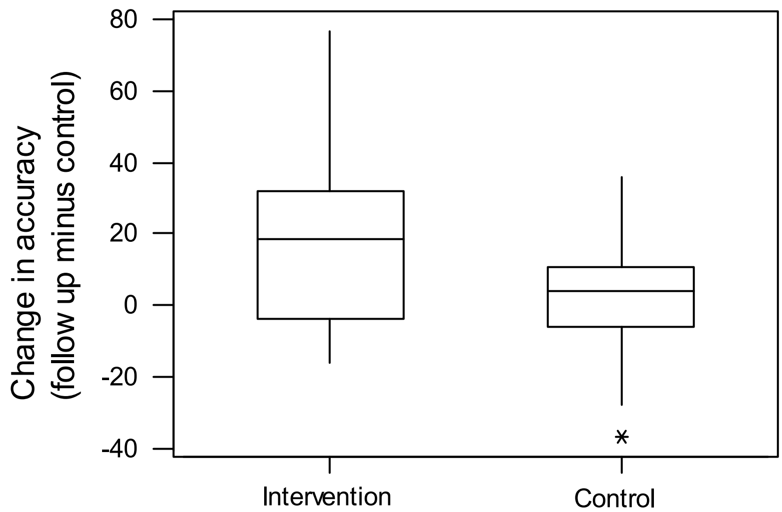


Fig 6.5. Change in ANT score from baseline to follow up (after 10 week intervention or control) in n=58

children mean age 6.1 SD 0.3 years in schools participating in the LEAPFROG study.

Cambridge Neuropsychological Test Battery (CANTAB)

There was a significant difference between the Intervention and Control group (p 0.002) for Spatial Working Memory score but on closer inspection, this was a factor of the Control group getting significantly worse (median change -1) and no improvement in the Intervention (median change 0). A large proportion of the data in both groups indicated negative values - it is improbable that Spatial Memory Span (i.e. the number of items that can be held in working memory) would decrease over time; therefore this analysis has been excluded as data could be misleading, and may further reflect problems in use of this particular test in children of this age.

There was a significant difference in change in the Spatial Working Memory Between Errors test between the Intervention and Control group by 2 sample t test, with the Intervention group showing a significant reduction in errors (improvement in performance) relative to the Control group (Intervention mean – 5 SD 14 Control 4 SD 8 Estimate for difference 9 95% CI 3, 16) $p = 0.009$. A general linear model containing Group (Intervention or Control), gender, school and age indicated there remained a significant effect of Group on change in Spatial Working Memory Between Error Score ($p = 0.01$) and the direction of the results indicated a significant reduction in errors at follow up in the Intervention relative to the Control group **(see Table 6.6).**

Secondary Outcome Measures (in the pilot study)

Body Mass Index (BMI) SD scores

There was no significant change in BMI SD scores from follow-up to baseline between groups by 2 sample t test (mean change in Intervention 0.05 SD 0.313; mean change in Control 0.026 SD 0.436; Estimate for difference 0.024, 95% CI -0.203, 0.252) p=0.830

Connor's Parents Rating Scale: short form (CPRS:S)

Response rates for postal questionnaires were low, so results should be viewed with caution (27 returned at both baseline and follow up). Raw scores from CPRS:S are converted to age and gender related T scores (see Appendix II a. and b. for scoring sheets). For Connor's Parents Rating Scales T Scores see **table 6.5**. Between group comparisons indicated differences between Intervention and Control T scores in all subscales ($p<0.05$), with a significant reduction in scores at follow up in the Intervention group relative to the Control, however, when gender, age, SES were controlled for using a General Linear Model, the Group difference remained only in the Cognitive Problems / Inattention subscales **(see table 6.6).**

Table 6. 5 Adjusted T scores for Conner's Parent Rating Scales Short Form

T Scores	Intervention (n=15) Baseline Mean	SD	Follow-Up Mean	SD	Control (n=12) Baseline Mean	SD	Follow-Up Mean	SD
Oppositional	53	7	46	4	51	9	52	12
Cognitive Problems / Inattention	54	7	48	4	51	5	52	7
Hyperactivity	57	13	52	6	55	9	57	13
ADHD Index	53	6	49	5	50	3	51	5

Questionnaires were administered by post due to time and staffing shortages (CPRS was a secondary outcome) and response rates were low. A lower score at follow up indicates a reduction in symptoms on the subscales (improved 'behaviour').

Scores are age and gender adjusted T scores.

Table 6. 6 Adjusted model for LEAPFROG psychological outcome measures

Outcome (Response) **CAS**	**Difference of Means**	**SE of Difference**	**T Value**	**P Value**
Full scale	-3	-5	-0.71	0.48
Planning	-7	-8	-0.94	0.35
Attention	-7	-8	-0.89	0.39
Simultaneous	-1	-8	-0.03	0.97
Successive	2	6	0.24	0.81
ANT				
Reaction time (ms)	28	41	0.67	0.50
Accuracy	-14	-7	-1.93	0.06
CANTAB				
SWM Between Errors	12	4	2.78	**0.01**
CPRS:S				
Oppositional	9	6	1.60	0.13
Cognitive Problems/Inattention	9	5	2	**0.04**
Hyperactivity	11	9	1.33	0.20
ADHD Index	2	3	0.56	0.60

Data are from general linear model containing the psychological outcome as a response, and group, school(with nested Group), gender and SES as factors, and decimal age as a covariate. Data are from children participating in the LEAPROG pilot RCT mean age 6.1 SD 0.3 years.

SE Standard Error
CAS Cognitive Assessment System
ANT Attention Network Test
CANTAB Cambridge Neuropsychological Test Batter
CPRS:S Connors Parent Rating Scale : Short Form

6.4. Discussion

The current study was a pilot study for a future RCT, designed to develop and monitor the intensity of an aerobic exercise intervention and determine the most suitable primary outcome measure for a future RCT in young children. All aims of the pilot study were achieved successfully. Though intended as a pilot/feasibility study, it was the first RCT examining the effects of exercise on cognitive function in children as young as 6 years old.

Aerobic exercise intervention

The present study suggests that the adapted specialist / trained teacher delivered Basic Moves Sessions was a feasible aerobic intervention for young children, and allowed them to reach a fairly high intensity of physical activity. Children in the Intervention group spent around 20% of their time in MVPA, during the 1 hour PE sessions. Despite the instruction to school teachers (both class teachers and primary school PE specialists) to keep children moving 'as much as possible' during the one hour of PE, the data suggest that children spent around 40% of their time inactive during even during the Intervention sessions (mean counts per minute <1100, Reilly et al., 2003). In a future full scale trial we would aim to monitor physical activity intensity of every session, and provide regular feedback to staff and videotape (where possible) the sessions to play back to them, to ensure that intensity levels are kept sufficiently high for as long as possible during each PE session. Due to the research staff and time limitations of the pilot study, this was not feasible. The use of heart rate during intervention sessions in a future full scale trial, may enhance motivation in children (Davis et al,. 2007), and allow the intervention to be sufficiently progressive in nature.

Ensuring high and sustained intensities of physical activity during school PE is not as straightforward as it may seem and a large amount of research effort has been put into attempts to make school PE more aerobically intense (Fairclough & Stratton, 2005; McMurray et al. 2002). Luekper et al., (1999) and McMurray et al., (2002) have previously observed that children only spend a very small percentage (typically around 6%) of their physical education time in aerobic activities (McMurray et al., 2002; Luekper et al., 1999). The current recommendations for physical activity are that all children should spend around 30 minutes of their time in MVPA during the school day (Koplan et al., 2004 p14) and a total of one hour per day in MVPA (Strong et al., 2005), whereas current estimates are less that 25 minutes of MVPA per school week (Nader et al., 2005). In our intervention, the children spent around 20% of their physical activity time in MVPA, which, as the sessions were run by educationalists (teachers and school PE specialists) rather than researchers, using resources freely available in the schools, and within school time, could be easily translatable. It is feasible that, working closely with PE specialists and teachers, and providing more opportunity for self monitoring (e.g. video observation of their own classes) the intervention could be enhanced further, to provide the recommended 30 minutes of MVPA recommeded in school time. Instruction time and time waiting should be kept to a minimum (Koplan et al., 2005; Gortmaker et al., 1999) – while we attempted to address this initially, due to funding limitations of the pilot, we did not have the staff to directly observe the PE classes, and did not have consent to video tape the full class of children.

Cognitive Assessment System (CAS)

The current study indicates that Cognitive Assessment System (CAS) is a feasible primary outcome measure for a future RCT in children in this age group, and setting. There were no significant effects of group in changes in any of the Cognitive Assessment System (CAS) Subscales. This may be due to not having a high enough 'dose' of exercise to benefit cognition, or due to insufficient power. Davis et al (2007) saw a significant improvement of the Planning scale in a High dose aerobic exercise group (40 minutes of aerobic exercise 5 times per week), but no significant improvement in a Low dose group (20 minutes of exercise 5 times per week). CAS scores in the Low dose group did not change significantly relative to the Control group, suggesting a 'threshold' that may have to be reached for exercise to positive impact cognition (Davis et al., 2007). It should be noted that when designing and implementing the current study, the data from the study by Davis et al., (2007) were not available. It is also feasible that very young children, at a different stage of cognitive development, respond differently to the positive cognitive effects of exercise (Tomporowski, 2008[R]). The good reliability of subscales that allow the executive function hypothesis to be tested and positive response from young Scottish children, administering psychologists, and staff in primary schools, indicate that the CAS would be a suitable primary outcome measure for a future RCT.

ANT & CANTAB

Due to very limited staff on the pilot RCT, and time involved to extract data from the ANT and CANTAB for analysis, test retest reliability data were not calculated prior to the follow up measurement period, so CANTAB and ANT follow-up measures were taken. While test and retest reliability data suggested the the Attention Network Test (ANT) or Cambridge Neuropsychological Test Battery (CANTAB) were not reliable enough to use as primary psychological outcome measures (full data presented in **Chapter 4**), a significant improvement in the Between Errors in the Spatial Working Memory Test of the CANTAB ($p=0.03$) in the present study. Interpretation of the results is difficult as we cannot be sure this was not down to error of measurement; however it is likely that a less reliable test may be more likely to mask any potential differences, rather than the opposite way around. The Between Errors outcome of the CANTAB test of Spatial Working Memory has been shown to be sensitive to executive dysfunction (Kempton et al., 1999), and therefore, it could be theorised that improved executive function through aerobic exercise could lead to enhanced performance on these tasks.

Although the results from the CPRS were encouraging, the low response rate to the postal questionnaires means that any results should be viewed with caution. The CPRS was originally a secondary outcome measure, and staffing limitations (only one full time research assistant) meant that there was possibly not enough emphasis to parents on return of the postal questionnaires in the present study. In a future trial, the CPRS would be a primary outcome measure, and a research assistant full responsible for the administration and follow-up of the CPRS would be employed.

Power calculation and considerations

One of the aims of the current study was to provide data to adequately power a future full scale RCT. With the Planning scale of the Cognitive Assessment System as a primary outcome measure, using the current data this would be problematic. Possibly due to the intervention not be intense enough (Davis et al., 2007) or the study being underpowered to detect change. Applying the mean difference in change in Planning scores of the CAS of 7 between groups after controlling for differences within schools (**Table 6.5**) and using our group mean standard deviation of 15, at 80% power we would require **74** children in each group (around double the number we had in the current study). The overall design of the RCT based on the current pilot is discussed in more detail in Chapter 8.

Potential mechanisms for findings of present study

The current study was a pilot, exploratory study, with small sample sizes, so results should be viewed with caution. The current pilot suggests that the enhanced PE intervention was associated with a possible improvement in the Attention Network Test accuracy but not reaction time in the Intervention groups versus Control. While it must be accepted that the difference may be due to test retest error, there are theoretical reasons why this difference could be seen. In their 2003 meta-analysis of older adult exercise and cognitive function data, Colcombe & Kramer indicated a stronger effect size for studies involving task that require executive control than tasks that fall in the authors (theoretical) category of *controlled-process*; tasks that initially require control then become automatic with practice e.g. choice reaction time. The Attention Network Test, and the Eriksen Flanker Task that the ANT is based on, provides examples of tests that contain both components – the choice reaction time (a controlled-process task) and the need to 'block out' interfering stimuli (an executive control task) (see Colcombe & Kramer, 2003 p127).. In adults, aerobic exercise is linked with a reduction in activity of the anterior cingulate corex (Colcombe et al. 2004), and an improvement in performance in executive function tests. The anterior cingulate cortex is linked with both behaviour and executive function, and it is feasible that, even in a ten week intervention in young children, aerobic exercise may enhance BDNF gene expression, improve long term potentiation and spatial memory (as seen in rodents – see **Table 1.2 Chapter 1**). Further studies in larger samples, using fMRI to examine changes in the brain would be warranted. In summary, though conclusions about relationships between these aspects of cognition and exercise can only be tentative from the present study, they are biologically plausible and consistent with current literature.

There was a significant reduction in scores in the CPRS:S Cognitive Problems and Inattention scale in the present study **(Table 6.6).** Behaviour and conflict response are regulated by the anterior cingulate cortex (ACC) (Divinsky et al., 1995[R]). The activity of the ACC has been demonstrated to be altered by aerobic exercise versus stretching and toning in older adults (Colcombe et al., 2004), and it is feasible this is also true of young children, so again there is a degree of biological plausibility and consistency with recent literature in the findings of the present study. However in a future RCT, it would be desirable to establish whether such effects exist in a larger sample, and it may be possible to use functional magnetic resonance imaging (fMRI) to confirm whether there are structural changes taking place in the brain of young children in response to exercise.

Limitations

There are a number of limitations to the present study. The sample size is small, however the study was a pilot, designed to adequately power a potential future full scale RCT. The intervention may not have been intense enough, as reported in the study by Davis et al. (2007), at least 40 minutes at least 5 times per week is required to see a change in the Cognitive Assessment System (CAS) however, these data were not available when designing the current study. Use of accelerometers only may not have been sufficient to monitor intervention intensity, and ensure that overload was being achieved. It is likely that the children would plateu as the intervention was not progress. The use of heart rate during the intervention would be employed in a future RCT. Children cannot achieve improvement in 'aerobic' fitness to the same extent as adults until puberty is reached, partly because they are naturally 'fitter' and partly due to low levels of testosterone (muscles, including the heart, cannot increase in size as much) (Rowland, 1996).

Children have a higher anaerobic threshold than adults; children tend to reach anaerobic threshold around 85 maximal HR (>170 beats per minute) so more intense exercise could be more beneficial for children. Children have greater aerobic enzyme activity than adults and burn greater fat burning capacity during exercise. Because of this higher intensity training that impacts the glycolytic system, rather than the fatty acid system may be more beneficial. It is feasible, therefore, that suitable interval training, rather than a continous aerobic sessions, would be a better intervention for children (Rowland, 1996).

6.5. Conclusion

The current pilot study provides the information required to design and implement a full scale randomised controlled trial in young Scottish children.

Chapter 7. Overall thesis discussion

7.1 Summary of findings

The results of the current studies suggest that movement skills and physical activity are only weakly related in young children (chapter 3). The pilot study in Chapter 6 provides data to adequately power a future full scale RCT examining the relationship between exercise and cognitive function in young children. The studies in this thesis are the first to examine the relationship between physical activity and motor and cognitive development in children under the age of 7 years. The studies in the thesis add to the literature that habitual physical activity and movement skills are not strongly related (Okely et al., 2001), although this relationship may be more important at higher levels of activity, and potentially different types of activities (sports participation).. The results of the thesis also lay the foundations for design of a full scale RCT to examine the relationship between chronic aerobic exercise and executive function, and suggest that chronic aerobic exercise, as compared to movement skill development, may positively enhance aspects of cognitive function (Colcombe et al., 2004). Chapter 6 provides the first data (to our knowledge) to suggest that aerobic exercise may positively influence behaviour in typically developing children (as opposed to children with behaviour problems / overweight obese children), and this is certainly an area for further research with larger samples. The results of all the studies included in this thesis add to the literature that modern children spend a large proportion of their time sedentary. In all samples in the current thesis, children spent around 70% of their time in sedentary behaviour, and only around 4% of their time in moderate and vigorous intensity physical activity (MVPA).

A combination of observational and RCT (pilot) studies were included in the thesis. It is noted that the observational nature of the study in chapter 3 may mean that the conclusions were confounded by other variables that were not measured, and may mask the relationship between movement skills and habitual activity. The relatively small samples in the intervention studies in chapters 6 and 7 make drawing conclusions difficult, but these studies were intended as pilot / feasibility studies for possible future work. This work in this thesis overall was intended to lay the foundation for a full scale RCT examining the relationship between exercise and cognitive function. At the beginning of the thesis work, research in the area of physical activity / exercise and motor and cognitive function was very limited, and non-existent in children under 7 years.

The original aim for the current PhD had been to examine the relationship between habitual physical activity and movement skills in preschoolers cross sectionally, as the nature of the data (being baseline data for an RCT) only allowed this study design, then follow up this work examining the relationship between physical activity and cognitive function in preschoolers. However, further research into the area and contact with expert psychologists, indicated that reliable cognitive measures for preschoolers did not exist (because many aspects of executive function have simply not developed in preschool children and they are an under-researched group), and our own experience indicated that it would be difficult to implement a purely aerobic intervention in preschools. The decision was taken (based on expert advice) to assess the feasibility of carrying out a study of this nature in a slightly older sample of 6-8 year old children within primary schools, but it was not even clear if this would be feasible, so pilot work had to be done to determine which outcomes could be used in children of this age, which exercise intervention to use in this age group, and how to best carry out research of this nature in schools. The rationale for studying the youngest age group feasible was that, due to their greater neural plasticity, it is believed that any cognitive effects of exercise would be greater in children and greatest in younger children in whom brain development proceeds rapidly. It is the author's belief that these aims were achieved successfully through the thesis work.

At present, in preschool and primary physical education a large percentage of time is spent of activities to promote movement skills development, and a small percentage of time is generally spent on aerobic activity (McMurray et al., (2002). While certainly important, as the ability to move underlies the ability to carry out any physical activity (Gabbard, 2004), it is possible the emphasis is too strongly on movement skills, with little time for children to carry out moderate to vigorous 'play'. In addition, in light of the fact that modern children are so sedentary, and that it appears that aerobic exercise can positively enhance cognitive function, a larger proportion of physical education time should possibly be spent on aerobic activity in future, with less emphasis on movement skills. Alternatively, more time could be devoted to school physical education .

The Scottish Government recently withdrew policy to increase school physical education time to two hours per week. Evidence now consistently shows that there are no negative effects on academic scores by enhancing physical education time in schools, even by as much as 1 hour per day, and, in fact, the right type of activity may positively enhance cognition, and possibly behaviour (although this is an area for futher research) therefore physical education time in schools should arguably increase. A large, adequately powered RCT would provide more robust and convincing evidence of possibly benefits of increased exercise in school, which may in turn influence Government Policy on school physical education.

Based on our data from Chapter 6 it appears that and RCT examining the effect of exercise on cognitive function is feasible in children as young as 6. We would aim to use the Cognitive Assessment System (CAS), Conner's Parents Rating Scale: Short Form (CPRS:S) and the Actigraph GT1M accelerometer as a primary outcome measures the Attention Network Test (ANT) as a secondary outcome (justifications are discussed in Chapter 6). Data on potential confounders; body mass index (BMI) and socio-economic status (SES) would be collected. We would also aim to use functional Magnetic Resonance Imaging (fMRI) in a subsample of participants to examine any structural changes in the brain (preliminary discussions with the University of Glasgow Centre for Cognitive Neuroimaging suggest that this would be feasible, and collaboration would be welcome).

Based on the data from our pilot study (chapter 6) using our data from the CAS Planning scale (a primary outcome), we would aim to have an n of around 100 children in each group so that full data n around 75 participants in each arm of the future RCT could be obtained. Our practical experience has suggested that around 10-15 children per school is feasible (due to the length of time required for CAS testing). In some schools in the pilot study presented in chapter 6 responses were low; to counteract this, we would work with teachers to determine the best ways to gain optimal recruitment (for example, talking at parent's evenings, providing translators for families who do not have English as a first language). Due to limited funding for the chronic effects of exercise study in chapter 6, we only had one member of staff available to deliver recruitment packs to schools (the thesis author) then rely on them being handed to children / parents, read and returned. We would include measures of heart rate during the intervention, and potentially employ a suitable paediatric interval training aspect to the intervention. Having staff available for recruitment in the full scale trial may also help to prevent bias of parents with low literacy. The recent study in overweight and obese children by Davis et al., (2007) and our preliminary findings suggest that a 10-15 week duration of intervention may be long enough to show improvements in cognitive function in children, but the intervention should probably be at least 40 minutes 5 times per week, as observed from our study, cognitive changes *may* be seen in younger children Carrying out an intervention of the proposed intensity (daily PE) would likely be more feasible over a single school term. It would also be important to examine how long any potential cognitive benefits of exercise lasted for following the end of the intervention.

We would hope to implement the intervention in much the same way (with Glasgow city council Primary PE specialists / trained teachers) but more frequently (daily) and work with PE specialists and teachers to enhance the aerobic activity during the sessions, so the children spend a greater proportion of time in moderate and vigorous physical activity (MVPA). It is likely that to achieve the recommended 60 minutes of MVPA recommended by Strong et al. (2005), a home intervention would have to be addressed

7.2 Directions for future research

Table 8.1 Indicates recent reviews suggest directions for future research in the area of exercise and cognitive function.

Observational studies have produced limited evidence on childhood physical activity and cognition, and physical activity and movement skills to date. Recent reviews (Tomporowski, 2008; Hillman, 2008) have concluded that RCT's are necessary and this is an obvious conclusion from the present thesis. It is clear more randomised controlled-trials, examining the dose reponse of exercise on cognitive function, and the interaction with fitness, are required in both adults and in children. Neuroimaging (including fMRI) in children would also allow researchers to determine whether the structural changes in the brain observered in older adults, are also observed in children, and neuroimaging studies could be nested within future RCT of intervention.

Public health strategies to promote exercise as an intervention for life long brain (as well as physical) health may have more impact than physical health alone, and in future health promotion (for example, obesity prevention) studies, researchers should consider including cognitive outcome measures.

Table 7. 1 Future directions for research.

Adult reviews & studies

Authors	**Findings / Conclusions**	**Future Directions for Research**
Tomporowski et al (2008) Review (child)	Exercise does appear to influence specific aspects of cognitive function (executive functions) in children, but the lack of true experimental studies, and variety of interventions and cognitive tests used, makes comparison difficult. The equivocal findings from previous research reflect this.	Examination of how long exercise-induced benefits in cognitive function last, especially if the exercise intervention is terminated (long term follow-ups needed). To tease out how the cognitive benefits gained from exercise are related to type, duration or intensity of exercise. Brain imaging studies, to determine how/if cognitive benefits of exercise relate to brain structure and function. Better understanding of how study design may influence results i.e. selection of age-appropriate tests that correctly measure the cognitive functions hypothesised to be influenced by exercise.
McAuley & Steriani (2008) Book chapter	Behaviour, cognition, physiology and environment act as determinants of one another. Self efficacy influences the initiation and continuation of physical activity. Self efficacy is also an outcome of PA., which would enhance the PA experience and thus indirectly influence cognitive function via the benefits of PA on physical and mental resources.	Teasing out the reciprocal relationships between exercise, self-efficacy and cognitive function.
Angevaren et al., (2008) Cochrane	11 RCT's reported aerobic exercise	To understand why some cognitive

Review (adult)	interventions resulted in increased CV fitness (improvement in maximal oxygen uptake test) of the intervention group. Of approximately 14%. This improvement coincided with an improvement in cognitive capacity. The largest effect sizes were found in auditory attention (0.52) and delayed memory (0.50). The largest impact was seen in motor function (effect size 1.17). Modest effects were seen on information processing speed (ES 0.26) and visual attention (ES 0.26). Data are insufficient to conclude that exercise-related improvement in cognitive functions are due to improvements in CV fitness.	functions improve with (aerobic) exercise, while some are insensitive to exercise. Development / agreement of a standardised set of neuropsychological tests by researchers in the field, to heighten the reproducibility of results. Further examination of the 'fitness effect'.
Rockwood & Middleton (2007) Review (adult)	Longitudinal studies suggest that the risk of dementia, cognitive impairment, cognitive decline, and Alzheimer's disease is lower among people engaging in high levels of PA. There is a dose-response relationship between between PA and cognitive function.	How interactions between the APOE e4 allele and physical activity affect the risk of cognitive impairment.

8.1. References

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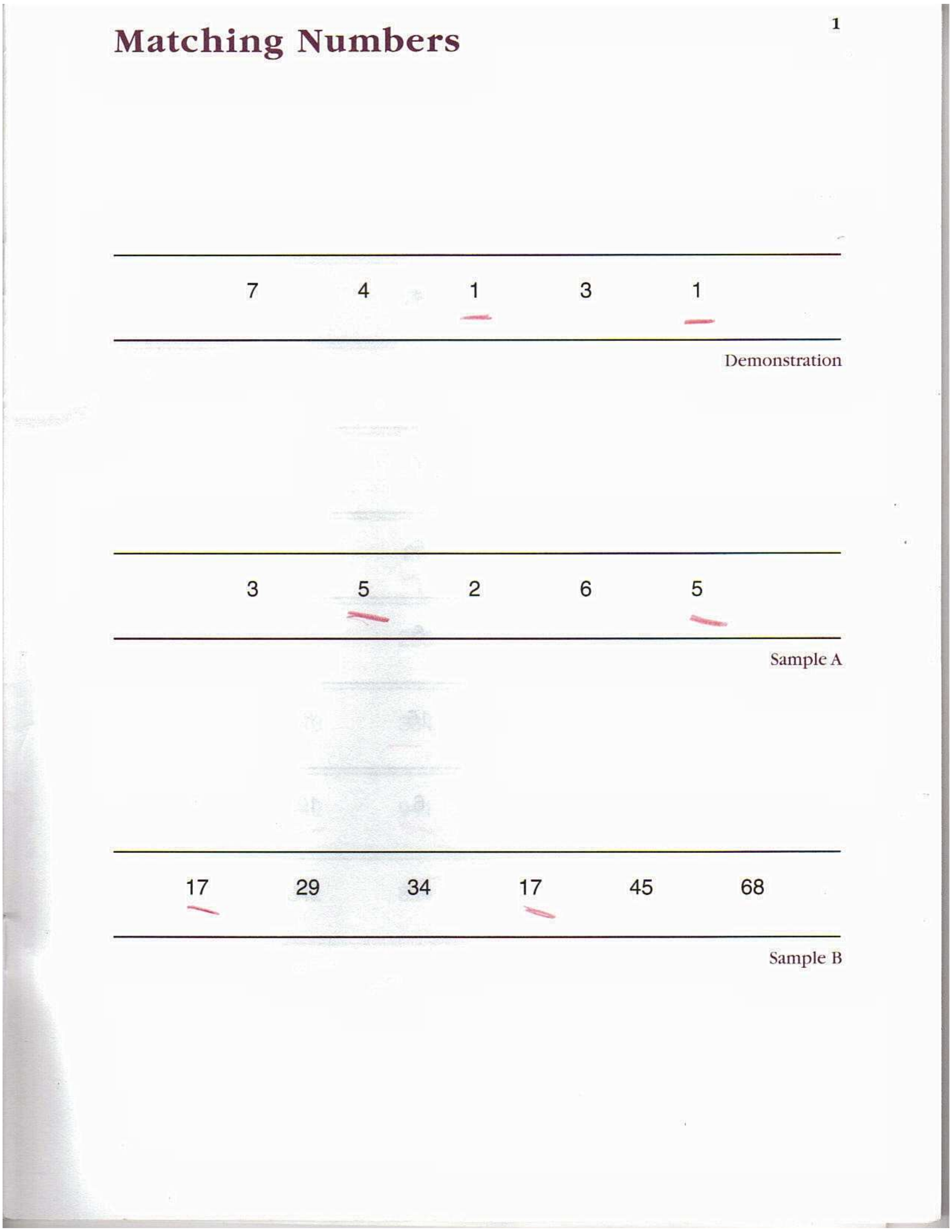
Appendix

Appendix I.a Cognitive Assessment System (CAS) Planning Scale: Matching Numbers



Matching Numbers

1

7	4	1	3	1

Demonstration

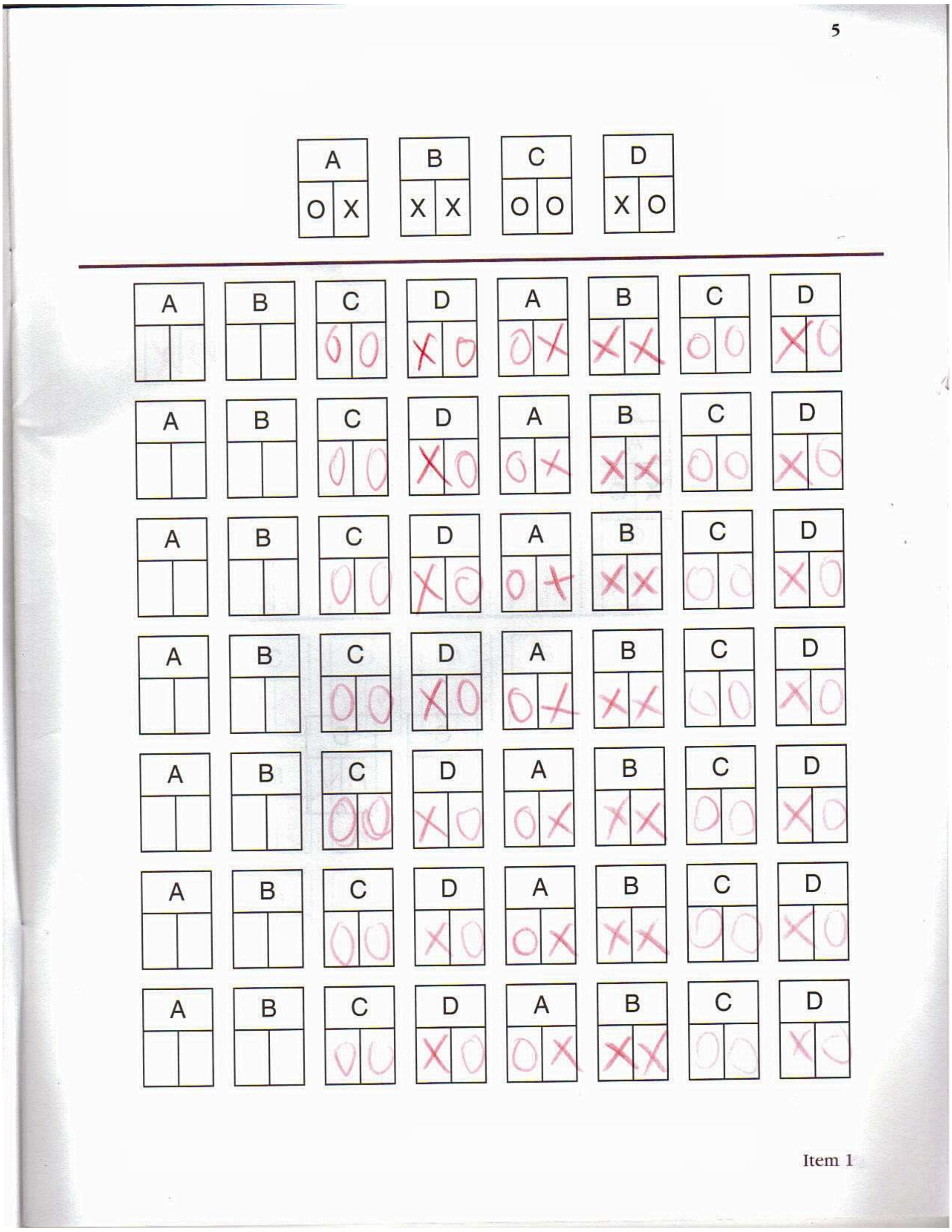
3	5	2	6	5

Sample A

17	29	34	17	45	68

Sample B

Appendix I.b Cognitive Assessment System (CAS) Planning Scale: Planned Codes



Appendix II.a

Conner's Parent Rating Scale: Short Form

Conners' Parent Rating Scale–Revised (S)

by C. Keith Conners, Ph.D.

Child's ID: ______________________ **Gender:** M F (Circle One)

Birthdate: ___/___/___ (Month Day Year) **Age:** _____ **School Grade:** _____

Parent's ID: ______________________ **Today's Date:** ___/___/___ (Month Day Year)

Instructions: Below are a number of common problems that children have. Please rate each item according to your child's behavior in the last month. For each item, ask yourself, "How much of a problem has this been in the last month?", and circle the best answer for each one. If none, not at all, seldom, or very infrequently, you would circle 0. If very much true, or it occurs very often or frequently, you would circle 3. You would circle 1 or 2 for ratings in between. Please respond to each item.

	NOT TRUE AT ALL (Never, Seldom)	JUST A LITTLE TRUE (Occasionally)	PRETTY MUCH TRUE (Often, Quite a Bit)	VERY MUCH TRUE (Very Often, Very Frequent)
1. Inattentive, easily distracted	0	1	2	3
2. Angry and resentful	0	1	2	3
3. Difficulty doing or completing homework	0	1	2	3
4. Is always "on the go" or acts as if driven by a motor	0	1	2	3
5. Short attention span	0	1	2	3
6. Argues with adults	0	1	2	3
7. Fidgets with hands or feet or squirms in seat	0	1	2	3
8. Fails to complete assignments	0	1	2	3
9. Hard to control in malls or while grocery shopping	0	1	2	3
10. Messy or disorganized at home or school	0	1	2	3
11. Loses temper	0	1	2	3
12. Needs close supervision to get through assignments	0	1	2	3
13. Only attends if it is something he/she is very interested in	0	1	2	3
14. Runs about or climbs excessively in situations where it is inappropriate	0	1	2	3
15. Distractibility or attention span a problem	0	1	2	3
16. Irritable	0	1	2	3
17. Avoids, expresses reluctance about, or has difficulties engaging in tasks that require sustained mental effort (such as schoolwork or homework)	0	1	2	3
18. Restless in the "squirmy" sense	0	1	2	3
19. Gets distracted when given instructions to do something	0	1	2	3
20. Actively defies or refuses to comply with adults' requests	0	1	2	3
21. Has trouble concentrating in class	0	1	2	3
22. Has difficulty waiting in lines or awaiting turn in games or group situations	0	1	2	3
23. Leaves seat in classroom or in other situations in which remaining seated is expected	0	1	2	3
24. Deliberately does things that annoy other people	0	1	2	3
25. Does not follow through on instructions and fails to finish schoolwork, chores or duties in the workplace (not due to oppositional behavior or failure to understand instructions)	0	1	2	3
26. Has difficulty playing or engaging in leisure activities quietly	0	1	2	3
27. Easily frustrated in efforts	0	1	2	3

Appendix II.b

Conner's Parent Rating Scale: Short Form Conversion sheet for age and gender related T scores

Profile for Females: Conners' Parent Rating Scale–Revised (S)

Child's ID: ______________________ **Gender: M F** (Circle One)

Birthdate: ___/___/___ (Month Day Year) **Age:**_____ **School Grade:**_____

Parent's ID: ______________________ **Today's Date:** ___/___/___ (Month Day Year)

T	A. Oppositional 1	2	3	4	5	B. Cognitive Problems/ Inattention 1	2	3	4	5	C. Hyperactivity 1	2	3	4	5	D. Conners' ADHD Index 1	2	3	4	5
90	.	.	17	16	17	.	.	16	.	.	.	15	.	.	.	27	33	30	.	.
89	.	16	.	.	.	12	15	.	16	.	.	.	9	.	.	.	32	.	28	29
88	.	.	.	.	.	.	.	15	.	16	.	.	.	.	.	26	.	29	27	28
87	14	.	16	15	16	.	.	.	15	.	12	14	.	.	6	.	31	28	.	.
86	.	15	.	.	.	.	14	.	.	.	.	.	.	6	.	25	30	.	26	27
85	.	.	.	.	.	11	.	14	.	15	.	.	.	.	.	.	.	27	.	.
84	13	.	15	14	15	.	.	.	14	.	.	13	8	.	.	24	29	26	25	26
83	.	14	.	.	.	.	13	.	.	14	11	.	.	.	.	.	28	.	24	25
82	.	.	.	.	.	.	.	13	.	.	.	.	.	.	.	23	.	25	.	.
81	.	.	14	13	14	10	.	.	13	.	.	12	.	.	.	22	27	24	23	24
80	12	13	.	.	.	.	12	.	.	13	.	.	.	5	5	.	26	.	.	23
79	.	.	.	.	.	.	.	12	.	.	10	.	7	.	.	21	.	23	22	.
78	.	.	13	12	13	.	.	.	12	.	.	11	.	.	.	.	25	.	.	22
77	11	12	.	.	.	9	11	.	.	12	.	.	.	.	.	20	24	22	21	.
76	.	.	12	.	12	.	.	11	.	.	9	.	.	.	.	.	23	21	20	21
75	.	.	.	11	.	.	.	.	11	.	.	10	.	.	.	19	.	.	.	20
74	.	11	.	.	.	8	10	.	.	11	.	.	6	.	.	.	22	20	19	.
73	10	.	11	.	11	.	.	10	.	.	.	.	.	4	4	18	21	19	.	19
72	.	.	.	.	.	.	.	.	10	.	8	9	.	.	.	.	.	.	18	.
71	.	10	.	10	.	.	9	.	.	10	.	.	.	.	.	17	20	18	17	18
70	9	.	10	.	10	7	.	9	9	.	.	.	.	.	.	.	19	.	.	17
69	.	.	.	.	.	.	.	.	.	9	.	8	5	.	.	16	.	17	16	.
68	.	9	.	9	.	.	8	.	.	.	7	.	.	.	.	15	18	16	.	16
67	.	.	9	.	9	.	.	8	8	.	.	.	.	.	.	.	17	.	15	.
66	8	.	.	.	.	6	.	.	.	8	.	7	.	3	3	14	.	15	14	15
65	.	.	.	8	.	.	7	.	.	.	.	.	.	.	.	.	16	14	.	14
64	.	8	8	.	8	.	.	7	7	.	6	.	4	.	.	13	15	.	13	.
63	7	.	.	.	.	5	.	.	.	7	.	6	.	.	.	.	.	13	.	13
62	.	.	.	7	.	.	6	.	.	.	.	.	.	.	.	12	14	.	12	12
61	.	7	7	.	7	.	.	6	6	.	.	.	.	.	.	.	13	12	11	.
60	.	.	.	.	.	.	.	.	.	6	5	5	3	.	.	11	.	11	.	11
59	6	.	.	6	.	4	5	5	.	.	.	.	.	2	2	.	12	.	10	.
58	.	6	6	.	6	.	.	.	5	5	.	.	.	.	.	10	11	10	.	10
57	.	.	.	.	.	.	.	.	.	.	4	.	.	.	.	.	.	9	9	9
56	5	.	.	5	.	.	4	4	4	.	.	4	.	.	.	9	10	.	8	.
55	.	5	5	.	5	3	.	.	.	4	.	.	2	.	.	8	9	8	.	8
54	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	8	.	7	.
53	.	.	.	4	.	.	3	3	3	.	3	3	.	.	.	7	.	7	.	7
52	4	4	4	.	4	.	.	.	.	3	.	.	.	1	1	.	7	6	6	6
51	.	.	.	.	.	2	.	.	.	.	.	.	.	.	.	6	6	.	5	.
50	.	.	3	3	.	.	2	2	2	.	.	2	1	.	.	.	.	5	.	5
49	3	3	.	.	3	.	.	.	.	2	2	.	.	.	.	5	5	4	4	4
48	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	4	.	.	.
47	.	.	2	2	.	.	1	1	1	1	.	1	.	.	.	4	.	3	3	3
46	.	2	.	.	2	.	.	.	.	.	.	.	.	0	.	.	3	.	2	.
45	2	.	.	.	.	.	.	.	.	.	1	.	0	.	0	3	2	2	.	2
44	.	.	1	.	.	0	0	0	0	0	.	0	.	.	.	.	.	1	1	1
43	.	1	.	1	1	.	.	.	.	.	.	.	.	.	.	2	1	.	.	.
42	1	.	.	.	.	.	.	.	.	.	0	.	.	.	.	1	0	0	0	0
41	.	.	0	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
40	.	0	.	0	0	.	.	.	.	.	.	.	.	.	.	0	.	.	.	.
39	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
38	0	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

Note:
For age-groups:

Column 1: ages 3 to 5

Column 2: ages 6 to 8

Column 3: ages 9 to 11

Column 4: ages 12 to 14

Column 5: ages 15 to 17

Please see back of scoring sheet for Scale Descriptions

Please see reverse for CPRS–R Male Profile

Appendix III.

Raw data from Attention Network Test in n=62 6 year old Scottish children at baseline.

Warning	Centre				Double				No				Down				Up			
Flanker	RT	SD	AC	SD	RT	SD	AC	SD	RT	SD	AC	SD	RT	SD	AC	SD	RT	SD	AC	SD
Congruent	928	176	9	3	924	150	10	3	990	152	9	2	956	214	5	1	923	187	5	1
Incongruent	1038	175	8	3	1019	178	8	3	1094	151	7	3	1045	187	4	2	1034	211	4	2
Neutral	919	155	10	2	888	190	10	2	992	150	9	3	868	163	5	1	922	193	5	2

Reaction time (RT) = mean of median (ms). Reaction time to stimulus (central fish) appearing on screen, mouse button is pressed and time recorded.
Accuracy (AC) = Centre / Double / No total correct out of a possible 12; Down & Up total correct from a possible 6. Accuracy is whether correct mouse button is pressed (in response to direction fish is facing).
Children were n=62 mean age 6.1 SD 0.2 participants of the LEAPFROG pilot study. Congruent – fish all pointing in the same direction; incongruent – middle fish pointing the opposite way from the others; Neutral only one fish. The warnings are stars that appear before stimulus onset – either a single in the centre, 2 (double) at top and bottom, none 'no' or down (bottom) up (top).

Raw data from Attention Network Test in n=62 6 year old Scottish children at 3 week retest.

3 week re- test	Centre				Double				No				Down				Up			
Flanker / Warning	RT	SD	AC	SD	RT	SD	AC	SD	RT	SD	AC	SD	RT	SD	AC	SD	RT	SD	AC	SD
Congruent	821	171	10	2	836	164	10	2	930	135	9	2	818	184	5	1	840	171	5	1
Incongruent	917	151	8	3	899	163	9	3	988	180	8	3	889	165	4	1	879	203	4	2
Neutral	829	159	9	2	798	170	10	2	908	156	9	2	788	172	5	1	824	185	5	1

Reaction time (RT) = mean of median (ms). Reaction time to stimulus (central fish) appearing on screen, mouse button is pressed and time recorded.
Accuracy (AC) = Centre / Double / No total correct out of a possible 12; Down & Up total correct from a possible 6. Accuracy is whether correct mouse button is pressed (in response to direction fish is facing).
Children were n=62 mean age 6.1 SD 0.2 participants of the LEAPFROG pilot study. Congruent – fish all pointing in the same direction; incongruent – middle fish pointing the opposite way from the others; Neutral only one fish. The warnings are stars that appear before stimulus onset – either a single in the centre, 2 (double) at top and bottom, none 'no' or down (bottom) up (top).

Correlation coefficients for correlations between baseline and 3 week rest test reaction time and accuracy data (raw data shown in tables 1a & b)

Flanker / Warning Type	Centre RT	ACC	Double RT	ACC	No	ACC	Down	ACC	Up	ACC
Congruent	0.23	0.30*	0.27*	0.37*	0.22	0.53**	0.56**	0.30*	-0.05	0.41**
Incongruent	0.13	0.50**	0.17	0.55**	0.24	0.42*	0.31*	0.39*	0.19	0.43**
Neutral	0.41**	0.48**	0.25	0.38*	0.24	0.42*	0.19	0.30*	0.13	0.30**

*p<0.05; **p<0.005

Intraclass correlations for baseline and 3 week retest between different flankers and warning types from the Attention Network Test (ANT)

Reaction time to stimulus (central fish) appearing on screen, mouse button is pressed and time recorded.; Accuracy (AC) = Centre / Double / No total correct out of a possible 12; Down & Up total correct from a possible 6. Accuracy is whether correct mouse button is pressed (in response to direction fish is facing). Children were n=62 mean age 6.1 SD 0.2 participants of the LEAPFROG pilot study. Congruent – fish all pointing in the same direction; incongruent – middle fish pointing the opposite way from the others; Neutral only one fish. The warnings are stars that appear before stimulus onset – either a single in the centre, 2 (double) at top and bottom, none 'no' or down (bottom) up (top).