An examination of neuro-cognitive functioning and its relationship with physical activity intensity levels and cardiovascular fitness, and the importance of a holistic approach to the development and education of a child

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Honesty Statement

I hereby certify that this material, which I now submit for assessment on the of study leading to the award of M.Sc. is entirely my own work, that I have exercised reasonable care to ensure that work is original, and does not, to the best of my knowledge, breach any law of copyright, and has not been taken from work of others save and to the extent that such work has been cited and acknowledge within the text of my work.

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List of Abbreviations

AA = Academic Achievement

ACSM = American College of Sports Medicine

AST = Attention Switching Task

ATT = Attention

BDNF = Brain Derived Neurotrophic Factor

BMI = Body Mass Index

CANTAB = Cambridge Neuropsychological Test Automated Battery

CF = Cognitive Flexibility

CFI = Confirmatory Fit Index

CVF = Cardiovascular Fitness

DCU = Dublin City University

DOH = Department of Health

EF = Executive Function

ERP = Event Related Potential

fMRI = Functional Magnetic Reasoning Imaging

HEA = Higher Education Authority

HW = Health and Wellbeing

LPA = Light Physical Activity

MPA = Moderate Physical Activity

MVPA = Moderate-Vigorous Physical Activity

NCCA = National Council for Curriculum and Assessment

NCF = Neuro-Cognitive Function

NFI = Normed Fit Index

NNFI = Non-Normed Fit Index

PA = Physical Activity

PFC = Pre-Frontal Cortex

QOL = Quality of Life

RTI = Reaction Time Task

RVP = Rapid Visual Performance Task

RMSEA = Root Mean Square Error of Approximation

SED = Sedentary

SEM = Standard Equation Modelling

SWM = Spatial Working Memory

SPSS = Statistical Packages for the Social Sciences

TLI = Tucker Lewis Index

USDHHS = United States Department of Health and Human Services

VPA = Vigorous Physical Activity

WHO = World Health Organization

WM = Working Memory

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Abstract

Introduction: It is reported that regular physical activity (PA) is linked to increased neuro-cognitive function (NCF) in children, with moderate-vigorous physical activity (MVPA) showing the most benefits (Syvaoja et al. 2015). What remains unclear is i) which elements of cognition, are affected by exercise intensities in healthy youth and ii) what model could demonstrate the importance of a holistic approach to the development and education of an individual.

Purpose: The aim of the study was to examine the association between NCF with PA, Cardiovascular Fitness (CVF), and psychological determinants in Irish youth mean age 12.25 years, at a crucial time point in their development. Specific attention was given to identifying whether a specific level of PA contributes to efficient NCF, while also investigating a potential model to demonstrate the importance of a holistic approach to the development and education of an individual.

Methods: Information was gathered on participants (n = 262) levels of PA (Actigraph Accelerometer GT1M, GT3X, or GT3X+), CV (20m progressive shuttle run test), NCF (Reaction time (RTI) Attention (AST), Working Memory (SWM), Cognitive Flexibility (RVP) and Executive Functioning), health and wellbeing (KIDSCREEN 27) and academic achievement (AA).

Results: This study reported that Light PA, Moderate PA, MVPA, Vigorous PA and CVF associated with NCF. A model of all variables was developed to demonstrate the importance of a holistic approach to child development. Path analysis (AMOS 21) demonstrated a good fit for this proposed model (NFI = .863, TLI = .998, CFI = .996 and RMSEA = .007).

Conclusion: Preliminary findings suggest that performance in NCF tasks are associated with specific PA intensity levels and CVF. The statistical significance of

the proposed model highlights the importance of a holistic approach in the development and education of an individual.

Future Recommendations: A longitudinal study is warranted to monitor and evaluate the development of NCF and the proposed model in preadolescence as they progress through to adolescence years. Adolescence is a time where a lot of change occurs with potential effects on NCF development. Research is needed on the effect of pre-and-post PA on NCF. This thesis along with previous research has demonstrated that there is a relationship between PA intensity levels, CVF and NCF.

Chapter One: Introduction

1.1 Introduction

Cognition can be defined as the mental action or process of acquiring knowledge and understanding through thought, experience and the senses (Matlin 2005). It can be influenced by a wide range of variables. There has been substantial interest in the association between PA and cognition. It is important to determine what components of both cognitive functioning and PA are affected or will affect the other. Booth et al (2013) have found that the greatest benefits of PA for children have been found for working memory, inhibition and attention. Cognitive skills are closely linked, and have been shown to influence academic achievement results (Finn et al. 2014). The term wellness or well-being is a holistic concept that explains a state of positive health in the individual and encompassing physical, social and psychological well-being (Bouchard et al. 2007). Health related quality of life refers to *the quality of one's personal and mental health and the ability to react to factors in the physical and social environments* (Bouchard et al. 2007, p18). Research has shown that PA has the potential to boost wellbeing and improve mood (Bushman 2017; McKenna & Riddoch 2003). It is extremely important to consider the interaction of all variables mentioned above in the health and development of a child (UNESCO 2014). In order to achieve this understanding an holistic approach is required.

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1.2 Justification of study

There has been an historical assumption that body and mind are two separate entities (Randell et al. 2016). In contrast to this, the World Health Organization (WHO) definition of health: *"A state of complete physical, mental and social well-being"* encapsulates the holistic meaning of the term 'health' (Randell et al. 2016). A healthy body equals a healthy mind, refers not only to physical health, mental health or well-being but also to general cognitive functioning. Cognitive functioning can be defined as a combination of three elements: intelligence, cognitive skills of concentration and attention and also academic achievement (Biddle & Assare 2011, p9). The way in which these three elements interact will lead to the formation of an individual's mental health and well-being status (Lubans et al. 2016).

There has been a distinct lack of research focus on the holistic health of Irish children. Late childhood (pre-adolescence) is a period where key changes in cognition, behaviour, physical activity, and overall health, including growth and maturation occur (Blakemore & Choudhoury 2006). Children begin to think and process information in different ways. They become more self-reflective than their younger selves, think in a more strategic manner and develop the capacity to hold multidimensional concepts (Blakemore & Choudhoury 2006). According to Carson et al. (2015), children at this age (11-12years) should begin to acquire and develop the ability to regulate their attention, thoughts, actions and emotions, and on occasion, suppress a dominant response to produce a more appropriate alternative.

In recent years, several important determinants of mental and cognitive health have been recognised: physical activity intensity levels (Moderate Vigorous Physical Activity - MVPA), cardiovascular fitness, motor skill proficiency, fitness and duration of exercise (aerobic vs anaerobic) (Breslin et al. 2017; Geertson et al. 2016; Lubans et al. 2016; Vanhelst et al. 2016; Marchetti et al. 2015; Tomporowski et al. 2015; Diamond, 2015; Pontifex et al. 2009 & Hillman et al. 2005). Those determinants play an important role through childhood and adolescence (Carson et al. 2015). Regular PA is linked to increased cognitive/executive functioning in both adults and children (Domazat et al. 2016), with MVPA showing the most benefits (Syvoaja et al. 2015). What remains unclear is which elements of cognitive functioning are specifically effected by specific PA intensity levels in Irish youth.

1.3 Aims and Objectives of the study

Aim: To examine the relationship between NCF, PA and CVF and propose a potential model highlighting the importance of a holistic approach to the development and education of an individual.

Objectives:

1. To collect data on NCF, PA intensity levels, CVF, HW and AA of preadolescent Irish youth.
2. To identify what specific PA intensity levels i.e. time spent in sedentary (SED), light (LPA), moderate (MPA), vigorous (VPA) and MVPA and VO2 max scores are associated with components of NCF.
3. To highlight the relationship between NCF and AA.
4. To highlight the relationship between NCF and HW.
5. Propose a model to highlight the importance of a holistic approach in the development and education of an individual.

1.4 Research Questions

1. What PA intensity level(s) demonstrates a relationship with NCF?
2. Is CVF associated with NCF?
3. Is there a relationship between NCF and HW and AA?
4. What variables are essential in a model to demonstrate the importance of a holistic approach to the development and education of a child?
5. How important is the inclusion of these variables in a holistic approach for the development and education of child?

Chapter 2: Review of Literature

The aim of this literature review is to examine the relationship between neuro-cognitive function (NCF) and physical activity (PA) intensity levels and cardiovascular fitness (CVF) in preadolescence, and the importance of a holistic approach to the development and education in an individual.

2.1 Neuro-Cognition

This section will aim to give an overview of what neuro-cognition is, the four main components of cognition and how cognition develops through the lifespan.

2.1.1 What is Cognition?

Cognition can be defined as the mental action or process of acquiring knowledge and understanding through thought, experience and the senses (Matlin 2005). In recent years, cognition and neuro-cognition have seen an increasing overlap in research. This has resulted in a new term being coined,' Cognitive Sciences'; the scientific study of thought, language and the brain (Ashcraft 2002). Neuro-cognition is any form of cognition associated with the functioning of one or more specific areas of the brain. It is the neuroscience of cognition (Matlin 2005; Ashcraft 2002). Cognitive neuroscience is the developing of methods that enable us to understand the neural basis of cognition (Anderson 2015). In order to understand how the brain and cognition relate we must look at the structure of the brain. The basic building block of the brain is the neuron. A neuron, is a cell that is specialized for receiving and transmitting a neural impulse (Ashcraft 2002). It is these building blocks that are found in all brain structures (Kolb & Whishaw 1996). Kolb & Whishaw (1996) estimate that the majority of these cells are directly involved in information and cognition. Research in neuro-cognition focuses primarily on the spinal cord and brain, in particular the top layer of the brain, the cerebral cortex, which is responsible for higher level mental process (Ashcraft 2002).

The cerebrum or cortex is the largest part of the brain that is associated with cognitive function. The cerebral cortex is divided into sections called lobes; the frontal lobe, the parietal lobe, the occipital lobe and the temporal lobe. The frontal lobe is associated with executive function, reasoning, planning, speech, movement, emotions and problem solving. The parietal lobe is linked with attention, movement, orientation, reading, calculation, recognition and perception of stimuli. The occipital lobe is associated with vision and visual processing. Finally, the temporal lobe is linked with perception, recognition of auditory stimuli, memory and speech. Table 2.1 below illustrates the cognitive domain, sub domain, and tests that will be used to assess cognition in this thesis, and the part of the brain that is associated with cognitive function (Filley 2011). It can be noted that some sub domains such as response inhibition have been omitted from this thesis and Table 2.1 as they were not relevant to this thesis

Table 2.1: Brain Structures and Functions.

Cognitive Domain	**Sub-cognitive domain**	**Associated part of brain**	**Cambridge Cognition CANTAB test**
Attention	Continuous performance and visual sustained attention.	Frontal, parietal and occipital lobe	Rapid Visual Information Processing test (RVP) (p58).
	Reaction time and movement.	Frontal lobe	Reaction Time test (RTI) (p56)
Working Memory	Retention of spatial information and manipulation of it in working memory.	Frontal lobe	Spatial Working Memory test (SWM) (p59)*.
Cognitive Flexibility	The ability to transition between different concepts.	Frontal lobe	Attention Switching Task (AST) (p57).
Executive Function	Comprises of high level thinking and decision making	Frontal lobe – Pre Frontal Cortex	Spatial Working Memory test (SWM) (p59)*.

*Note: SWM test was chosen to assess working memory and executive function as the SWM task has notable executive function demands as well as assessing spatial working memory ability.

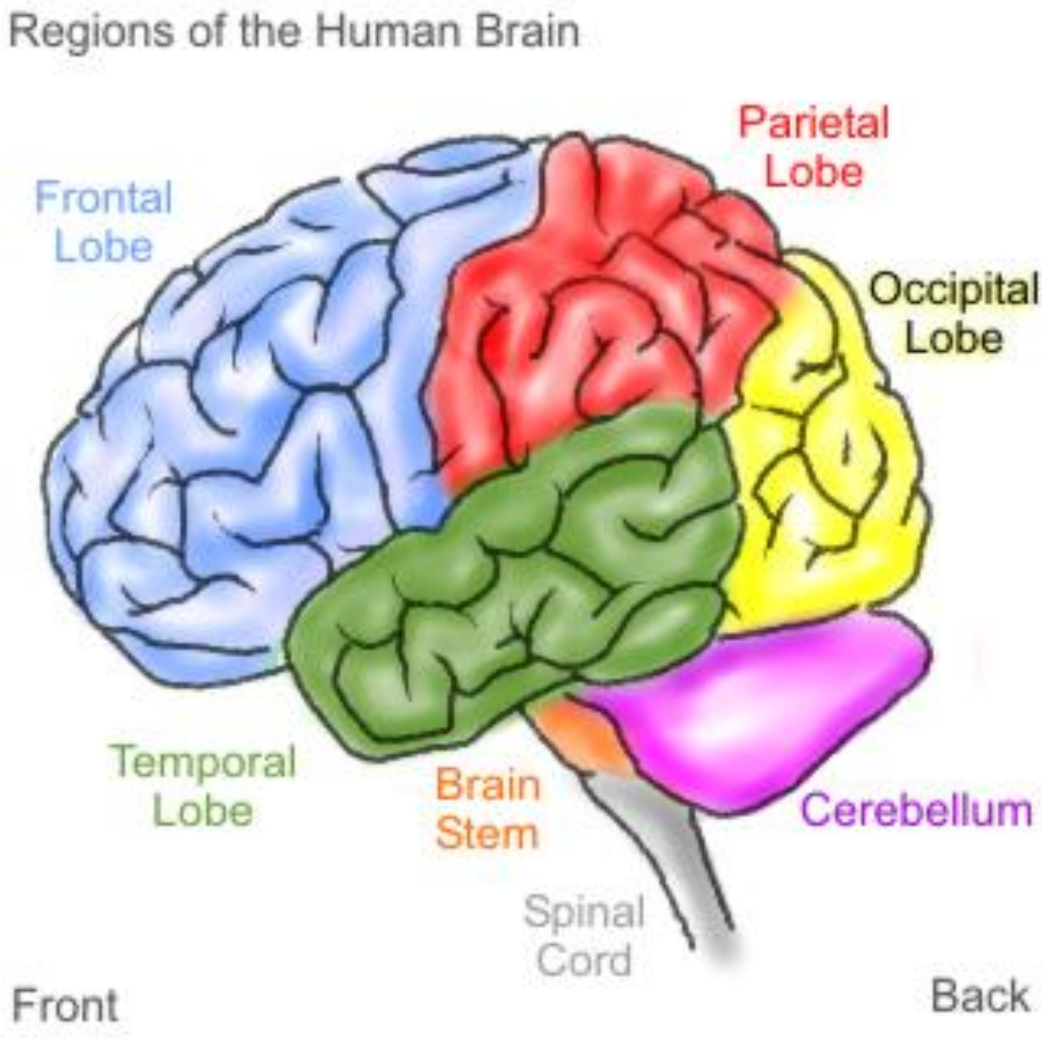


Figure 2.1: Regions of the Human Brain (Cambridge Cognition 2015).

2.1.2 The Cognition Family

When you ask the question what happens exactly in your brain? Do you simply just answer the question? Is there a train of thought? Do you need to retrieve information from your memory? What was your attention span during this process? Were you aware of every single mental process that occurred in your brain? By asking ourselves these questions we quickly realize that cognition and neuro-cognitive functioning encompasses a wide variety of higher mental processes. The term neuro-cognition or cognitive functioning is simply an umbrella term.

Figure 2.2 below illustrates the diversity of the 'cognition family'. Sachdev et al. (2014) defined six principal domains for cognitive functions; perceptual-motor function, language, learning and memory, social cognition, complex attention and executive function, each with sub domains.

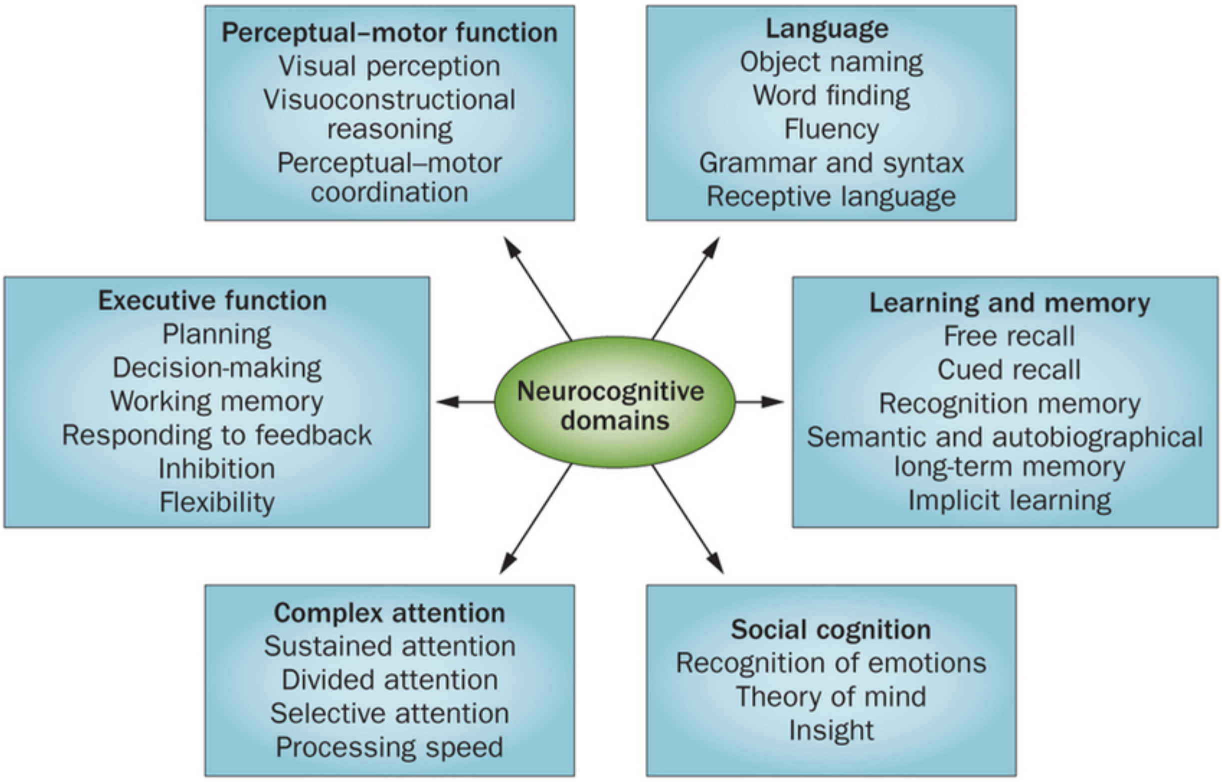


Figure 2.2: The Cognition Family. Neuro-cognitive domains and sub domains (Sachdev et al. 2014).

All components in the cognition family are vital in the input, processing and output of information. There are four core components that are important in the development of a child, through adolescence and into adulthood (Diamond 2013; Munakata et al. 2012; Casey et al. 2008 & APA 2002). These are the components that give children the ability to pay attention, retain and manipulate information appropriately, process information and respond quickly and accurately and alternate between task conditions (Davidson et al. 2006). This thesis will, therefore, focus on the sub domains of (i) attention, (ii) working memory, (iii) flexibility and (iv) executive function during a critical period of development as children transition from childhood to adolescence. Working memory and flexibility are treated as separate constructs to executive function as the researcher aimed to examine specific aspects of cognition. Almost all executive function models do in fact include working memory and flexibility as sub components and not separate.

2.1.2.1 Attention

The attention system consists of three basic neural networks (Posner 1990). The first, the alerting network, which targets the brain stem arousal systems along with the right hemisphere systems associated with sustained attention (Peterson & Posner 2012). Since Posner's original article on attentional system in 1990 there has been increasing emphasis on creating and maintaining optimal attention and performance during tasks. To study the alerting network, one could induce a change to alertness. The warning cue would replace the resting state with a new state involving the preparation for detecting and responding to an expected signal (Peterson & Posner 2012). If a fast response is required to the target, the reaction time will improve following the warning, however the improvement is not due to receiving more information about the target but rather the warning signal will change the speed of orienting attention and therefore responding to the signal (Peterson & Posner 2012). Peterson & Posner (2012) discuss other methods in relation to examining alertness. One such example is the change of circadian rhythm over the course of the day. Reaction times are longer in the early morning and decline as the day progresses, they will rise again during the night and peak again come morning (Peterson & Posner 2012). Attention tasks rely heavily on the mechanisms of the right cerebral cortex. The second, the orienting network, was centered around the parietal cortex (Posner 1990). The parietal areas (Peterson & Posner 2012) have now also become associated with forms of processing. Finally, the executive network, which involves the frontal/anterior cingulate cortex (Posner 1990).

Attention can have a multitude and variety of meanings, for example, to pay attention, to grab attention, to sustain attention, to focus your attention on only element at a specific moment in time, to lose attention due to fatigue or boredom. Attention can be seen as both a mental process and resource. By referring to it as a mental process we see it as a way of concentrating on a mental effort or process. For example; examining a picture or a paragraph of text. Ashcraft (2002) describes attention as limited mental resource and refers to it as being the driving force behind the cognitive system, to make it operate sufficiently.

Attention can be broken into two sections. The first Input Attention consists of alertness or arousal, orienting reflex or response and spotlight attention. The processes named under input attention are involved in the basic process of getting sensory information into the cognitive system. The second section, controlled attention, consists of selective attention, mental resources and conscious processing and supervisory attentional system

(Peterson & Posner 2012). The processes involved with controlled attention on the other hand refer to forms of processing in which there is a deliberate, voluntary allocation of mental effort or concentration i.e. you decide to pay attention to something which requires mental effort and energy on your part. Children and adolescents are often confronted with much more information than they can process or pay attention too. They can only pay attention to so much at any one time. Some task will require little attention and with practice some tasks will become less and less demanding on our attentional processes (Ashcraft 2002). Attention can be broken down into four simple categories (Figure 2.3); sustained attention, selective attention, alternating attention and divided attention.

Input Attention

Input attention is the process involved in getting information from the environment into the cognitive system (Ashcraft 2002).

Explicit processing, which falls under the category of input attention refers to the processes that are involved in conscious processing, conscious awareness that a task is being performed and the corresponding outcome of that performance. Implicit processing is the opposite of this, referring to processing with no necessary involvement of conscious awareness. These types of input attentional processes can be linked with both short term and long-term memory e.g. when trying to pay attention to a list of words you are trying to remember.

Another attention process that falls under the category of input attention is orienting reflex or response. This is something which grabs your attention unexpectedly towards a stimulus which you weren't originally paying attention to. This reflex or response can be strongly linked to the nervous system. The body is triggered to react to the stimulus and locate it, therefore enabling you to protect yourself if necessary.

The final attentional process that falls under the category of input attention is, spotlight attention and visual search. It is a type of visual attention. In contrast to the orienting reflex where your whole body responded to a stimulus, spotlight attention has no movement of the body or eyes (Styles 1990). There is a mental shift of attentional focus. It prepares you to encode stimulus information. The orienting reflex is a response to an unexpected stimulus, spotlight attention is cognitive, a mental process (Styles 1990).

In summary, input attention is involved in how we process the information we pay attention too. For example, processing a list of words we are trying to sustain our attention and remember them as part of the working memory system. This is important in the development and life of a child as they learn content set by their teachers in school (Stevens & Bavelier 2012).

Controlled Attention

Controlled attention, a voluntary mental or cognitive process where an individual will make mental effort to focus or pay attention.

The first attentional process that falls under this section is selective attention. It is the ability to attend or be selective to one source of information while ignoring or excluding other ongoing messages around us. Selective attention requires an individual to respond to certain fragments of information whilst ignoring others (Styles. 2005; Matlin,.2005). Scheider (1999)), discuss selective attention in terms of a 'bottleneck'. Individuals will have the ability to give preference to certain stimuli at the expense of another stimulus in order to pass through the 'bottleneck' easily. For example, children or adolescents focusing on a task set by a teacher in a classroom environment, attempting to ignore all other stimuli around them. This is a constant process undertaken by students and is vital to their learning and their ability to absorb information taught to them by teachers (Stevens & Bavelier 2012). Alternating attention involves the ability to alternate or switch between two tasks simultaneously (Styles 2005). The final category of attention, divided attention is the ability to pay attention to two or more tasks concurrently (Matlin 2005). Sustained attention refers to the ability to hold your attention on a specific task for a certain time period (Styles 2005; Johnson, cited in, Gazziniga 1995).

In summary, controlled attention is ability to pay attention, to sustain attention to something whereas input attention is concerned with process of getting information that we have attended to from the environment and into the cognitive system.

Summary

The ability to concentrate and sustain attention, particularly as a child can often be challenging (Luque-Casado et al. 2015). Children are easily distracted by other objects in their environment (Kohl & Cook 2013). Children and adolescents are often confronted with much more information than they can process or pay attention too. They can only pay attention to so much at any one time (Dye & Bavelier 2010). Their ability to sustain attention, react appropriately and process information that they are attending to can often be influenced by other factors, such as their fitness, physical activity intensity levels and relationships with family, friends, teachers and school life (Best 2010; Geertsen et al. 2016 & Awartani et al. 2008). A poor attention capacity could also negatively influence aspects of their life such as academic achievement in school (Engel de Abreu et al. 2014 & Anobile et al. 2013). For this reason, this thesis will examine the efficient functioning of sustained attentional processes within the cognitive system at a critical time point in a child's development.

2.1.2.2 Working Memory

Cognitive neuroscience is the study of thoughts and processes within the structures of the brain (Anderson 2015). The connections among neurons are capable of changing in response to experiences and perceptions (Anderson 2015). Anderson maintains that it is this neural plasticity that provides the basis for memory. There are two regions within the brain that are predominately responsible for memory. Firstly, there is a region within the temporal cortex that includes the hippocampus. It is the hippocampus and surrounding structures that play an important role in the storage of new memories (Anderson 2015). Secondly, the prefrontal brain regions are strongly associated with both the encoding of new memories and the retrieval of old memories (Anderson 2015). Verbal material is associated with the left hemisphere of the brain and pictorial material is associated with the right hemisphere of the brain (Anderson 2015). Neuroscience research has shown the that human memory depends heavily on frontal structures of the brain for the formation and retrieval of memories and temporal structures for the permanent storage of these memories (Anderson 2015).

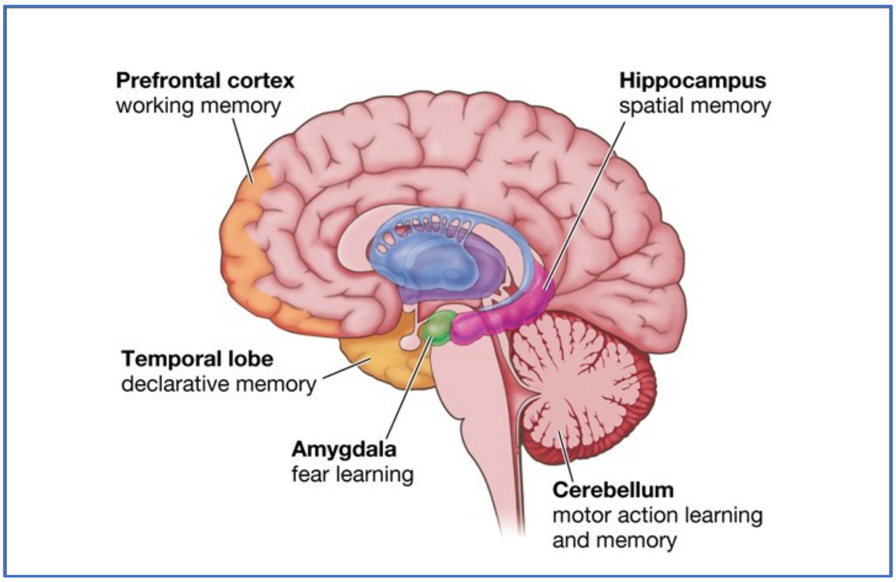


Figure 2.3: Brain structures involved in memory (Gazzaniga, 2010).

Human memory is a system for storing and retrieving information that has been acquired through our senses (Baddely 1999). However, memory is not just one system in the body but it consists of multiple memory systems (Baddeley 1999); primary memory, elementary memory, immediate memory, short term memory, short term store, temporary memory, long-term memory, supervisory attention system and working memory (WM). Baddeley (1999) maintains that WM is essential for making sense for anything that takes place over time. Elements of cognitive functioning e.g. reasoning would not be possible without WM. Diamond (2013) gives a detailed account of WM and its importance in optimum cognitive functioning in an individual. Diamond (2013) further argues that WM is crucial to our ability to see connections between ostensibly unrelated things and to pull apart and reassemble elements promoting creativity in the brain. WM also allows us to remember past events and future hopes to plan and makes decisions, its draws on both conceptual and perceptual knowledge (Diamond 2013).

An individual will store different types of information in different ways. Vision and hearing appear to have a temporary storage stage, this is often referred to as short-term memory (STM). Sights and sounds will be associated with long term memory (LTM) (Baddeley 1999).

The term WM usually refers to the mental workplace, the conscious attentional system where cognitive effort is expended (Ashcraft 2002). Baddeley & Hitch (1974) define WM as the ability to maintain and manipulate material in the mind. For example; if a student was to retrieve words from their long-term memory to define a term in science, it is the WM component that ultimately puts things together. The WM component is like the classroom, it is an action packed, busy place where mental activity occurs.

Marchetti et al (2015) describes memory as an umbrella term incorporating several aspects of retention and recall of information. Baddeley & Hitch (1974) proposed a WM system with three complex components (Fig. 6); the central executive system which is assisted by two slave systems, the phonological loop (verbal/auditory) and visuospatial sketch pad (non-verbal) (Ashcraft, 2002).

The Central Executive

The central executive system as proposed by in Baddeley's 1984 model is the heart of the WM system. It is like a CEO or principal of a school who oversees all planning, initiating activities and making decisions (Ashcraft 2002). The central executive is responsible for planning future actions, language comprehension, reasoning, storage and retrieval of operations involving long term memory, initiating retrieval and decision processes when needed and integrating information coming into the system (Ashcraft 2002). For example; in a math's class, students would be asked to calculate a simple multiplication equation. It is this central executive system that arouses the problem-solving rule i.e. how to multiply.

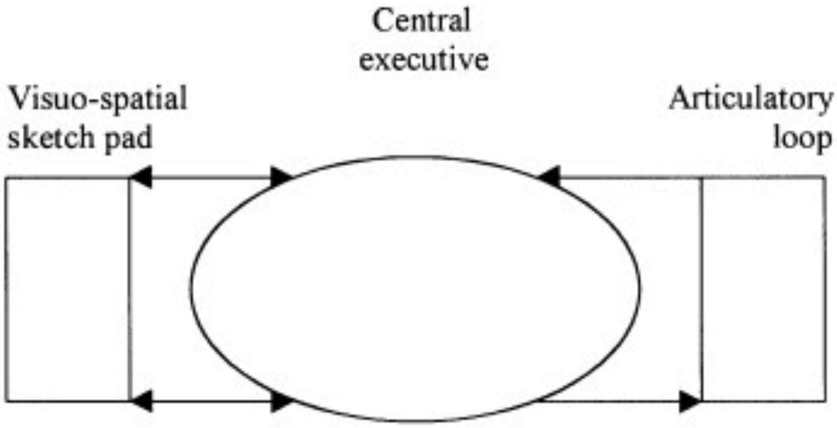


Figure 2.4: Simplified version of Baddeley's (1984) working memory model.

The systems that assist the central executive system are the phonological loop and the visuo-spatial sketchpad.

The phonological loop

The phonological loop is responsible for the rehearsal of verbal information, phonological processing and memory span performance. It consists of the phonological store and the articulatory control process. It recycles information for immediate recall, including formulating the information for auditory rehearsal or expression (Ashcraft 2002). Baddeley (1999) explains that memory traces within the phonological store are assumed to become irretrievable after one and half to two seconds. However, the memory trace can be refreshed by a process of reading off the trace into the articulatory control process which then feeds back into the store (Baddeley 2000). The articulatory control process is also efficient in taking written material, converting it into a phonological code and registering it in the phonological store (Baddeley 2000). The phonological loop plays and important role in learning, language comprehension, long term learning and acquiring vocabulary (Baddeley 2000).

The visuo-spatial loop

Where the phonological loop is considered responsible for verbal information, the visuo-spatial loop is responsible for visual and spatial information and the holding or maintaining of this information (Ashcraft 2002; Baddeley 1999). For example; in a classroom setting, the teacher asks the student to remember a set of words, terms or phrases that they display on a board or in a book for immediate recall, it is the phonological loop that holds this information and if you need to generate and hold a visual image for further processing, it is the visuo-spatial sketch pad that does this. The visuo-spatial loop can be fed directly through perception or indirectly through the generation of a visual image (Baddeley 1999). This system appears to be responsible for the setting up and use of visual imagery memories but not for the imageability effect in long term verbal memory (Baddeley 1999). The visuo spatial loop consists of; (1) the visual cache, which stores information relating to colour and visual form, and (2) the inner scribe which rehearses information from the visual cache and transfers this information to the central executive (Baddeley 1999). The inner scribe also has additional functions such as; dealing with spatial and movement information, and the planning and execution of body movements (Baddeley 1999). The visuo-spatial loop is important for geographical orientation, e.g. finding your way around a new building and for planning spatial tasks, e.g. packing a bag/box and using a mirror to brush your hair.

If we take a closer look at Baddeley's current working memory model (Fig. 2.6), we can see the addition of two components; the episodic buffer and long-term memory. The central executive incorporates all information from the visuospatial sketchpad, episodic buffer, phonological loop and long-term memory.

The episodic buffer

The episodic buffer was not part of Baddeley's original model as seen in Fig. 2.5. It was a much later addition to the model. The purpose of the episodic buffer is to temporarily integrate information obtained from the phonological loop, visuospatial sketchpad and long-term memory (Baddeley 2000). The episodic buffer is controlled by the central executive, however if transfers information into and out of the long-term memory store. The current model differs from the old in that it now focuses attention on the processes of integrating information rather than on the isolation of subsystems (Badeley 2000). The addition of the episodic buffer allowed a cleared connection to be made between working memory and long-term memory.

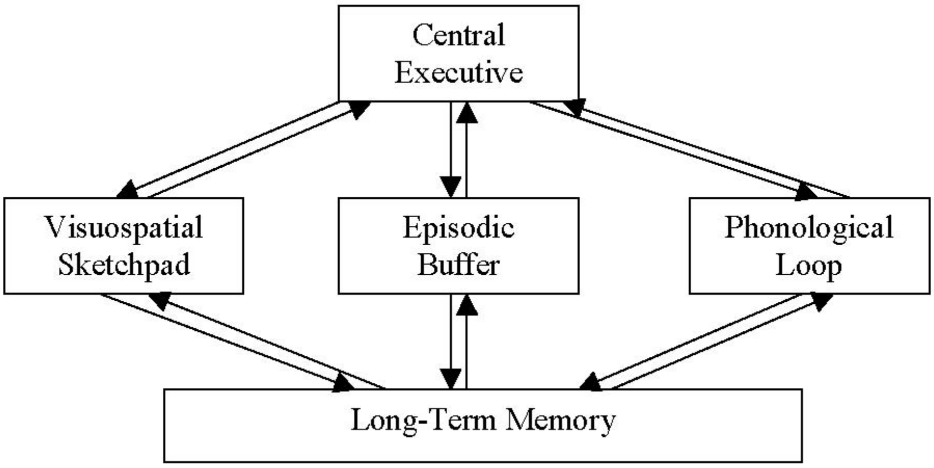


Figure 2.5: Current version of Baddeley's working memory model.

Ashcraft (2002) discusses certain limitations to both the phonological loop and visuo-spatial sketch pad. Both systems are responsible for low level information processing and storage. It is the central executive that deals with higher level processing such as language comprehension and reasoning. The phonological loop and visuo-sketchpad are also domain specific i.e. visual and spatial based respectively. The central executive on the other hand can deal with a variety of information types and processes. If both the phonological loop and visuo-spatial sketchpad are over worked they must pull resources from the central executive. This give and take relationship is referred to by Baddeley as the dual task method. The dual task method operates in such a way by identifying a primary task, and then a secondary task that can be run in conjunction with the primary task. When two tasks are performed in conjunction with one another, they will either be dependent, independent or show some form of intermediate dependency on each other (Ashcraft 2002). If they don't rely on each other we assume they rely on different mental processes or resources. If one task is seen to disrupt the other, then it can be assumed that they rely on the same mental resource. When this occurs, the task being performed by the central executive usually suffers in terms of speed and accuracy (Hubber et al. 2014). WM one of the main core processes associated with cognitive functioning, alongside cognitive flexibility and attention (Pindus et al. 2015). Memory storage is a cognitive function that is involved in learning and is therefore crucial to physical and social functioning and essential for children to cope with academics and general life demands (Sibley & Beilock 2007).

Summary

This thesis will focus on the function of the visuo-spatial sketch pad in particular. This element of working memory is responsible for the retention and manipulation of visual spatial information. More and more, education and learning in the classroom is becoming more visual and less 'text book' orientated. This results in children learning more from visual learning resources. The ability to retain and manipulate this information in their memory will affect this process. The ability to sustain attention effectively will influence whether children retain and manipulate any visuospatial information. This thesis will measure they efficient functioning of both of these cognitive functions at a critical time point in a child's development.

2.1.2.3 Cognitive Flexibility

Cognitive Flexibility (CF) is the ability to adapt and switch between mental processes to generate appropriate behavioural responses (Deak & Wiseheart 2015; Dajani & Uddin 2015). Ionescu (2012) defines CF as the ability to change perspectives spatially or interpersonally, which requires us to inhibit previous perspectives and tap into working memory to activate a different perspective. CF can also have referred to or discussed in the context of processes involved shifts in attention (Dajani & Uddin 2015). These processes include: attention switching, attentional set shifting, mental flexibility, set shifting and mental set shifting (Diamond 2013). These mental processes are required to process information, concentrate, pay attention and switch between mental tasks. CF allows the individual to perform competently to separate from a task, re-arrange a new response set, and apply this new response set to the task at hand (Dajani & Uddin 2015).

Before we go any further in our discussion on CF, it is important to understand the terms associated with CF and often used to describe CF.

Set shifting:

Set shifting is a type of lower level CF task. Shifting, according to Dajani & Uddin (2015) and Ionescu (2011) reflects a person's ability to rapidly change from one criterion, rule of task to another when giving a response.

Switch cost:

Both task switching and set shifting give rise to the slowing of response times and reduction in accuracy. This main measure of shifting within CF is switch cost. Switch cost is the deaccelerating of response time and reduction in accuracy, in reconfiguring a mental set, following a switch trial during task switching and set shifting tasks (Dajani & Uddin 2015; Ionescu 2011). Switch costs are believed to occur as a consequence of the time it takes to inhibit the response set of the previous task as well as the time it takes reconfigure ones' response to the new task (Dajani & Uddini 2015).

Task switching:

This is a higher-level CF tasks that implicates shifting between two types of trials where participants (1) alternate between two simple tasks and, (2) duplicate identical tasks (Dajani & Uddin 2015). The ability to have selective attention and to switch between tasks is fundamental to nearly all cognitive tasks and deficits in these processes can have a wide variety of consequences on one's development (Hanania & Smith 2011).

Ionescu (2011) argues that CF is dependent on two kinds of interactions; the interactions of several cognitive mechanisms and the interaction of sensorimotor mechanisms, cognition and context in developmental time. He maintains, like many other leading researchers in this area that flexibility is considered a symbol of human cognition and intelligent behaviour. There are several behaviours which we as individuals undertake daily that are considered 'flexible'; multitasking, novelty generation and flexible problem solving. Fig. 2.8 summarizes the cognitive mechanisms involved in CF.

There are number of mental processes involved in the implementation of efficient CF which are presented below.

1. Salience detection and attention

   Salience detection is the first phase concerning the attention allocation and preceding implementation of flexible responses.

2. Working memory

   Some CF tasks will require the individual to remember a series of rules in order to complete the task. For example, in a CF task develop by Armbruster et al. (2012), participants were required to remember a number or rules with the main objective of using the brighter number presented to them to determine whether the number was (1) odd or even and, (2) less then or greater than five depending on the cue (Dajani & Uddin 2015).

3. Attention

   The attention model, allows for the hypothesis that the CF process can be broken down into goal directed top down processing and a stimulus driven bottom up processing (Dajani & Uddin 2015).

4. Inhibition

   When actions and goals need to be updated, to adapt to new environments, former responses need to be inhibited. Therefore, inhibitory control is a crucial element of CF (Dajani & Uddin 2015).

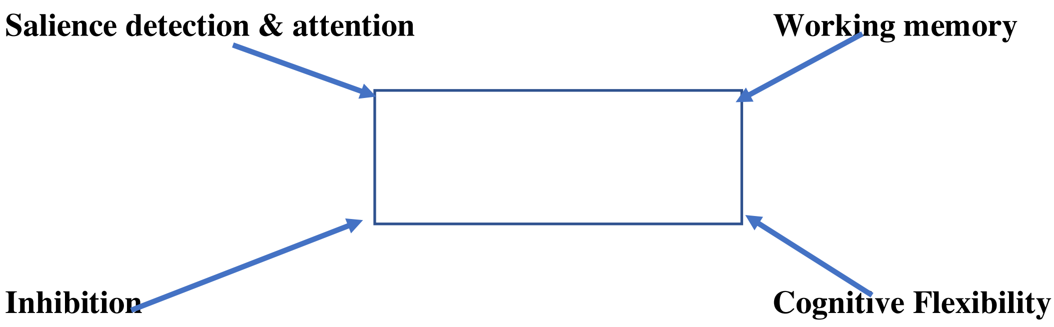


Fig. 2.6: Processes that contribute to the implementation of CF. (Dajani & Uddin 2015).

Diamond's 'all or nothing' principle explains that it easier to switch everything then to switch one thing. For example, in the study conducted by Davidson et al. (2006) hypothesized that it would be easier to inhibit a response all the time in the Dots-Incongruent task then inhibit a response only some of the time in the Mixed Blocks of Dots task. They found that inhibiting response some of the time with minimal memory requirements effected an individuals speed and accuracy of the task negatively.

Summary

Diamond (2013) explains that being cognitively flexible also involves the ability to be flexible, to adjust to changed demands, admit you were wrong, and to take advantage of sudden and unexpected opportunities. CF is critical for everyday language use, requires semantic knowledge (Deak 2003), is vital in today's changing world and is essential for the adaptability and creativity that is needed to see things in new and different ways (Davidson et al. 2006). As children develop and grow through into adolescence and onto adult hood they will encounter situations where they must adapt to a change a task demand and learn to be flexible to changing situations and be mature enough to realize there can often be more than one solution to a situation or problem. In a classroom environment, where much of their learning and development will take place, children are often faced with situations where they may have to adapt to changed demands of task or switch from one subject to another for example English to Music to Irish. The demands of each subject are very different in what they require from the student and will require other cognitive processes such as the ability to sustain attention effectively and the retention and manipulation of visuo-spatial information. This thesis will measure the efficient functioning of cognitive flexibility at a critical time point in a child's development.

2.1.2.4 Executive Function (EF)

Executive functioning is the umbrella term for cognitive processes that regulate, control, and manage other cognitive processes, such as planning, problem solving, organisation, and prioritising. It plays a vital role in the ability of an individual to develop an adaptive response to the environment (Hanania & Smith 2010). The frontal lobe is responsible for much of the EF of the brain, in particular specific areas of the pre-frontal cortex (PFC). These specific areas of the PFC are interconnected with the structure of the midbrain that are associated with emotional reactivity and stress response (Clancy 2016). The mid-brain area can register stimulation very rapidly. This stimulation, according to Clancy (2016) causes an increase in the amount of dopamine and norepinephrine which can enhance executive function or just as quickly hinder it if too much of it is released due to stress, or not enough due to laziness or boredom.

The sheer number of functions that EF provides is exhaustive and will be detailed here briefly. Firstly, Executive control is essential in order to deal with tasks that necessitate us to create a goal, to plan, and to decide between differentiating sequences of behavior to attain this goal, to associate these plans in respect of their probabilities of success and their effectiveness in attaining the selected goal, to commence the plan chosen and to carry it through, alternating it if required, until it is successful or until approaching failure is recognised (Rabbit 1997). From this, the definition of executive function arises; the set of cognitive operations underlying the selection, scheduling, coordination, and monitoring of complex, goal-directing processes involved in perception, memory and action, EF is ultimately the CEO of the brain (Donnelly et al 2016).

EF behaviors can be started and controlled independently of environmental input, and has the ability to recollect the flexibility to salvage plans even when the environment does not behave as planned (Rabbit 1997). Should the rules in a EF task change, as seen in the Cambridge connect AST task, EF will be necessary to grasp from feedback that a change has occurred create and test new plans/rules until successful (Rabbit 1997).

Secondly, EF is essential to start new sequences of behavior and to disrupt other ongoing sequences or responses in order to do so (Rabbit 1997). EF also has the ability and control to inspect involuntary preservation by correctly switching and allocating attention to new sources of information (Rabbit 1997). EF are needed to avoid responses that are unsuitable in context. In addition to this, dual task performance has become a topic of exploration of functions of planning and control (Rabbit 1997). This is achieved by switching from one task to the other, rapidly as their demands fluctuate over time. EF is also required to oversee the performance to detect and correct errors, to alter plans when it becomes clear that they aren't going to succeed, or to recognise prospects for new and more pleasing goals and to create, select among, start and implement new plans to attain them (Rabbit 1997). Finally, EF can enable attention to be maintained over long periods (Rabbit 1997).

Summary

Executive function is the process that underlies the operations of the cognitive system. Executive function is involved in the regulation, control and management of other cognitive processes such as attention, working memory and cognitive flexibility. We know that too much stress, laziness and boredom can inhibit executive function. It is important that educators provide healthy working environments for children (Frankel & Kaplan 2013 & French 2007). This thesis will measure they efficient executive performance at a critical time point in a child's development.

2.1.3 Cognitive development through the lifespan

To understand what is involved in cognitive development we must differentiate between intelligence and cognitive development, as the two are vastly different, something which a lot of individual's mistake. Intelligence can be defined as the ability to acquire knowledge and apply skill, is historically what many believed to be cognitive development i.e. the ability to remember a grocery lists, solve problems or learn new words (Biddle et al. 2011). This definition of intelligence does not deal with the fact that intelligence develops (Bee 2000). Piaget focused on the development structures of cognition rather than intellectual power (Bee 2000). As children grow and develop their thinking becomes much more abstract and complex. Where a five-year-old would struggle to remembers items on a grocery list, an eight-year-old would remember more items from the list and recite as they made their way to the store (Bee 2000).

In order to understand how each of the domains of the cognitive systems develop we must first discuss the foundations of cognitive development and how it applies to children. The foundation of cognitive development is the capability to withhold inappropriate thoughts, promoted by the presence of compelling incentives, in favor of goal directed ones (Casey et al. 2008). This ability to withstand inappropriate thoughts develops throughout childhood and adolescence (Casey et al. 2008). For example, the ability to resist chocolate before dinner, something which many young children will find difficult to do without adult guidance. Several theorists have put forward the idea that cognitive development is not due to an increase in mental capacity but due to an increase in processing speed and efficiency (Casey et al. 2008). Others have discussed the hypothesis of the inhibitory process in relation to cognitive development (Casey et al. 2008). This idea refers to the ability to suppress and control impulses, and this ability appears to mature across childhood and into adolescence (Casey et al. 2008).

From a neuroscience perspective, associations have been found between prefrontal white matter development and cognitive function in children (Casey et al. 2008). Nagy et al. (2004) have both shown positive correlations between the maturation of prefrontal-parietal fiber tracts and working memory in children, but it was only the prefrontal cortex and basal ganglia that were linked with impulse control. Research has also shown that children often recruit different prefrontal regions when performing task than adults (Casey et al. 2008).

The next section will examine how each of the four core domains, attention, working memory, cognitive flexibility and executive function develop from infancy, through childhood into adolescence and finally onto adulthood.

2.1.3.1 Attention

The brain networks that underlie attention are present during infancy and are vital for the developing ability of children and adolescence to control their emotions and thoughts (Posner et al. 2014). The reactive and self-regulatory systems of attention are active during the first years of a childs life (Rueda, Pozuelos & Combita 2015). The orienting network is the dominant neural network during infancy, eventually over taken by the executive function at around three years of age (Posner et al. 2014). The orienting network is in control of selecting the region of space to be focused upon (Redick & Engle 2006). As the child enters their toddler and preschool years, the function of the executive network becomes more dominant, controlling attentional processes and allowing for a more flexible control of attentional resources (Rueda, Pozuelos & Combita 2015). The executive network is important for voluntary control and self-regulation (Posner et al., 2014). During childhood and adulthood, self-regulation is correlated with school performance, physical and mental health, social relationships and income (Posner et al. 2014). As children reach the age of three, they begin to follow instructions and perform reaction time tasks (Rueda, Pozuelos & Combita,2015). Rueda, Pozuelos & Combita (2015) suggest different developmental paths for each attention network. The alerting network takes an early maturation path, whilst the orienting and executive networks display a more prolonged path during childhood.

Research has shown that young children have a lesser ability in the early processing of warning cues compared to 10 – 13 year old's and adults (Rueda, Pozuelos & Combita 2015). Children below the age of nine years displayed poor ability in the process of orienting cues, signifying that they may not yet be able to obtain a full faciliatory effect from valid cues and must there activate the orienting network to a greater level in order to move attention when invalid cases are presented (Rueda, Pozuelos & Combita 2015).

Evidence suggests that increased attentional performance is linked with greater efficiency of information transfer in the brain (Rueda, Pozuelos & Combita 2015). This information transfer is characterized by the contribution of brain nodes and paths connecting those nodes (Rueda, Pozuelos & Combita 2015). During their first year of life, the anterior cingulate shows very small amounts of connectivity to other areas (Rueda, Pozuelos & Combita 2015). As they enter their 2nd year, children begin to develop the long-range connectivity that is typically seen in adults (Rueda, Pozuelos & Combita 2015).

A child's development is often influenced by other factors. One such factor that affects cognitive skills such as attention is parenting and socioeconomic status (Stevens & Bavelier 2012). The parent – child relationship, an element of wellbeing which is discussed in Chapter five, has shown to play a pivotal role in the development of attention during the first years of a child's life (Rueda, Pozuelos & Combita 2015). It has been noted that parents who support their child's autonomy by offering age appropriate problem-solving strategies and provide opportunities to use, help in the development of self-regulatory skills that are involved in attention (Rueda, Pozuelos & Combita 2015), whereas approaches that involve control and intrusiveness can be detrimental to a child's cognitive development (Rueda, Pozuelos & Combita 2015 & Gaetner et al. 2008).

Summary

In summary, elements of the attention system will develop and mature at different rates. The alerting network takes an early maturation path, whilst the orienting and executive networks display a more prolonged path during childhood. Parent child relationships is an important factor in the development of attention. This will be an important point to remember when discussing wellbeing in Chapter five.

2.1.3.2 Working Memory

In terms of the development of memory in an individual, short term memory (STM) will develop earlier and faster than WM (Diamond 2013), mainly because it simply focuses on the input and storage of new information (Ashcraft 2002). The ability to hold information in the mind develops from an early age. In a study conducted by Vuontela et al. (2003) they showed that auditory and visual WM performance improves with age. They also state that visual WM may develop and reach functional maturity earlier then the auditory system. Infants and young children can hold one or two things in their mind at any one time. The ability to hold multiple things or manipulate thoughts develops at a slower rate, with research showing a prolonged developmental progression (Diamond 2013). WM will eventually begin to decline as we age due to a decline in inhibitory control (Diamond 2013).

Lawton & Hatcher (2005) examined gender differences in the integration of visuo-spatial images in short term working memory. Although this study used an adult population sample (mean age 22.85 years) as opposed to a sample of children, the principle and theory behind the results is important. In the study conducted by Lawton & Hatcher (2005) both genders were requested to recall the combined abstract shape that would be generated by combining two separate shapes that would briefly appear on the screen. Males were faster than females, which may suggest that males process visuospatial information faster than women (Lawton & Hatcher 2005). Lawton & Hatcher (2005) proposed that it could be due to the fact the males spend more time playing video games, but this is yet to be explored. Lawton & Hatcher (2005) reported no difference between genders in terms of accuracy. Vuontela, Steenari & Carlson et al. (2003) investigated visuospatial working memory in school children aged 6 – 13 years. They similarly reported that boys were less accurate and made more errors than girls amongst children 6 – 8 years old. Based on these results, they suggest that the maturation of cognitive systems take longer to develop in boys than girls.

Summary

In summary, working memory develops with age, but has different developmental trajectories in males and females. According to Pesce (2010), children with deficits in storage and WM functions will have difficulty with learning and behavior. It is these memory deficits that potentially underlie learning difficulties and poor academic performance in school aged children and adolescents. Pesce (2010) further maintains that memory is central to cognitive development which is thought to be connected to an age-related increase in both storage capacity and the ability to better use available storage capacity. Cognitive development of working memory will be an important consideration in the analysis on cognitive performance in children in this thesis.

2.1.3.3 Cognitive Flexibility

Diamond (2013) maintains that CF builds on inhibition and working memory and comes much later in a child's development. Adults have shown to switch costs immediately after a task switch, whereas children, whom we know have a longer developmental trajectory in terms of CF are more error prone in shifting tasks (Ionescu 2011). In cognitive neuroscience and neuropsychology, cognitive flexibility has mainly been operationalized by sudden and implicit shifts in reward contingencies that have to be detected based on external feedback (Scott, 1962).

CF is one of the most challenging EF as it requires inhibition and working memory to be developed in an individual before the ability to switch back and forth between mental sets is acquired. This is reinforced by Cepeda et al. (2001) who explains that the ability to switch tasks improves during child development and declines again during ageing. Deak & Wiseheart (2015) however argue against this point. Deak & Wiseheart (2015) proposed a hypothesis that flexibility develops as children gain task specific skills and knowledge as opposed to development of generalized EF. For examples scores in reading related tasks would therefore be related to an individual's reading skills. From this proposed hypothesis, it can then be argued that a child's CF could be determined by both a general EF and task or by a domain specific skills and knowledge.

Deak & Wiseheart (2015) conducted research on 3 – 5 year old children and found that task and knowledge specific factors could determine a child's flexibility in each task. They found that response speed, vocabulary size and causal reasoning skills predicted individual and age differences in CF.

To test their hypothesis Deak & Wiseheart (2015) gave preschool children 3 tests of cognitive flexibility representing two types of cognitive skill/domains. They found that response speed was a significant predictor of CF in all three tests. Processing speed has emerged to be a general predictor of higher order cognitive and linguistic processes and fluid intelligence in both young and older children. Deak & Wiseheart concluded that a child's CF is in fact determined by a multitude of factors and processes; processing factors relating to the task type, subtask specific factors, cognitive mediators, including response speed, WM efficiency and a faculty for fluid intelligence.

In a study conducted by Davidson et al. (2006) that examined the development of CF in participants aged between 4 – 13 years. It was found that CF had a long developmental progression, with children even by age 13 they were not performing at adult levels. Many researchers have suggested that the largest increase in development occurs between the age of 3 – 6 years (Deak & Wiseheart 2015), with further improvements after the age of 6 (Vandenbrouke et al. 2016).

Researchers also reported that young children and older adults tend to exercise EF's in response to environmental demands whereas older children and young adults tend to be more planful and anticipatory (Munallata et al. 2012).

Hauser et al. (2015) describes the adolescent period as one which is associated with quickly changing environmental demands which require excellent adaptive skills and high

CF to adjust to the new requirements, to disengage from previous and engage in novel targets. The inability to adjust may cause social exclusion, dropout from school or even psychiatric disorders and it is therefore important for adolescents to possess high CF (Hauser et al. 2015). It was noted that if an individual was not physical, mentally or emotionally fit their ability to be cognitively flexible suffered (Kashdan 2010).

Summary

In summary, development of cognitive flexibility comes much later compared to other NCF in a child's development and depends on working memory and inhibition. The development and efficient functioning of working memory will be important for the development of cognitive flexibility. Development of CF has the longest developmental trajectory of the four cognitive functions (Davidson et al. 2006) discussed in this thesis. Cognitive development of cognitive flexibility will be an important consideration in the analysis on cognitive performance in children in this thesis.

2.1.3.4 Executive function

Cognitive function models initially presented executive function as an adult capacity that reached maturity around puberty (De Luca et al. 2003). Research has since shown that executive function develops in 'spurts' from the age of 12 months, with the majority of executive functions coming to fruition by the age of eight years (De Luca et al. 2003). De Luca et al. (2003) confirmed that, in line with other research, an immature executive function system exists in children as young as 8 – 10 years of age and it matures differentially for different executive functions. This would suggest that executive functions develop at different rates in line with developing brain structures, namely the prefrontal cortex (De Luca et al. 2003). The neural circuit within the prefrontal cortex is essential to executive function (Best 2010). The prefrontal cortex matures late in adolescence. Adolescence is time of great change in individuals. The growth of the brain develops in parallel to the maturity of cognitive functions (Best 2010). The instabilities in performance in executive functions between the ages of 11 – 14 years is thought to mirror the increasing neural capacity and the relative inexperience of adolescence in how to implement and control their new found cognitive skills (De Luca et al. 2003). Assuming the reliability of the cerebral regions, the efficiency and functioning of the executive system improves with age as the cortico-cortical connections develop and mature with age (De Luca et al. 2003). This develop of the cortico-cortical connections allows for the executive function processes to become more comprehensive and flexible in early adulthood (De Luca et al. 2003). Due to the complexity of the executive function processes, executive function will not mature fully until late adolescence or early adulthood (Best 2010). As children progress through adolescence and into early adulthood, they begin to demonstrate greater competence on tasks that evaluate each executive component individually and tasks that require the use of multiple executive function components (Diamond 2006).

Summary

In summary, executive function can still be underdeveloped in children as young as 8 – 10 years of age. Full development may not be reached until adulthood. Different elements of executive function will develop differentially. This will have knock on effects on other cognitive functions such as attention, working memory and cognitive flexibility as executive function is involved in the control, regulation and management of cognitive systems. Cognitive development of executive function will be an important consideration in the analysis on cognitive performance in children in this thesis.

2.1.5 Conclusion

This thesis chose to examine cognitive function in young children as they transition to adolescence and the aim was to develop a greater understanding of how the brain and its corresponding functions develop. There has also been a considerable lack of research done on children in this area. We now know that sustained attention is the ability to hold and control attention on a task or situation and develops as children grow and age. Spatial working memory is the ability to retain and manipulate visuo-spatial information and also develops and improves with age. Cognitive flexibility is the ability to switch attentively and efficiently between tasks and develops with age with the help of working memory. Executive function is involved in the control, regulation and management of the other cognitive processes and matures differently depending on its functions throughout childhood and into adulthood. The efficient functioning of attention, working memory, cognitive flexibility and executive function can be influenced by many other external factors. These factors included but are not limited to physical activity intensity levels, cardiovascular fitness, academic achievement and wellbeing (Breslin et al. 2017; Geertson et al. 2016; Lubans et al. 2016; Vanhelst et al. 2016; Marchetti et al. 2015; Tomporowski et al. 2015; Diamond 2015; Pontifex et al. 2009 & Hillman et al. 2005). These variables were chosen as they all play a big role and are present in a child's life at different time points or all together. These next sections will discuss each of these in relation to cognitive functioning.

2.2 The Brain and Exercise

The term 'exercise' has been used interchangeably in research on the brain, referring to physical activity levels, cardiovascular fitness, bouts of exercise training.

There is a plethora of research that suggests physical exercise training will lead to improve cognitive function (Dupuy, Gauthier, Fraser et al. 2015 & Ploughman 2008), including physiological effects such as increased cerebral blood flow and increased secretion of neurotrophines as a consequence of increasing levels of PA (Dalziel et al. 2015). Acute exercise has been found to promote an immediate neurochemical response that has the ability to enhance cognitive performance whilst chronic exercise will induce morphological changes to brain regions essential to learning (Best, 2010). McMorris et al. (2011) proposed that exercise intensity may positively affect one aspect of the task and negatively affect the other. Ji, Wang, Guo & Zhou (2017) investigated the association between the processes underlying visuospatial working memory and self-reported physical activity on 56 undergraduate students. They reported that PA was positively associated with visuospatial working memory, but interestingly, it was more so associated with rapid cognitive processing during the manipulation stage, with little to no relationship reported between PA and the retention of visuospatial working memory. The exercise-neuro-cognition relationship and the neuro-physiological mechanisms that underlie this relationship has been under constant scrutiny by researchers in recent years, however more in-depth research is needed to understand the effect of specific exercise intensities on neuro-cognition functions in youth (Peruyero, Zapata, Pastor & Cervelló 2017; Harveson et al. 2016; Domazet et al. 2016; Diamond 2015; Chang et al. 2015).

2.2.1 Neuro-cognition and Fitness level

Berchcci et al. 2015 demonstrated a positive relationship between fitness and cognitive processing. In a study involving preadolescence from both genders aged 10 years, Berchcci et al. (2005) reported that the benefits of being aerobically fit appear at the stage of cognitive preparation of a task that involves cognitive control.

Dubuy et al. (2015) demonstrated a positive relationship between fitness and executive function in older adults. They postulated that the cause of this relationship was due to the neurophysiological adaptations in the brain regions controlled by executive function. There are several neurophysiological adaptations that occur in the prefrontal cortex that could contribute to these exercise-cognition relationships (Dubuy et al. 2015). Ploughman (2008) suggested improved cognitive performance in individuals with higher fitness levels is associated with an increase in gray and white volume and an increased hippocampal volume (Colcombe et al. 2003 & Chaddock et al. 2010 cited in Dubuy et al. 2015). However, Donnelly et al. (2016) argued that fitness is selective to specific structures in the basal ganglia as some regions do not demonstrate comparable fitness related variances. They made note that higher fit children demonstrated better performance during a task requiring the alteration of executive function which was mediated by the basal ganglia volume. There has been a considerable lack of research done on this area in children. With cognitive functions at peak development, this would be a very interesting time point to conduct research on the influence of fitness on the functioning of cognitive systems. The relationship between fitness and cognitive function will be discussed in section 2.4.3 of this thesis.

Secondly, cognitive processing in the brain is dependent on sufficient blood flow in order to respond effectively to the energy and oxygen needs of the tissue (Dubuy et al.

2015). This blow flood is facilitated by the cerebral vasculature (Dubuy et al. 2015). The cerebralvascular reserve could be the link between fitness and cognition (Davenport et al. 2012). Higher fit people demonstrate a superior cerebrovascular health and have subsequently shown, through the use of neuroimaging that they have a higher cerebral blood flow at rest and during exercise (Dubuy et al. 2015). Additionally, Hillman, Kamijo and Scudder (2011) & Luque-Casado et al. (2015) reported that highly fit children, demonstrated enhanced distribution of attentional resources towards the task being performed and a heightened planned response at the beginning of the task (Luque-Casado et al. 2015).

2.2.2 Neurobiological mechanisms and exercise

It has been proposed by many researchers that different neurobiological mechanism generated by regular PA, may contribute to the exercise-cognitive relationship (Lubans, Richards, Hillman et al. 2016). Neurotrophins are proteins that have been identified as mediators of neuronal survival and development (Ploughman 2008). Neurotrophins control target genes which may program structural proteins, enzymes or neurotransmitters that lead to the modification of neuronal morphology and function (Ploughman 2008). The increased expression of brain derived neurotrophic factor (BNDF) and insulin-like growth factor-1 as well as structural changes of cortical and subcortical regions contribute to a development of cognitive performance (Mucke et al. 2017). The BNDF has emerged in recent years as the key mediator of synaptic plasticity in the hippocampus, the memory centre of the brain. The ability for synaptic plasticity allows for one to form and train memories and to learn spatially, cognitively and motorically (Ploughman 2008). Low intensity exercise, specifically moderate physical activity, has shown gradual increases in neurotrophin levels in youth whose brains are highly plastic (Ploughman 2008) and susceptible to structural changes in the brain that could result in the enhancement of cognitive performance.

2.2.3 Functional Magnetic Reasoning Imaging (fMRI) and exercise

Functional Magnetic Reasoning Imaging (fMRI) has been using to research the exercise-cognition relationship. fMRI is a type of imaging methods established to detect and demonstrate regional changes in brain metabolism (Ogawa et al. 1990 cited in Glover 2011). fMRI research has shown that fitness and regular participation in PA has an effect on the initiation of the prefrontal cortex and other neural circuits that assist executive control (Khan & Hillman 2014). In particular, Hillman et al. (2005) has demonstrated increases in P3 amplitude located in the fronto-central, central and parietal regions of the brain were observed post exercise in children, mean age 9.6 years. The P3 is an endogenous element of the Event Related Brain Potentials (ERP), part of the neuroelectric system which exhibit patterns of voltage alteration in ongoing neuroelectric activity that happens in response to or in preparation of a stimulus or response (Hillman et al. 2005). The P3 occurs roughly 300 – 800ms after a stimulus begins, which is initiated when participants attend and differentiate between stimuli (Polich, Ladish & Burns 1990 cited in Hillman et al. 2005). The P3 is speculated to guide processes involved in the allocation of attention and working memory resources (Donchin cited in Hillman et al. 2005). Hillman et al. (2005) demonstrated that higher fit children had a greater P3 amplitude and faster P3 latency at the occipital recording site compared to low fit children. Both of these results indicate a large neuron recruitment and faster neurocognitive processing related to the distribution of attention and working memory resources is taking place (Hillman et al. 2005). Brockett et al. (2015) investigated whether running alters running performance on cognitive task that require the prefrontal cortex. They found that running improves performance on cognitive tasks that depend on the prefrontal cortex.

2.2.4 Conclusion

Physical fitness has shown to have positive effects on the brain such as increased cerebral blood flow and increased secretion of neurotrophines as a consequence of increasing levels of PA in children of both genders aged 9 – 10 years (Dalziel et al. 2015). Certain structures of the brain will also be susceptible to the effects of physical fitness level.

Different neurobiological mechanism, such as increased expression of BDNF, generated by regular PA, may contribute to the exercise-cognitive relationship (Lubans, Richards, Hillman et al.,2016). Finally, fMRI research has shown that fitness and regular participation in PA has an effect on the initiation of the prefrontal cortex and other neural circuits that assist executive control (Khan & Hillman 2014). The following sections will review physical activity and physical fitness and their connection with cognition. Chapter four of this thesis will explore the relationships between physical activity, physical fitness and cognitive functions.

2.3 Physical Activity

The term physical activity (PA) refers to any bodily movement produced by skeletal muscles that requires energy expenditure (Bouchard, Blair & Haskell 2007; Casperson, Powell & Christenson 1985 & Donnelly et al. 2016). This section will examine the importance of PA and its relationship with neuro-cognitive functioning. Physical activities in daily life can be broken down into occupational, sports, household, recreational activities and other activities (Casperson et al. 1985). As physical activity covers such as wide range of activities, further definition is required when examining physical activity intensity levels of individuals.

2.3.1 Importance of Physical Activity

It is a renowned fact that PA is associated with a multitude of health benefits (Bouchard et al. 2007). However, if we delve in further, the benefits of PA are more complex. In the majority of the population, physical activity will increase physical fitness which will in turn have a positive effect on health (Bouchard et al. 2007). Being physically active is one of the most essential and easiest habits individuals of all ages can develop in order to improve their overall health (Bushman 2017). The benefits of regular PA extend into many areas in life. Improved body function, physiological, psychological and mental health benefits, relief from symptoms of depression, anxiety and an enhance quality of life

(Bushman 2017 & Mckenna & Ruddoch 2003). Youth who are more active have a greater chance of having a healthy body weight, perform better in school, have a higher self-esteem and improved cognitive functioning (Bushman 2017) and are more likely to be active adults (Woods et al. 2010) There is a decreased likelihood of developing risk factors for heart disease, diabetes and obesity (WHO 2010). More and more evidence is amassing that, those children who are more active are leaner, develop higher peak bone mass and show healthier cardiovascular profiles (Boreham & Riddoch 2001). The US Department of Health and Human Services (2008) draw attention to strong evidence for the health benefits of regular PA for children. These health benefits include; improved cardiorespiratory and muscular fitness, improved bone health, improved cardiovascular and metabolic health biomarkers and favorable body composition (Bushman, 2017). Furthermore, those individuals who are healthier are more inclined to be more physically active and fitter. This highlights the fact that habitual PA can influence fitness, which in turn can alter the level of habitual PA (Bouchard et al. 2007). This shows that the fittest are the most active and the more active you are the fitter you become. This also highlights another reciprocal relationship between fitness and health. PA will influence fitness which influences health which influences PA (Blair & Church 2004). It must be noted however that PA and health aren't the only factors that influence fitness; factors such as genetics, lifestyle, personal attributes, social and physical environment must also be considered (Bouchard et al. 2007).

Being physically active during childhood, has demonstrated favorable health behavioral results in adult hood, that is those that are active young have a greater chance of being active when they are older (Boreham & Riddoch 2001). There is also a chance that that those who are physically active as children will more likely be active as adults (Boreham & Riddoch 2001). Along with the obvious health benefits, PA has been shown to have benefits for cognitive and mental performance. Studies have found that varying levels of PA were positively associated with cognitive function performance (Diamond & Lee 2011). Section 2.3.4 will discuss the of topic cognition and PA intensity levels.

2.3.2 Physical Activity Guidelines

Regular PA during childhood has favorable results on cardiovascular and musculoskeletal health, body composition, bone mineral density, blood lipid levels, blood pressure, mental health, academic performance, classroom behavior (Bushman 2017 & Mckenna & Riddoch 2003). The current Department of Health and Children Guidelines recommend that Irish youth participate in at least 60 minutes of moderate to vigorous physical activity per day in order to acquire the above benefits (WHO 2010; Woods et al. 2010 & Boreham & Riddoch 2001), which should include at least three days of VPA in that same week (USDHHS 2008). The American College of Sports Medicine (2015) recommended that children participate in 30 minutes of VPA per day. The ACSM (2015) add that on top of the aforementioned guideline, that youth should also amass several hours of age appropriate PA of at least moderate intensity exercise per day. Lower intensity PA may also lead to reduced risk of cardiovascular disease (Sibley 2016). As a result, a set of recommendations was introduced for adults; 30 minutes of MPA at least five days per week and 20 minutes of VPA at least three days a week, or a combination of both (USDHSS 2008). Similar guidelines were introduced in Ireland, whereby from 18 years upwards, 30 minutes of MPA is recommended on at least three days of the week (DOH 2009). For additional health benefits, the WHO (2011) further recommend that adults increase their MPA to 300 minutes per week or engage in an equivalent 150 minutes of VPA per week. LPA and MVPA will be discussed in the next section.

2.3.3 Physical Activity Intensity levels

The duration of PA can be expressed in the form of minutes per day, per week, per weekday and per weekend day (Owens et al. 2015). Intensity, according to the WHO, refers to the degree and effort at which the activity is being performed. Expressing the intensity of exercise is often challenging and varied. Some examples include; VO2 max scores, percentage of max heart rate, caloric expenditure, step and accelerometer counts, MET's and perceived exertion (Owens et al. 2015). PA intensity is most often obtained from accelerometry and measured in counts per minute (cpm). Freedson (2005) cut points, used by many researchers in the area of childhood PA patterns, breakdown PA into the following intensity levels using cut points.

Sedentary refers to an inactive lifestyle, one where activities do not increase energy expenditure significantly above the resting level (Pate et al. 2008). Activities that are classed as sedentary include; sleeping, lying down, sitting for large parts of the day, watching TV and playing video/computer games (Dept. of Health & Children 2009 & Pate et al. 2008). A sedentary lifestyle and obesity have been strongly correlated in the United States, with a proven increased risk of heart disease (Bushman 2017). LPA is closely linked and associated with sedentary behavior. LPA involves energy expenditure at the level of 1.6 – 2.9 Metabolic Equivalents (METs) (Pate et al. 2008). Activities include; slow walking and sitting and writing. LPA involves some degree of movement. LPA requires the least amount of activity compared to MPA and VPA.

Moderate PA (MPA) can be defined as any activity that raises your heartbeat and leaves feeling slightly out of breath. A brisk walk or slow jog would be classified as MPA (Dept. of Health & Children 2009). Vigorous PA (VPA) causes to work up a sweat and become out of breath. Activities that are classed as VPA include, sports or exercises such as running (Dept. of Health & Children 2009). It is a combination of both moderate – vigorous PA (MVPA) that is the optimal PA intensity level for both children and adults as it elicits the most physical and health benefits.

MPA has been associated with numerous health benefits. However, it is VPA that has gained attention in recent years (Swain & Franklin 2006 cited in Sibley 2016). It has been noted, that not only will VPA contribute to aerobic capacity but it also does it in a shorter period of time compared to other PA intensities (Owens et al. 2015). Wittmeier et al. (2008) concluded that 45 minutes of MPA would be needed, compared to just 15 minutes of VPA, in order to reduce BMI levels.

VPA has shown clear advantages in terms of improving CVF. It is perhaps something worth noting for future policy makers in Physical Education (Sibley 2016). The fact that VPA can achieve health benefits in a shorter period of time compared to other PA intensity levels, could potential appeal to many schools in terms of implementing a physical education curriculum focused around shorter periods of VPA. This theory is further supported by Steele et al. (2009) who reported that a mere 6.5 minutes of VPA was associated with a reduction in waist circumference compared to 13.6 minutes of MPA.

2.3.4 Physical Activity intensity levels and cognition

There has been substantial interest in the association between PA and cognition. In a meta-analysis study conducted by Sibley & Etnier (2003), they found that there was significant positive relationship between PA and cognitive functioning in youth aged 4 – 18 years. It is important to note that not all domains of cognitive functioning will be associated with PA intensity levels. It is important to determine what components of both cognitive functioning and PA are affected or will affect the other. Booth et al. (2013) have found that the greatest benefits of PA for children have been found for WM, inhibition and attention. A growing body of literature has pointed towards MVPA being the PA intensity level most positively associated with cognitive function in preadolescent youth, showing the most benefits to cognitive performance (Fedewa et al. 2011 & de Greeff et al. 2018).

2.3.4.1 Physical Activity intensity levels and Attention

Attention is one of the most important measures of cognition in children and adolescents (Vanhelst et al. 2016). Attention is indispensable in comprehension and learning. Attention is a behavioral and cognitive process involved in selectively concentrating on one aspect of the environment whilst ignoring others (Vanhelst et al. 2016). Sustained attention is an important function that allows us to focus on specific stimuli over extended periods of time (Ciria et al. 2017). Physical activity intensity levels have made an impact on the performance of attention capacity in children and adolescents (Vanhelst et al. 2016 & Booth et al. 2013). Vanhelst and collegues (2016) demonstrated a positive association between physical activity intensity level and attention capacity in adolescents. In their study, they found that spending more time at certain physical activity intensity levels, namely MPA was associated with improved attention capacity in adolescents. Vanhelst et al. (2016) further postulated that the effect of physical activity on cognition could be due to increased levels of brain derived neurotrophic factor (BDNF). The faster speed of processing could be due to the increased brain concentrations of the neurotransmitters dopamine, norepinephrine and BDNF during MPA (McMorris & Hale 2012). McMorris et al. (2011) explains that, response time is calculated from the introduction of the stimulus to the conclusion of the response. From this we can conclude that this process will not only include a stimulus detection and identification, response selection and preparation and initiation but also on a neuro level it will also involve the transmission of nerve impulses from the premotor cortex and supplementary motor area to the muscles (McMorris et al. 2011). Increases in norepinephrine and dopamine concentrations in the brain as a result of increased participation in the VPA and MVPA and greater neurotransmitter availably resulting in faster response times (McMorris et al. 2011).

Dye & Mathew (2009) reported that children who played video games had faster reaction times in tests for attention. Syvaoja et al. (2014) made an interesting point that some cognitive tests are touch screen based, this would favor children who are accustomed to handling screen based devices on a regular basis. This could be due to the significant recent increase in use of phones, Ipads, laptops both at home and school environment. Children are spending increasing amount of time interacting with screen based technology. Not all screen based sedentary viewing is viewed as having negative impact on children's cognition performance. Aadland et al. (2017) reported associations between time spent in sedentary and working memory in girls only, and cognitive flexibility and executive function in boys only. Syvaoja et al. (2014) also found associations between time spent in sedentary and sustained attention.

It is possible that as more time spent in sedentary would produce positive test scores in cognitive function tests. Some PA intensity levels have shown to induce fatigue and reduce cognitive skills such as attention and working memory ability. Time spent in sedentary and its impact on cognitive function is interesting as it can both result in boredom and lethargy as well as leaving the student rested and ready to attend to tasks involving a range of cognitive skills. This thesis will examine this hypothesis in Chapter four.

2.3.4.2 Physical Activity intensity levels and Working Memory

Research on working memory and its link with exercise has been quite positive. Several studies have found encouraging results when examining the relationship between cognitive functioning and exercise in children. Recent studies have revealed that children with a high aerobic fitness have demonstrated better WM performance (Syvaoja et al. 2014). Several school based interventions have shown that increased physical activity (PA) may improve children's WM. Research has suggested that an acute bout of submaximal exercise, as performed by students in a PE lesson may facilitate memory storage (Pesce 2010). Pesce (2012) discusses as study conducted by Sibley & Beilock (2007) which showed positive and beneficial results of acute bouts of exercise on individuals with a poor baseline WM performance. Lambourne (2006) reported that those (adults aged 19 – 30 years) who participated in vigorous physical activity at least 5 times per week had improved working memory capacity.

The improvements that Booth et al. (2013) found in WM in children can be strongly linked to learning and educational processes as memory is the most basic and fundamental concept required for academic success and general learning (Brown & Minns 1991). Syvaoja et al. (2014) reported a high amount of self-reported use of computer games was associated with weaker performance in WM tests in children with a mean age of 7.2 years. Similar studies have also reported a negative association between sedentary behavior and WM.

Children and not just adults need WM to mentally work with masses of data and to see new connections among different elements in life (Diamond & Lee 2011).

This thesis will examine what PA intensity is associated with WM function in Chapter four.

2.3.4.3 Physical Activity intensity levels and Cognitive Flexibility

Masley et al. (2009) led a study on the older adult population on the effect of exercise on cognitive functioning. It was conducted over a 10-week period where increasing frequency of aerobic activity was shown to be associated with enhanced cognitive performance in particular CF. They concluded that aerobic exercise had a positive effect on neuro-cognition overall. The tests that measure CF that were the most responsive to the aerobic exercise. The reason why these were affected more than memory is due to the location of these central mechanisms, one of which is CF in the prefrontal cortex (Masley et al. 2009). Many studies have linked shifting with exercise. For example, according to Ionescu (2011), he refers to a study conducted by Masley et al. (2009) where they found that aerobic exercise enhances performance in a shifting attention test and concluded that CF improved as a result. Diamond and Lee (2011) also found similar results to Masley et al. (2009) in their research. They established that aerobic running improved 8 – 12 year old's CF and creativity. Interestingly, it was significantly more than the activity of a standard physical education class. In a study conducted by Monti et al. (2012), they reported that children who received the daily physical activity intervention showed improvements for EF task that tapped CF.

This thesis will examine what PA intensity is associated with CF function in Chapter four.

2.3.4.4 Physical Activity intensity levels and Executive Function

Executive function refers to the cognitive processes essential for goal directed cognition and behavior that occurs in children and adolescence (Best 2010). Executive functions are often considered as important prerequisites for effective learning in preadolescent children (Diamond, 2013). Majority of research has focused on the executive function hypothesis (Colcombe & Kramer 2003. Colcombe & Kramer (2003) explain that this hypothesis looks at the effect of MVPA on increasing activity in certain parts of the brain structural network, with a specific focus on improving executive function performance. Based on the results of a meta-analysis study conducted by de Greeff et al. (2018), positive effects have been found on both acute and longitudinal PA programs for cognitive function performance in preadolescent children. It was found that acute PA benefited only attention whilst longitudinal PA programs benefited all cognitive domains. This could potentially indicate that preadolescent children would need to active at a certain PA level over a longitudinal period for executive and other cognitive functions to benefit from. This thesis will look at this possibility. Aadland et al. (2017) argue that even though objectively measured PA is a more accurate estimate of habitual PA is still does not give a full picture of a child's or adolescents' PA behavior.

2.3.5 Conclusion

There have been numerous positive associations among PA and cognition, however there have been many inconsistent findings in relation to specific PA elements, such as type, amount, frequency and cognition and academic achievement (Donnelly et al. 2016). This thesis will look to examine the relationship between PA intensity levels and the four components of cognitive function.

2.4 Cardiovascular Fitness

PA, we now know is associated with movement (Casperson et al. 1985). Physical fitness can be seen as a set of features or abilities that people have or achieve in order to perform muscular work adequately (Casperson et al. 1985 & Bouchard et al. 2007). Being physically fit can be seen as having the ability to perform daily activities with strength and alertness and with sufficient energy to enjoy other aspects of life (President's Council on Physical Fitness and Sport (1971) cited in Casperson et al. 1985).

Fitness can be seen from two points of view: performance and health. Performance related fitness refers to those elements of fitness that are required for optimal athletic performance (Bouchard et al. 2007). Health related fitness on the other hand refers to the element of fitness that are affected positively or negatively by habitual physical activity habits and that relate to health status (Bouchard et al. 2007). Health related fitness can be defined as "an ability to perform daily activities with vigor and by traits and capacities that are associated with a low risk for the development of chronic diseases and premature death" (Pate 1988 cited in Bouchard et al. 2000, p14). Health related fitness is broken down into the following components; cardiorespiratory endurance, muscular endurance, muscular strength, body composition and flexibility (Casperson et al. 1985 & Bouchard et al. 2007). The cardiorespiratory component consists of; submaximal exercise capacity, maximal aerobic power, heart functions, lung functions and blood pressure (Bouchard et al. 2007).

This section of the literature review will primarily focus on submaximal exercise capacity, referred to as cardiovascular fitness hence forth. For the purpose of this study, physical fitness will focus on cardiovascular fitness (CVF). CVF was chosen to represent physical fitness in this thesis, as it is most strongly associated with a health (Boreham & Riddoch 2001). Cardiovascular endurance or aerobic fitness man be defined as the ability to deliver oxygen to the muscles and to utilize this oxygen to generate energy during exercise in a sustained moderate intensity, whole body exercise for a period of time (Armstrong, 2006 & Boreham & Riddoch 2001). VO2 max is widely documented as the best single measure of CVF (Armstrong 2006). VO2 max (maximal oxygen uptake), was first defined back in 1923 by Hill & Lupton, as the oxygen uptake attained during maximal exercise intensity that could not be increased further despite additional increases in exercise workload, thus defining the limits of the cardiorespiratory system. There is a plethora of benefits from children having a high CVF. Not only does it reflect the ability to carry out prolonged periods of PA at a certain intensity level but it also reflects the general capability of the cardiovascular and respiratory systems (Ruiz et al. 2007). CVF is a known direct marker of physiologic status (Ruiz et al. 2007). Twisk, Kemper & Mechelen (2002) reported, now commonly known fact amongst researchers and in parts the general public, that a high VO2max during childhood and adolescence has been correlated highly with a healthier cardiovascular profile during those years of development and also later in life.

2.4.1 Cardiovascular fitness and neuro-cognition

Donnelly et al. (2016) reported that there were only two valid longitudinal studies conducted in recent years exploring baseline measures of fitness and neuro-cognitive functioning in children. Both studies, Chaddock et al. (2012) and Niederer et al. (2011), indicated that higher fitness is better associated with better cognitive performance over a time period.

Ciria et al. (2017) discusses the "cardiovascular hypothesis" which suggests that aerobic exercise leads to measurable gains in cardiorespiratory fitness, resulting in benefits at the cognitive and brain level. Some of these benefits include an increased ability of the heart to deliver oxygen to the working muscles thought to be associated with changes in the cerebral structure, cerebral blood flow and BDNF (Ciria et al. 2017).

2.4.1.1 Cardiovascular Fitness and attention

Cadenas-Sanchez et al. (2017) reported that CVF (measured using FITNESSGRAM 20m shuttle run test) was positively related with attention in adolescents aged between 12.5 – 17.5 years from six European countries. Their study suggested that adolescents who had a higher CVF had a higher attention capacity. Niederer et al. (2011) reported similar results in their study investigating the relationship of CVF on attention in children, mean age 5.2. It has been postulated that the influence of CVF on attention could be due to the relationship between high CVF with a healthier status of neural tissue (Cadenas-Sanchez et al. (2017). This neural tissue is crucial for attentional processes. There is a distinct lack of research in the area of CVF and attention in young children. This thesis will highlight the relationship between both. Hillman et al. (2005) reported that fitness was positively associated with neuroelectric indices of attention in children, mean age 9.6 years. Similar results have been reported in adults aged 18 – 22 years and 61 – 73 years (Pontifex et al. 2009). Pontiex et al. (2009) reported that CVF may be linked with an increased ability to suppress extraneous neural activity to assist attentional processing. Luque-Casado et al. (2015) reported that higher fit adults were better able to sustain attention. Ciria et al. (2017) also reported that higher fit individuals compared to lower fit ones, demonstrated a greater capacity to maintain attention over a period of time.

2.4.1.2 Cardiovascular Fitness and working memory

It has been suggested that the short-term effects of acute bouts of exercise on memory storage may transfer into positive long-term effects for mental health outcomes (Sibley & Beilock 2007). Sibley & Beilock (2007) question whether repeated transient enhancements of memory performance can have a direct impact on structural changes in the brain which in turn would promote mental efficiency among adolescent youth. Scudder et al. (2014) discuss the idea that a high VO2 max reading may be associated with improved WM performance, but it would only become evident with WM demands increase. In a study conducted by Diamond & Lee (2011), they assigned 7-9yr old's to two hours of fitness training daily for the school year, the two hours was broken down into 70 minutes of aerobic work and the remainder given to motor skill development. They found an improvement in WM as a result. Kao et al. (2016) reported that those with a higher level of fitness was linked with a greater performance in working memory tasks. Geertson et al. (2016) also reported a relationship between fitness and working memory in their study. There is a distinct lack of research in the area of CVF and working memory in young children. This thesis will highlight the relationship between both.

2.4.1.3 Cardiovascular Fitness and cognitive flexibility

Masley et al. (2009) led a study on the older adult population on the effect of exercise on cognitive functioning. It was conducted over a 10-week period where increasing frequency of aerobic activity was shown to be associated with enhanced cognitive performance in particular CF. They concluded that aerobic exercise had a positive effect on neuro-cognition. Many studies have linked shifting with exercise. For example, according to Ionescu (2011), he refers to a study conducted by Masley et al. (2009) where they found that aerobic exercise enhances performance in a shifting attention test and concluded that CF improved as a result. Diamond and Lee (2011) also found similar results to Masley et al. (2009) in their research. They established that aerobic running improved 8 – 12 year old's CF and creativity. Interestingly it was significantly more than the activity of a standard physical education class. In a study conducted by Monti et al. (2012), they reported that children who received the daily physical activity intervention showed improvements for EF task that tapped CF. There is a distinct lack of research in the area of CVF and cognitive flexibility in young children. This thesis will highlight the relationship between both.

2.4.1.4 Cardiovascular Fitness and Executive Function

There is a large agreement that cardiovascular fitness is a correlate of executive function (Aadland et al. 2017 & Diamond 2013). This association could be a result of two factors, (1) the increase in neural efficiency in neural processing and changes in brain structure in higher fit children, and (2) the genetic component of aerobic fitness i.e. a child's phenotype may be more important than their participation at a certain PA level when it comes to performance in executive function tasks (Aadland et al. 2017). Best (2010) argues that it could be the extended cognitive and neural development as to why children's' executive function is sensitive to the effects of exercise (Best 2010). Due to the immaturity of executive function and its corresponding neural activity circuit during childhood, executive function could be very susceptible to the influence of exercise on it (Best 2010, McMorris & Hale 2012). There is a distinct lack of research in the area of CVF and executive function in young children. This thesis will highlight the relationship between both.

2.4.2 Conclusion

There have been many positive associations between CVF and cognitive functions. From research, it is evident that there has been a lack of cross sectional research done in this area on children. This thesis will give a comprehensive overview of the relationship, if any, between CVF and attention, working memory, cognitive flexibility and executive function.

2.5 Academic Achievement

The term academic achievement (AA) refers to the extent to which a student, teacher or institution have achieved their educational goals, commonly measured by examinations or continuous assessment (Salvia & Ysseldyke 2001; Donnelly et al, 2016). The first standardized testing came into existence in the 1900's (Kubiszyn & Borich, 2003). Most AA tests, for example Drumcondra and Sigma T tests, focus on two components, reading and maths. Reading is a multifaceted cognitive task that depends on a range of cognitive skills (Engel de Abreu et al. 2014), for example, the ability to sustain attention, spatial working memory and a well-developed executive function system. Phonological awareness, the ability to sound letters and broader language abilities play a key role in children's' reading development (Engel de Abreu et al. 2014). The processing of such information requires a healthy set of strong cognitive skills aforementioned above.

The tests are intended to assess what students have learnt compared to other students of the same age or grade (Salvia & Ysseldyke 2001). Learning has an obvious and major role to play in the process of AA. Learning describes the course of acquiring new, or modifying and reinforcing, existing knowledge, behaviours, skills, values, or preferences and may be involved synthesizing different types of information (Donnelly et al. 2016). Measuring AA allows for monitoring of students' academic progress as they move through the education system.

2.5.1 The academic achievement and neuro-cognition link

Finn et al. (2014) explicitly state that the central goal of the education system is to provide students with the knowledge and skills necessary to think critically, solve complex problems and reach their individual potential in all areas of life. The measurement of such knowledge and skills is critical in following students' development (Finn et al. 2014). Studies of cognitive development have focused on areas of attention, working memory, cognitive flexibility and executive function, and studies of educational development and academic achievement have focused on mainly reading and math's ability. Cognitive skills are closely linked and influence academic achievement results (Finn et al. 2014). Executive function is a crucial building block for reading development in children and adolescence (Engel de Abreu et al. 2014). Having optimal attention capacity allows for optimal information processing and retrieval in the learning process. Studies have demonstrated a link between visual attention and reading acquisition in children (Anobile, Stievano & Burr et al. 2013). Math skills have also been found to be correlated with visual sustained attention (Anobile, Stievano & Burr et al. 2013). Whilst reading could be associated with sustained auditory attention then it is to visual attention (Anobile, Stievano & Burr et al. 2013). Blair & Razza (2007) reported that executive function ability was predictor of math and reading scores. WM plays a vital role in the many forms of complex cognition i.e. learning, reasoning, problem solving and language comprehension (Vuontela et al. 2003). WM is the most prominent predictor of AA scores (Lan et al. 2011) and the ability to solve mathematical problems (Beilock & Carr 2005). It is essential in making sense of written and spoken language and performing math equation in your head (Diamond, 2013). WM ability has been correlated with math and reading ability amongst adolescents (Finn et al. 2014). Similarly, Alloway & Alloway (2010) reported that working memory ability was related to math and reading ability. When gender was examined, it was reported that girls perform better than boys on tests that involve reading, writing and math calculation (Finn et al. 2014). Boys perform better on math tests that involved spatial representation of mathematical relationships, mental rotation and mechanical reasoning (Finn et al. 2014). This thesis looks to examine at further relationships between cognitive function and academic achievement in reading and maths.

2.6 Mental Health and Well-being in youth

Mental Health can be defined as “the emotional and spiritual resilience which enables us to enjoy life and to survive pain, disappointment and sadness and is a positive sense of well-being and an underlying belief in our own and others’ dignity and worth” (HEA 1997 cited in Mckenna & Riddoch 2003, p62). More often than not, negativity is associated with the term mental health. Everyone has a state of ‘mental health’, similar to a state of ‘physical health’, it is only when one develops a mental health disorder that one should grow concerned. The United States Department of Health and Human Sciences (1999) define a mental health disorder as a change in the condition of one’s health, characterized by differences in thinking, mood or behavior associated with distress and/or impaired functioning.

The term wellness or well-being is a holistic concept that explains a state of positive health in the individual and encompassing physical, social and psychological well-being (Bouchard et al. 2007). Health related quality of life refers to *the quality of one’s personal and mental health and the ability to react to factors in the physical and social environments* (Bouchard et al. 2007, p18). Research has shown that PA has the potential to boost wellbeing and improve mood (Bushman 2017 & Mckenna & Riddoch 2003). Reasons as to why PA promotes positive mental well-being is still being explored but some reasons include offers a distraction, increasing self-confidence, provides physical relaxation and helps in the promotion of a positive body image (Bushman 2007 & Mckenna & Riddoch 2003). Fox et al. (2000), cited in Mckenna & Riddoch (2003) outline five potential benefits of using PA positively in mental health and well-being promotion. PA is cheap and easily accessible, PA has negligible side effects, PA is sustainable through life compared to pharmaceutical drugs, non-drug treatments such as cognitive behavioural therapy are often in short supply and expensive and finally PA should be promoted for physical health regardless of its effects on mental health. Research on youth mental health and well-being have received significantly less attention than research on adults (Biddle & Asare 2011).

2.7 Holistic Development of Irish youth

Childhood development is a maturational and interactive process involving physical fitness, cognitive, language, socio-emotional, perceptual and self-awareness skills (Black et al. 2017). Children develop optimally when they attain developmental competencies for academic, behavioural, socio-emotional and economic achievements (Black et al. 2017). There are multiple elements that influence the ability to acquire these competencies, such as, health (physical and mental), early learning and education that will benefit their cognition an academic performance (Black et al. 2017). It is the interaction of these elements, that will result in optimal development during childhood, into adolescence and onto adulthood.

2.8 Conclusion

PA has many potential benefits on neuro-cognitive performance, learning, brain function and brain structure. It is these potential benefits that may pave the way for improvements in academic achievement (Donnelly et al. 2016). EF will generally function at an improved rate if the individual has a strong and healthy body. If students emotional, social or physical needs are ignored it may work against achieving performance goals. There has been a substantial interest in the association between PA, cognition, academic achievement, and mental health and wellbeing in recent years (Biddle et al. 2011 & Biddle et al. 2004).

Chapter Three: Methodology

3.1 Research Design

A cross-sectional research design was employed. Twelve primary schools were initially selected from the areas of Dublin, Meath and Wicklow. These primary schools were selected as they were feeders into specific second level schools as part of a larger DCU longitudinal tracking study. Six mixed gender primary schools took part in the final study, three from both Meath and Wicklow. A mixed method study involving collection of physical activity (PA) via accelerometers, cardiovascular fitness (CVF) via the 20m shuttle run test, and neuro-cognitive function (NCF) via the Cambridge Neuropsychological Test Automated Battery (CANTAB) connect software on iPads was used. A questionnaire was used to assess health and wellbeing (HW). National standardized academic achievement (AA) scores were collected from the class teacher in each school. Each dependent variable and its corresponding test are detailed in Table 3.1. A testing timeline is shown in Table 3.2. This chapter will describe participant selection, data collection measurements and data analysis procedures for Chapters four and five.

Table 3.1: Summary of dependent variables and corresponding test

Dependent Variable/Outcome	Test
Physical Activity	Accelerometer (Actigraph GT1M, GT3X, or GT3X+ illustrated in Figure 3.1
Cardiovascular Fitness	FITNESSGRAM 20m progressive shuttle run test
Height	Standard collapsible portable Leicester Height Measure
Weight	Standard portable calibrated Secca scales
NCF: Attention (Reaction time and movement)	Reaction Time task (RTI)
NCF: Cognitive Flexibility (The ability to transition between different concepts)	Attention Switching task (AST)
NCF: Attention (Continuous performance and visual sustained attention)	Rapid Visual Information Processing (RVP)
NCF: Working Memory (Retention of spatial information and manipulation of it in working memory)	Spatial Working Memory task (SWM)
NCF: Executive function (Comprises of high level thinking and decision making)	Spatial Working Memory task (SWM)
Well being	KIDSCREEN Quality of Life (QOL) questionnaire

Academic Achievement	Data from the standardized Drumcondra test (reading) and Sigma T test (math) from primary schools participating in the study

Table 3.2: Testing Timeline for three time points. Data collection was planned around this.

Time Point 1	13/02/2017	14/02/2017	15/02/2017	16/02/2017	17/02/2017	18/02/2017	19/02/2017	20/02/2017	21/02/2017	22/02/2017
PA Accelerometer Data	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
CVF Data	✓	✓	✓	✓	✓					
NCF Data						✓	✓	✓	✓	✓
HW Data	✓	✓	✓	✓	✓					
AA Data	Collected from Schools at end of academic school year. Schools conducted tests in May/June									
Time Point 2	27/02/2017	28/02/2017	01/03/2017	02/03/2017	03/03/2017	04/03/2017	05/03/2017	06/03/2017	07/03/2017	08/03/2017
PA Accelerometer Data	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
CVF Data	✓	✓	✓	✓	✓					
NCF Data						✓	✓	✓	✓	✓
HW Data	✓	✓	✓	✓	✓					
AA Data	Collected from Schools at end of academic school year. Schools conducted tests in May/June									
Time Point 3	13/03/2017	14/03/2017	15/03/2017	16/03/2017	17/03/2017	18/03/2017	19/03/2017	20/03/2017	21/03/2017	22/03/2017
PA Accelerometer Data	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
CVF Data	✓	✓	✓	✓						
NCF Data					✓	✓	✓	✓	✓	
HW Data	✓	✓	✓	✓						
AA Data	Collected from Schools at end of academic school year. Schools conducted tests in May/June									

3.2 Participants and Recruitment

Twelve mix gender Irish feeder primary schools were initially contacted by phone. If schools were interested, the principal and board of management in each of the schools received a letter outlining the purpose of the study, what it would involve, what would be required from students and requesting permission to involve their particular school and students. This was followed up with a phone call to confirm participation in the study. Six mixed gender Irish feeder primary schools participated in the final study from Meath and Wicklow. Informed assent and consent was granted by each participant and their parent/guardian; all participants were free to withdraw from the research at any stage. Participants, between the ages of 11 – 13 years from 6th class in each primary school were involved in this study. Ethical approval for the study was obtained from Dublin City University (DCU) Research Ethics Committee (REC Reference: DCUREC/2016/109).

3.3 Measures

A number of measures were employed in the collection of data. Each of these will be described in detail below.

3.3.1 Accelerometer Data Collection

The Actigraph accelerometer detects activity by sensing motion via an internal accelerometer. Participants were asked to wear an accelerometer (Actigraph GT1M, GT3X, or GT3X+ illustrated in Figure 3.1 below) above the iliac crest on the right hip for a period of nine days during waking hours unless showering, swimming or taking part in an activity which an adult deemed unsafe to wear. The first and last day that the accelerometer was worn were excluded from data analysis to allow for subject reactivity (Esliger et al. 2005), leaving seven full days of wear time. Participants were asked to note on a diary sheet any times (and reasons) during each of the nine days they had to remove the monitor. In order to boost participant compliance with the wear protocol, participants that provided their mobile phone numbers were sent an SMS each morning for nine days to remind them to wear the monitor (Belton et al. 2016). PA was recorded in 10-s epochs to capture the intermittent and sporadic behavior of youth (Esliger et al. 2005).

(a) (b) (c)

Figure 3.1: (a) Actigraph GT1M, (b) Actigraph GTX3, and (c) Actigraph GT3X+ accelerometers

A detailed set of instructions and procedures for accelerometer distribution that was carried out by the research team at the time of data collection can be found in Appendix A of this thesis.

3.3.2 Physical Fitness Data Collection

Physical Fitness data collection comprised of two sections; cardiovascular fitness and anthropometric data (height and weight).

3.3.2.1 Cardiovascular Fitness

The FITNESSGRAM 20m progressive shuttle run test was used to assess cardiovascular endurance (Leger et al. 1988). The 20m shuttle run test detailed in the FITNESSGRAM protocol was fully adhered to. Participants ran back and forth between two lines 20 meters apart, in time to recorded beeps. The speed increased each minute, signaled by shorter time between successive beeps. If an individual failed to reach the line in time to the beep they received a warning. After the warning, if the individual failed to make the subsequent line in time with the beeps, the test was finished, the participant stopped and left the test. Cardiovascular endurance can be estimated from the distance achieved in the shuttle run (Leger et al. 1988), this is outlined in section 3.3.6.2.2 Physical Fitness data analysis.

A detailed set of instructions and procedures for cardiovascular fitness measurement that was carried out by research team at the time of data collection is outlined in Appendix B of this thesis.

3.3.2.2 Anthropometric Fitness Data

Height

Height was taken using the standard collapsible portable Leicester Height Measure. It was placed on a flat level hard surface with the stabilizing bar against a vertical surface. Accuracy was essential; therefore, measurements were taken at eye level and marks recorded in meters to the nearest two decimal places e.g. 1.45m. Before measurements were taken, head and shoulder position were checked, participants were encouraged to breath normally throughout the test.

A detailed set of instructions and procedures for height measurement that was carried out by research team at the time of data collection is outlined in Appendix C of this thesis.

Weight

Weight was taken using the standard portable calibrated Secca scales. Scales were pre-calibrated with a known weight. Scales were placed on a hard level surface. Measurements were taken by looking directly over the needle to take the most accurate reading. Weight was recorded in kilograms (kg) to the nearest 0.5kg e.g. 44.5kg.

A detailed set of instructions and procedures for weight measurement that was carried out by research team at the time of data collection is outlined in Appendix D of this thesis.

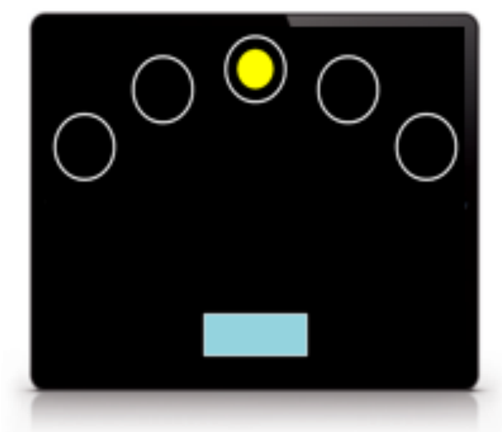
3.3.3 Cognitive Function Data Collection

The Cambridge Neuropsychological Test Automated Battery (CANTAB) tests were used to assess cognitive performance and function in: motor and mental response speeds, measurements of movement time, reaction time, response accuracy and impulsivity, the ability to manage conflicting information, ability to sustain visual attention, retention and manipulation of visuospatial information, and executive function. Details on each of the specific CANTAB tests used are given below.

1. Reaction time task (RTI):

   This test provides assessments on motor and mental response speeds, measures of movement time, reaction time, response accuracy and impulsivity. The participant holds down a white button on the bottom of the iPad screen until a yellow button appeared at the top of the iPad screen. They have to touch this yellow button as quickly and as accurately as possible. The participant begins with one yellow button (simple) and progresses to five yellow buttons (five choice). Both of these are illustrated in Figure 3.2. The outcome measure used was; RTI median five-choice movement time (RTIFMDMT). This outcome measure examined the median time it took for a participant to release the response button and select the target stimulus after it flashed yellow on screen. The score was calculated across correct, assessed trials in which the stimulus could appear in any of five locations. It was measured in milliseconds. The mode that was used was five-choice movement time – child mode.

(a)



(b)

Figure 3.2: Reaction Time Task; (a) Simple Choice and (b) Five Choice.

2. Attention Switching Task (AST):

This test examines a participant's ability to manage conflicting information provided by the direction of an arrow and its location of the screen and to ignore task irrelevant information. In this test, the participant had to switch their attention between the direction of the arrow and its location on the screen. There were two buttons located on the left and right side of the screen. Participants had to press the button of the direction the arrow was pointing in; then press the button of the side the arrow was on (Figure 3.3).

Figure 3.3: Excerpt from the beginning of the AST task.

Each trial displayed a cue at the top of the screen that indicated if the participant was to press the left of right button according to; 1) the side the arrow appeared on or, 2) the direction the arrow was pointing in. Some trials displayed congruent stimuli i.e. arrow on the right side of the screen pointing right, whilst other trials displayed incongruent stimuli i.e. arrow on the right side pointing left. This required a higher cognitive demand from participants. The outcome measured used was attention switching task median switching blocks (ASTSWMD). This refers to the median latency response (from stimulus to button press) in assessed blocks in which the rule is switching. This test provides a measure of attention switching.

3. Rapid Visual Information Processing (RVP):

This test examines the participants' ability to sustain visual attention. In this, a black box with a white border appeared on the screen. This box had a series of numbers from 2 – 9 which played continuously in this box. Every time participants saw the sequence 3-5-7 they would press the button on the bottom of their iPad screen as quickly and accurately as possible (Figure 3.6). The mode that was used was the '3-5-7 mode' which is recommended for children aged 7 – 14 years. The outcome measure used was rapid visual information processing A prime (RVPA). This is a signal detection measure of a participants' sensitivity to the target sequence, regardless of the tendency. In simple terms, it is a metric used to measure how good a participant is at detecting target sequences.

Figure 3.4: Excerpt of AST task.

4. Spatial Working Memory (SWM):

This test requires retention and manipulation of visuospatial information and can be used as a measure of executive function. This test has also noticeable executive function demands and provides a measure of strategy and working memory errors. In this test participants had to search for a small yellow box hidden inside a blue square, the test would start with three squares and progress to 12 squares. They would tap each blue or orange (illustrated in Figure 3.5) box on the screen to locate the yellow square. There is a small yellow box for each blue box present. The outcome measure used was spatial working memory between error six boxes (SWMBE6). This refers to the number of times the participants revisits the box in which a token has previously been found.

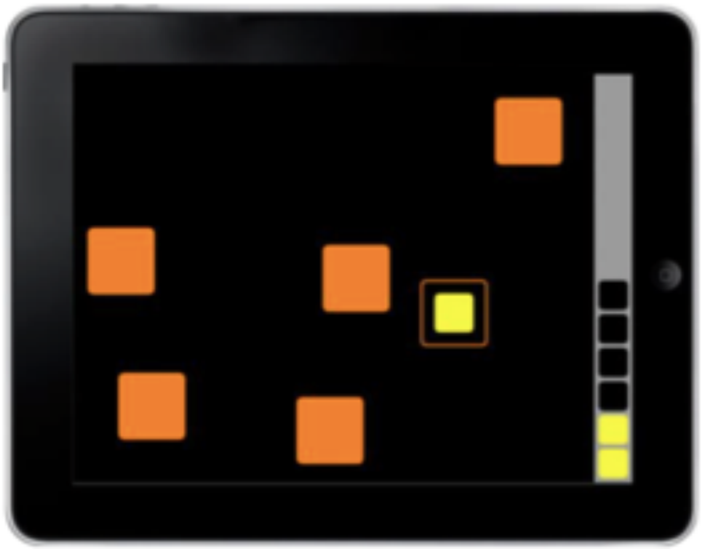


Figure 3.5: Excerpt of SWM task.

Participants completed the tests individually on a researcher-provided IPad placed 30 cm from the edge of the table, during the school day in a designated classroom. Testing per individual took approximately 40 minutes. Four children were tested simultaneously with no interaction between students. Students wore headphones and were shown how to adjust the volume to allow for optimal listening of instructions.

A detailed set of instructions and procedures for cognition measurement that was carried out by the research team at the time of data collection is outlined in Appendix E of this thesis.

3.3.4 Health and wellbeing data collection

The KIDSCREEN Quality of Life (QOL) questionnaire was developed to comprehensively assess physical, physiological, social, family and school aspect of wellbeing of children between the ages of 8 – 18 years (Ravens-Sieberer, Herdman & Devine et al. 2014). There are three versions of the KIDSCREEN QOL questionnaire available; KIDSCREEN-52 (original long version covering 10 dimensions of QOL), KIDSCREEN-27 (a shorter version covering five dimensions of QOL) and KIDSCREEN-10 (a 10-item QOL index) (Ravens-Sieberer et al., 2014). KIDSCREEN-27 was used in this study, it is a questionnaire that measures the following five health related quality of life dimensions:

1. Physical wellbeing: This dimension examines the level of the participants physical activity, energy, fitness, and the extent to which a participant feels unwell and complains of ill health (Ravens-Sieberer et al. 2014).
2. Psychological wellbeing: This dimension examines the participants positive emotions and satisfaction with life and the absence of feeling such as loneliness and sadness (Ravens-Sieberer et al. 2014).
3. Autonomy and parent relation: This dimension examines the quality of relations between the participant and parent/guardian, whether the participant feels loved and supported by their family, and participants perceive level of autonomy and quality of the financial resources available to the participant (Ravens-Sieberer et al. 2014).
4. Social Support and Peers: This dimension examines the quality of the social interactions with friends and peers and their support.
5. School environment: This dimension examined the participants perception of their cognitive capacity, learning, concentration, their feelings about school, and their relationship with their teachers (Ravens-Sieberer et al. 2014).

Two researchers and the class teacher in each school supervised questionnaire administration. Questionnaires were completed on paper in a school classroom and took approximately 15 minutes for students to complete. The questionnaire was administered to students in their class groups of no more than 30, giving a ratio of approximately 1:10 between testers and participants.

A detailed set of instructions and procedures for the distribution and administration of the KIDSCREEN-27 QOL questionnaire that was carried out by the research team at the time of data collection is outlined in Appendix F of this thesis.

3.3.5 Academic Achievement Data Collection

The national standardized testing strategy for academic achievement at primary school level in Ireland is guided by the 'Drumcondra' test (reading) and 'Sigma-T' test (math's). These standardized tests in reading and math's measure a child's achievement compared to another child in other schools all over Ireland at the same class level or age level, as well as individual comparison as they progress through primary school (NCCA 2007). The reading test assesses how well the student understands what they read (NCCA 2007). The math's test assesses how well the student can use numbers for different purposes and solve math problems (NCCA 2007).

Academic Achievement data for both English and Math was collected from all six participating primary schools. In total five schools supplied data on the current academic year i.e. 2016/2017 and one primary school provided data on students from 3rd to 5th class. Tests were administered in May/June of each academic year. Both Sigma T and Drumcondra tests were conducted in a classroom setting by the class teacher. The researcher had no input in the testing protocol as it is a standardized testing protocol used by schools nationwide. Once the tests were completed and test scores processed, the data was given to the researcher for further analysis.

3.4 Data Storage

After each round of data collection, all data was labeled, with a unique identifier given to each participant to ensure suitability for tracking purposes. All hard copies of questionnaires, accelerometer diaries, cardiovascular fitness scores and cognitive function data were stored securely away in a locked room on campus at Dublin City University. Descriptive statistics and frequency analysis were used to detect missing data and for initial preliminary analysis. Manual cleaning of the data by the researcher took place to identify any unusual results or missing data.

3.5 Data Processing

All data, once collected was processed in preparation for statistical analysis in Statistical Package for Social Sciences (SPSS 23.0). Data processing for each measurement is detailed the following sections. Numbers pre-and post-data processing are detailed in Table 3.3.

Table 3.3: Numbers pre-and post-data processing

Dependent Variable/Outcome	Test	N Pre-Processing	N Post Processing
Physical Activity	Accelerometer (Actigraph GT1M, GT3X, or GT3X+ illustrated in Figure 3.1	262	193
Cardiovascular Fitness	FITNESSGRAM 20m progressive shuttle run test	262	246
Height	Standard collapsible portable Leicester Height Measure	262	251
Weight	Standard portable calibrated Secca scales	262	251
NCF: Attention (Reaction time and movement)	Reaction Time task (RTI)	262	255
NCF: Cognitive Flexibility (The ability to transition between different concepts)	Attention Switching task (AST)	262	255
NCF: Attention (Continuous performance and visual sustained attention)	Rapid Visual Information Processing (RVP)	262	254
NCF: Working Memory (Retention of spatial information and manipulation of it in working memory)	Spatial Working Memory task (SWM)	262	255
NCF: Executive function (Comprises of high level thinking and decision making)	Spatial Working Memory task (SWM)	262	255
Well being	KIDSCREEN Quality of Life (QOL) questionnaire	262	232
Academic Achievement	Data from the standardized Drumcondra test (reading) and Sigma T test (math) from primary schools participating in the study	132	232

3.5.1 Accelerometer Data

Raw accelerometer counts were downloaded using ActiLife Software (version 6.13.3). The first and last day of accelerometer data were omitted from analysis to allow for subject reactivity (Esliger et al. 2005). Non – wear time was defined as ≥ 20 consecutive minutes of zero counts (Belton et al., 2016, Fairclough, Boddy & Mackintosh et al. 2015 & Esliger et al. 2005). The minimum number of valid days for inclusion in analysis was any two days of the week (Rich et al. 2013). Minutes in sedentary, light, moderate, vigorous and moderate-vigorous were estimated from the data using the Evenson et al. (2008) cut-points; sedentary: ≤ 100 counts/min, light: >100 counts/min, moderate: ≥ 2296 counts/min, vigorous: ≥4012 counts/min, moderate – vigorous: ≥ 2296 counts/min. Mean daily minutes were calculated for each intensity.

3.5.2 Physical Fitness Data

Physical Fitness data comprised of four components: cardiovascular fitness, height, weight and BMI.

Cardiovascular Fitness (CVF)

CVF data was collected from 246 participants via the 20m shuttle run test. This was used to calculate the maximal aerobic power of each participant. The last announced stage number is then used as the VO2max index (Léger et al. 1984), (Appendix). For example, if a participant aged 12 years, stopped at stage 3 their max speed would be 9.5km/hr, with a VO2 max of 40.3. Age, final stage number and corresponding maximal shuttle run speed were inputted into an excel sheet. From here the following formula was used to calculate V02 max (Léger et al., 1984):

VO2 max = 31.025 + 3.238 (speed km/hr derived from final shuttle run rest stage) – 3.248 (age to the nearest year) + .1536 (age) (speed km/hr)

The VO2max value was then aligned with the participant ID numbers in an SPSS data sheet.

Body Mass Index (BMI)

BMI was calculated using height and weight data. Height and weight data were inputted into an excel sheet. Weight was entered in kilograms and height was entered in meters. Height was then squared to meet the criteria for the formula. BMI was then calculated using the following formula:

BMI = Weight (kg) / Height (m^2)

BMI of participants was then classified under either, underweight, normal weight, overweight or obese according to Coles & Lobstein (2012) classification. Cole provided BMI scores for each month up to the age of 18 years. For example, a 12-year-old boy with a BMI of 19.36 would be classified as normal weight and lie in the 23rd percentile. The detailed classifications table can be found in Appendix G of this thesis.

3.5.3 Cognitive Function Data

Cognitive Function data were collected from 255 participants (n = 254 for the RVP test). Data was collated by the CANTAB connect software in a format that can be used with excel. This excel sheet included participant's ID numbers, age, date of birth and scores from all outcome measures on all four tests; RTI, RVP, SWM and AST. Selected outcome measures were merged with accelerometer, cardiovascular and BMI data in an SPSS data sheet.

3.5.4 Health and well-being Data

Health and well-being data were collected from 232 participants. A five point Likert scale was used to answer each item on the questionnaire. The options ranged from, 'never', 'seldom', 'sometimes', 'often', and 'always'. Certain items on the questionnaire had reverse scoring (scores 1 – 5). Raw scores from each item on the questionnaire were inputted into SPSS (version 23.0) The items of the KIDSCREEN questionnaire satisfy the assumptions of the Rasch model: unidimensionality, homogeneity of items and persons and sufficiency of the sum score (The KIDSCREEN Group Europe 2006). The assumption of the Rasch model is that both persons and items can be arranged on the same continuum (The KIDSCREEN Group Europe 2006). The location of an item is specified by one or more parameters, called threshold parameters. Both of these parameters are calculated by using Rasch analysis pertained to a reference data set (The KIDSCREEN Group Europe 2006). If the Rasch model fits, the variances between person estimates can be translated on an interval scale (The KIDSCREEN Group Europe 2006). To make the estimates more pertinent these scores are translated in to T-values (The KIDSCREEN Group Europe 2006), scaled with a mean of 50 and a standard deviation of 10. A higher score indicated a more positive wellbeing. This meant scores could be standardized and compared to other countries who used the KIDSCREEN QOL questionnaire (Ravens-Sieberer et al. 2014). These T-values were entered into an SPSS data sheet.

3.5.5 Academic Achievement Data

Academic achievement data were collected from 132 participants. Once academic achievement data were collected from each school, data for both reading and math scores were inputted into excel according to participant ID. Schools provided results in mixed formats; raw, standardized and STen. Standardized and STen scores are the scores that are given to parents/guardians and published for nationwide comparison. STen scores were chosen to input into SPSS with all other data. STen scores range from 1 – 10 and will be discussed further in Chapter five of this thesis.

3.6 Statistical Analysis

All data, once processed, were entered into Statistical Package for Social Sciences (SPSS 23.0). Where participants had incomplete data for a given variable, participants were excluded from analysis of this variable only. The analysis used in each of the subsequent chapters in this thesis is detailed below.

Chapter 4: The relationship between neuro-cognitive function and exercise intensity and cardiovascular fitness.

The aim of this chapter was to examine the relationship between NCF, PA and CVF. Specific exercise intensities i.e. time spent in sedentary (SED), light (LPA), moderate (MPA), vigorous (VPA) and moderate-vigorous (VPA) and VO2 max scores, were correlated with four NCF test scores (RTI, RVP, AST, SWM). The specific objective was to determine which exercise intensity and VO2 max score demonstrated a relationship with NCF and what effect if any exercise intensity had on NCF. In order to do this, preliminary data analysis was used to obtain descriptive statistics on participants anthropometric data: age, BMI, mean values for VO2max, mean daily minutes spent in SED, LPA, MPA, VPA and MVPA, mean scores for the four cognitive functions tests, AST, RTI, RVP and SWM. Independent sample t-tests were used to identify gender differences in cognitive function tests, PA measurement and CVF scores. Pearson product moment correlations were used to examine the strength and direction of the linear relationships between cognitive function and exercise intensity and cardiovascular fitness. Multiple regression was used to identify the unique interaction effect of the independent variables (SED, LPA, MPA, VPA, MVPA, and CVF) on the dependent variables (AST, RTI, RVP and SWM).

Chapter 5: The importance of holistic development in preadolescent Irish youth.

The aim of this chapter is to identify a model to illustrate the interaction and importance of focusing on all variables aforementioned (NCF, PA, CVF, HW and AA) in the development of preadolescent youth. Path analysis is a precursor to structural equation modeling (SEM). It employs a hypothesis testing approach to the multivariate analysis of a structural theory bearing on some phenomenon (Byrne 1998). In path analysis whilst there is no consensus on what constitutes the ‘correct sample size’, an $n > 200$ is considered a large sample size (Kline, 1998). Furthermore, SEM postulates ‘a number of participants’ to ‘number of model parameters’ of 20:1 (Kline 1998).

Specifically, this chapter looks to determine the key variables of the proposed model and how they interact with one another. In order to do this, descriptive statistics (minimum, maximum, mean and standard deviation) for HW questionnaire data, of which there were five components (physical wellbeing, psychological wellbeing, autonomy and parent relation, social support and peers, and school environment), and AA (English and Math's) were calculated. Pearson product moment correlations were used to examine the strength and direction of the linear relationships among NCF, HW, and AA. Multiple regression was used to identify the unique interaction effect of the independent variables (HW and AA) on the dependent variables (AST, RTI, RVP and SWM).

Pathway analysis (AMOS 21) was employed to test the proposed model in Chapter 5: Figure 5.1. This proposed model examines the interaction between the following variables; moderate-vigorous physical activity, cardiovascular fitness, BMI, health and well-being, cognitive function, and academic achievement. Various fit indices were employed to determine how well the proposed model fits the sample data. Chi-square statistics are initially used to determine the measure of fit between the sample covariance and fitted covariance matrices (Byrne 1998). A statistically insignificant value of chi square indicates a good fit with proposed model data. Furthermore, the Comparative Fit Index (CFI), the Normed Fit Index (NFI) and the Tucker-Lewis Index (TLI) (also known as the Non-Normed Fit Index (NNFI)) are additional values used to assess the appropriateness of the proposed model to the sample data. For these indices, values in the .90 range and above are indicative of optimal fit (Hu & Bentler 1995 & Schumaker & Lomax 1996). Additionally, the Root Mean Square of Approximation (RMSEA) is another fit index which considers the error of approximation in the population (Byrne 1998). Values less than .05 are indicative of good fit, values of .08 or less are indicative of reasonable errors of estimation in the population whilst values of .08 to .10 are indicative of mediocre fit (MacCullum, Browne, & Sugawara1996). Model assumptions for descriptive and inferential (e.g. correlational) statistics were met.

Chapter Four: The relationship between neuro-cognitive function and physical activity intensity levels and cardiovascular fitness.

It is reported that regular physical activity (PA) is linked to increased neuro-cognitive function (NCF) in children, with moderate-vigorous physical activity (MVPA) showing the most benefits (Syvaoja et al. 2015). There has been a plethora of research carried out investigating the effect of physical activity, exercise and physical fitness on cognition. Physically fit children and those participating in PA have shown better performance on cognitive function tests (Donelly et al. 2016). Many questions remain in term frequency, timing, duration and type of PA and its effect on cognition (Donnelly et al. 2016).

The aim of this chapter was to examine the relationship between NCF, PA and cardiovascular fitness (CVF). Specific PA intensity levels i.e. time spent in sedentary (SED), light (LPA), moderate (MPA), vigorous (VPA) and MVPA and VO2 max scores, were correlated with four NCF test scores (reaction time task (RTI), rapid visual processing task (RVP), attention switching task (AST), spatial working memory task (SWM)). The specific objective was to determine which PA intensity level and VO2 max score demonstrated a relationship with NCF and what effect if any PA intensity had on NCF. In order to do this, preliminary data analysis was used to obtain descriptive statistics on participants anthropometric data: age, body mass index (BMI), mean values for VO2max, mean daily minutes spent in SED, LPA, MPA, VPA and MVPA, mean scores for the four cognitive functions tests, AST, RTI, RVP and SWM. Independent sample t-tests were used to identify gender differences in cognitive functions tests, PA measurement and CVF scores. Pearson product moment correlations were used to examine the strength and direction of the linear relationships between cognitive function and PA intensity and cardiovascular fitness. Multiple regression was used to identify the unique interaction effect of the independent variables (SED, LPA, MPA, VPA, MVPA, and CVF) on the dependent variables (AST, RTI, RVP and SWM). In the analysis two separate model were used with each dependent variable examined. This was done to avoid a high correlation among independent variables in the multiple regression model. Model 1: time spent in sedentary, LPA, MPA and VPA, Model 2: MVPA and VO2 max. The assumptions of multicollinearity, normality, linearity, homoscedicity, descriptive and inferential were met in all multiple regression models. P values reported are 2 tailed.

4.1 Results

Descriptive and anthropometric characteristics of participants' accelerometer data, cardiovascular fitness and cognitive function data are presented in Table 4.1. The available sample for each measure is shown in Table 4.1. Gender differences were identified using independent samples t-tests are shown in Table 4.1.

4.1.1 Descriptive and anthropometric characteristics

This section will provide results on descriptive and anthropometric characteristics of participants.

Table 4.1: Anthropometric characteristics and descriptive statistics for PA intensity levels CVF and NCF.

	All			**Males**			**Females**			**Independent Samples T-Test**
	N	Mean	Std Deviation	N	Mean	Std Deviation	N	Mean	Std Deviation	**Significance value (p <.05)**
Age (yrs)	262	12.25	0.37	129	12.27	0.40	133	12.24	0.34	
BMI	251	18.68	3.60	126	18.55	3.19	125	18.81	3.98	
VO2(ml/kg/min)	246	49.66	5.03	123	51.11	5.39	123	48.21	4.19	0.00
Mean daily Sedentary (min)	193	469.43	78.01	88	462.18	103.51	101	476.72	46.93	0.00
Mean daily Light (min)	193	195.13	41.63	88	202.32	45.69	101	188.31	37.17	0.04
Mean daily Moderate (min)	193	35.04	13.03	88	38.93	15.13	101	31.56	10.07	0.00
Mean Daily Vigorous (min)	193	21.82	12.94	88	25.30	15.37	101	18.68	9.63	0.01
Mean Daily MVPA (min)	193	56.36	23.16	88	63.15	26.66	101	50.24	18.13	0.00
**AST (100 - ∞ ms)	255	774.58	126.98	124	750.71	126.70	131	797.16	123.52	0.03
**RTI (100 - 5100 ms)	255	187.11	41.52	124	181.72	40.94	131	192.20	41.57	0.04
*RVP (0 - 1)	254	0.96	0.05	124	0.96	0.05	130	0.96	0.04	0.38
**SWM (0 - 30)	255	4.23	2.92	124	4.48	2.93	131	3.99	2.90	0.17

*For AST, RTI and SWM a higher score indicates a worse performance.

**For RVP, a higher score indicates a better performance.

The average daily MVPA accumulation of participants was 56.36 minutes. An independent samples t-test revealed significant differences in PA intensity levels between genders (Table 4.2). Males spent more time in MVPA daily than females (63.15 minutes compared to females, mean score 50.24 minutes, $t = 3.34$, $p = 0.00$.

Males spent less time in sedentary then females, mean score 462.18 and 476.72 minutes respectively, $t = -3.08$, $p = 0.00$, and LPA, 195.13 (males) and 188.31 (females), $t = 2.11$, $p = .04$. Subsequently males spent more time in both MPA, mean score 38.93 minutes' vs 31.56 minutes (females), $t = 3.30$, $p = 0.00$, and VPA, mean score 25.30 minutes' vs 18.68 minutes (females), $t = 2.81$, $p = .01$.

Participants performed well across the cognitive function tests as indicated by the scoring range in this test; AST – 774.58ms (range 100 – infinity), RTI - 187.11ms (range 100 – 5100), RVP - .96 (range 0 – 1) and SWM – 4.23 (0 – 30). A higher indicated a worse performance in AST, RTI and SWM and a better performance in RVP. An independent samples T-Test revealed significant differences between males and females in both the AST and RTI test. Males were faster in the AST test, mean score 750.51ms vs 797.16ms, $t = -2.964$, $p = .003$, and RTI task, mean score 181.72ms vs 192.20ms compared to females (a higher score indicates a worse performance in both tasks), $t = -2.027$, $p = .044$. The independent samples t-test showed no significant differences between males and females in the RVP task, $t = -8.75$, $p = .382$, both with a mean score of .96 with a higher score indicating a better performance. There was no significant gender difference in the SWM task, $t = 1.346$, $p = .179$.

Females reported a mean score of 48.21 for VO2 max. The FITNESSGRAM performance standards (2015) indicate that females aged 12 years should have a VO2 max reading of ≥ 40.2 to be considered in the Healthy Fitness Zone. Males reported a mean score of 51.11 for VO2 max. This is also well above the FITNESSGRAM performance standards (2015) of ≥ 40.3. An independent samples t-test revealed significant differences in exercise intensities between genders. Males had slightly higher VO2 max scores compared to females, mean score 51.11 (males) compared to 48.21 (females), $t = 4.44$, $p = 0.00$.

4.1.2 Relationship between Neuro – cognition, Physical Activity Intensity Levels and Cardiovascular Endurance

This section will highlight relationships between NCF, PA intensity level and CVF.

Table 4.2: Pearson Product moment correlations – NCF and PA intensity level.

	Sedentary	**Light**		**Moderate**	**Vigorous**	**MVPA**	**VO2 max**		
	All	All	Females	Males	Females	Females	All	Males	Females
AST	.030	.001	.045	-.125	-.007	.010	-.195**	-.214*	-.071
	.681	.991	.659	.250	.948	.920	.002	.020	.440
RTI	.000	-.062	.100	-.269*	.125	.167	-.176**	-.138	-.155
	.996	.400	.324	.012	.217	.099	.006	.134	.089
RVP	.144*	-.019	-.007	-.074	-.293**	-.259**	.064	.033	.201*
	.050	.792	.948	.497	.003	.010	.326	.721	.028
SWM	-.099	.159*	.238*	.022	.037	.068	.023	.007	-.022
	.180	.031	.018	.840	.719	.507	.718	.943	.813

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

*For AST, RTI and SWM a higher score indicates a worse performance.

**For RVP, a higher score indicates a better performance.

Initial Pearson product moment correlations revealed a small negative significant relationship between RTI and MPA for boys ($r = -.269$, $p < .05$) i.e. as boys spent more time in MPA, RTI scores decreased (improved). There was a small positive significant relationship between RVP and time spent in sedentary ($r = .144$, $p < .05$) i.e. as girls spent more time in sedentary, their RVP scores increased (improved), and a medium positive relationship between RVP and VPA ($r = .293$, $p < .01$) i.e. as time spent in VPA increased, RVP scores also increased (improved), and MVPA for girls, ($r = .259$, $p < .01$) i.e. as time spent in MVPA increased, RVP scores also increased (improved). There was a small positive relationship between SWM and LPA ($r = .159$, $p < .05$) i.e. as time spent in LPA increased, SWM scores increased (worsened), and a medium positive relationship between SWM and LPA for girls ($r = .238$, $p < .01$) i.e. as time spent in LPA increased, SWM scores increased (worsened) for girls. There was a small negative significant relationship between AST and VO2 max ($r = -.195$, $p < .01$) i.e. a higher VO2 max score resulted in a lower (improved) AST score, and between RTI and VO2 max ($r = -.176$, $p < .01$) i.e. a higher VO2 max score resulted in a lower (improved) RTI Score. There was a small negative relationship found between AST and VO2 max ($r = -.214$, $p < .01$) i.e. a higher VO2 max score resulted in a lower (improved) AST score for boys and a small positive relationship between RVP and VO2 max for girls ($r = .201$, $p < .05$) i.e. a higher VO2 max resulted in a higher (improved) RVP score for girls.

In multiple regression analysis two separate models were used with each dependent variable examined. Model 1: time spent in sedentary, LPA, MPA and VPA, Model 2: MVPA and VO2 max

Model 1 predicted 8.5% of the variance of RTI for males ($r^2 = .13$, $F(4, 78) = 2.905$, $p = .03$, $p \leq .05$). MPA ($r = -.388$, $p < .05$) was statistically the strongest predictor of RTI scores for males. RTI scores for males decreased by 1.238ms for every minute spent in MPA.

Model 1 predicted 6.4 of the variance of RVP for females ($r^2 = .102$, $F(4, 94) = 2.673$, $p = .04$, $p \leq .05$). VPA ($r = .302$, $p < .05$) was statistically the strongest predictor of RVP scores for females. RVP scores decreased .001 for every minute spent in VPA.

Model 1 predicted 3.5% of the variance of SWM scores in all participants ($r^2 = .056$, $F(4, 177) = 2.621$, $p = .04, .000$, $p \leq .05$). LPA ($r = 245$, $p < .05$) was statistically the strongest predictor of SWM scores in all participants. SWM scores increased by .019 for every minute spent in LPA.

In a multiple regression analysis, model 2 predicted 2.4% of the variance of AST in all participants ($r^2 = .035$, $F (2, 74) = 3.122$, $p = .05$, $p \leq .05$). VO2 max ($r = -.194$, $p < .05$) was statistically the strongest predictor of AST scores. Participants scores decreased by 4.878ms for every ml/kg/min of VO2 max.

Model 2 predicted 5.9% of the variance of RTI for females ($r^2 = .079$, $F (2, 93) = 3.978$, $p = .02$, $p \leq .05$). MVPA ($r = .249$, $p < .05$) and VO2 max ($r = -.240$, $p < .05$) were statistically strong predictors of RTI scores for females. RTI score for females increased .570ms for every minute spent in MVPA and decreased -2.380ms for every ml/kg/min of VO2 max.

Model 2 predicted 3.1% of the variance of RVP in all participants ($r^2 = .042$, $F (2, 174) = 3.788$, $p = .03$, $p \leq .05$). MVPA ($r = -.212$, $p < .05$) was statistically the strongest predictor of RVP scores in all participants. RVP scores were not affected by time spent in MVPA.

Model 2 predicted 14.3% of the variance of RVP for females ($r^2 = .16$, $F (2, 93) = 8.948$, $p = .000$, $p \leq .05$). MVPA ($r = -.370$, $p < .05$) and VO2 max ($r= .327$, $p < .05$) were statistically strong predictors of RVP scores for females. RVP scores decreased .001 for every minute spent in MVPA and increased .003ms for every ml/kg/min of VO2 max.

4.2 Discussion

The purpose of this study was to examine the relationship between NCF, PA intensity levels and CVF in pre-adolescent Irish youth. There were significant gender differences in PA intensity levels, CVF, and AST and RTI cognitive function tasks. Males outperformed females in both the AST and RTI tasks, and reported a higher VO2 max compared to females.

4.2.1 Attention

Attention is one of the most important measures of cognition in children and adolescents (Vanhelst et al. 2016). Many studies have shown that PA intensity levels have made an impact on the performance of attention capacity in children and adolescents (Vanhelst et al. 2016). The extent of this impact remains unclear.

4.2.1.1 Time spent in Sedentary

There was no significant relationship between RTI and time spent in sedentary. There was a small positive relationship found between RVP and time spent in sedentary ($r = .144$, $p < .05$). This correlation should be interpreted with caution as multiple regression analysis revealed no statistical significant results between RVP and SED. A higher score in the RVP task indicates a better performance. As time spent in sedentary increased so did the score in the RVP task. This would indicate that time spent in sedentary had a positive effect on an individual's ability to detect target sequences. Syvaoja et al. (2014) reported a similar relationship between RVP and sedentary time when they investigated the associations of objectively measured PA and sedentary time on cognitive functions in school aged children. They reported that children who spent larger amounts of time in sedentary had better scores on the sustained attention test then their counterparts. This could be due to the fact that some sedentary activities require the use of sustained attention such as reading and doing homework (Syvaoja et al. 2014).

4.2.1.2 Time spent in MPA

Multiple regression results indicate that for every minute spent in MPA, boys' score in the RTI task decreased by 1.238ms (a higher score indicates a worse performance). This meant that in the RTI task, the length of time between releasing the response button and selecting the target stimulus after it flashed yellow on the screen decreased if time in MPA increased. This indicates that MPA had a positive effect on individuals processing and psychomotor speed. It has been reported that those children who are more physically active above the moderate threshold exhibit greater attention resources and develop a faster cognitive processing speed (Kohl, 2013). This is similar to previous studies where MPA is seen to have a benefit on NCF, in particular attention (Peruyeo et al. 2017). Equivalent results elsewhere have reported that PA sessions of moderate intensity have led to improvement in attention (Verbugh et al. 2014; Cooper et al. 2016 & Vanhelst et al. 2016). Further to this, Hillman et al. (2008) and Ponitfex et al. (2012) reported that just a single bout of MPA has been understood to increase neural and behavioral processes associated with the distribution of attention to a specific task, in this case the RTI task, which required participants to respond to a flashing yellow button as quickly and as accurately as possible. Shephard (1996) suggested that participation in physical activity may encourage arousal and relief of boredom resulting in improved attention capacity. This would be similar for those who have a higher VO2 max. Those that are more fit will have a higher chance of taking part in activities of moderate exercise intensity or higher, although it is important to note that those that do take part in PA at a certain intensity level may not necessarily have a high VO2 max score. Males reported both a higher VO2 max (51.1) compared to girls (48.2) and reported more time spent in MPA (36.60 and 30.37 respectively) which might contribute to the reason why males correlated with psychomotor speed and girls didn't at the MPA intensity level. In conclusion, MPA has shown itself to be a strong predictor in cognition in particular for processing and psychomotor speed in males.

4.2.1.3 Time spent in VPA

Results suggest that VPA was statistically the strongest predictor of RVP scores in females. RVP scores decreased by .001 for every minute spent in VPA, where a higher score in the RVP test indicates a better performance. While it must be acknowledged that the decrease indicated (0.001) is very small, the result would indicate that as females spent more time in VPA, the greater difficulty they had at detecting a target sequence and maintaining sustained visual attention on the task. This would mean that exercising at the VPA level has a negative impact on females sustained visual attention. This is not uncommon. Exercise of vigorous intensity can often lead to fatigue and thus reduced attention capacity (Coe et al. 2006; Vanhelst et al. 2016). This may imply that a certain exercise intensity i.e. moderate is required to elicit a positive effect on attention capacity (Coe et al. 2006). Cooper et al. (2016) investigated the effect of bouts of high intensity intermittent exercise on cognitive function of adolescents. They reported that high intensity exercise had no effect on psychomotor speed.

4.2.1.4 Time spent in MVPA

Results suggest that MVPA was the strongest predictor of RVP scores for all participants, however analysis showed no change in RVP score as a result of time spent in MVPA. Pindus, Davis, Hillman et al. (2015) used a similar methodology to the one in this thesis. They used Actigraph GT1M accelerometers to measure MVPA levels and to investigate the relationship with reaction time, cognitive processing speed and attention. They too found that MVPA was not significantly related to reaction time, cognitive processing speed or attention capacity. Syvaoja et al. (2014) used the same RVP test in their study on an adolescent population. They also reported no significant association between MVPA and sustained visual attention. Pindus et al. (2015) suggest that the lack of significant association between MVPA and RVP scores could be due to the differences in task characteristics. Certainly, in this present study, this holds true. This present study used the RTI and RVP from the CANTAB cognitive function test battery. This has yet to be validated in a youth population. These tests were originally designed for the adult generation in order to test for neurocognitive deficiencies. Participants in this current study, achieved high results in this test, compared to those with a neurocognitive deficiency, this may explain the lack of correlation between MVPA overall and the inconsistencies in results for females (Syvaoja et al. 2014).

Time spent in MVPA was a significant predictor of performance in tasks on attention. Results suggest that MVPA was a statistically significant strong predictor of RVP scores for females. RVP scores decreased .001 for every minute spent in MVPA. This would imply that as females spent more time in MVPA, the greater difficulty they had a detecting a target sequence and maintaining sustained visual attention on the task. MVPA was also a statistically significant predictor of RTI scores for females. RTI scores increased .570ms for every minute spent in MVPA by females. This would imply that as females spent more time in MVPA, the greater the length of time it took females to release the response button and selecting the target stimulus after it flashed yellow on the screen. MVPA had negative effects on both females' ability to sustain visual attention and their processing and psychomotor speed. It has been suggested by many researchers (Coe et al. 2006 & Vanhelst et al. 2016) that a certain level of activity is needed to produce such desirable effects. Once a certain level of PA intensity is reached this could also induce physiological changes, such as increased BDNF factor (Vanhelst et al. 2016). BDNF facilitates learning and maintains cognitive function by improving synaptic plasticity, acts as a neuroprotective agent, increases brain circulation, and improving neuroelectric function (Vanhelst et al. 2016). The results in this chapter are in line with previous research that reported that MVPA had beneficial effects on attention capacity (Vanhelst et al. 2016 & Booth et al. 2013). Involvement in MVPA may induce immediate arousal and relief from boredom, resulting in superior attention capacity (Shephard, 1996).

4.2.1.5 Cardiovascular fitness (CVF)

Results suggest that VO2 max was a significant predictor of both RTI and RVP scores for females. RTI scores decreased -2.380ms for every ml/kg/min of VO2 max, and RVP scores increased .003 for every ml/kg/min of VO2 max. A higher score in the RTI indicated a worse performance by the participant. These results show that VO2 max had a positive effect on RTI scores in females, meaning that for every ml/kg/min of VO2 max, females were better able to detect a target sequence and maintain visual attention. RVP scores increased .003ms for every ml/kg/min of VO2 max. A higher score in the RVP task indicated a better performance by the participant. These results show that VO2 max had a positive effect on RVP scores. This meant that for every ml/kg/min of VO2 max, females were more likely to quickly release the response button and select the target stimulus after it flashed yellow.

Greater aerobic fitness has been found to be associated with a shorter reaction time and greater accuracy in children (Scuddler et al. 2014). In a meta-analytic review of randomized controlled trials, Smith et al., (2010) reported that aerobic training results in modest improvements in attention. Higher fit children have the capability to regulate attention more efficiently in task demands similar to the RTI and RVP task, resulting in a greater performance (Pindus et al. 2015).

The results of this study indicate that both males and females VO2 max performance was well above the FITNESSSGRAM performance standards for this age group. Higher fit individuals have been found to perform better in tests on cognition. This could be why they performed favorably on the RTI task, which measures processing and psychomotor speed in addition to response time. This function occurs in the area of the brain concerned with the neuroelectic system. The neuro-electric system has provided much insight into the understanding of cognitive processing (Hillman et al. 2005). The P3 is an endogenous element of the Event Related Brain Potentials (ERP), part of the neuroelectic system which exhibit patterns of voltage alteration in ongoing neuroelectric activity that happens in response to or in preparation of a stimulus or response (Hillman, Castelli & Buck 2005). The P3 occurs roughly 300 – 800ms after a stimulus begins, which is initiated when participants attend and differentiate between stimuli (Polich, Ladish & Burns, 1990 cited in Hillman, Castelli & Buck 2005). The RTI task, which was used in this thesis, requires the participant to differentiate between stimuli and attend to the appropriate response. The P3 is speculated to guide processes involved in the allocation of attention (Donchin cited in Hillman, Castelli & Buck 2005). Hillman, Castelli & Buck (2005) demonstrated that higher fit children had a greater P3 amplitude and faster P3 latency at the occipital recording site compared to low fit children. Both of these results indicate a large neuron recruitment and faster neurocognitive processing related to the distribution of attention resources is taking place (Hillman, Castelli & Buck 2005). Based on the above discussion, the following conclusion could be hypothetically formed; those with a high fitness level performed well on both the RTI and RVP task. This could potentially be attributed to having a favorable P3 latency and amplitude resulting in the optimal allocation of resources in order to respond to the task parameters efficiently. Further research on a neuro-science level would be necessary to validate this hypothesis.

4.2.2 Working Memory and Executive Function

This study examined a general baseline performance of participants retention and manipulation of visuospatial information from working memory and executive function ability. Significant relationships were shown between SWM and LPA overall and in particular for girls. The specific measure that participants were examined on was how many times they revisited the box in which a token had previously been found. A higher score indicated a weaker performance.

4.2.2.1 Time spent in LPA.

Multiple regression results suggest that LPA was a significant predictor of SWM. A participants' score on the SWM task increased by .019 for every minute spent in LPA. LPA proved to be a significant predictor of SWM for females only. Females score on the SWM task increased by .022 for every minute spent in LPA. A higher score in SWM indicates a reduced ability to retain and manipulate visuospatial information and a poorer executive function capacity. This result indicated that time spent in LPA had a negative effect on performance in the SWM task.

The absence of any effect of exercise on SWM is not unusual and is supported by Sibley & Beilock (2007) who demonstrated that there was more likely to be benefits on WM from exercise intensity on individuals with a poor baseline WM performance. Similar findings were reported by Cole & Tomporowski (2008). They found that exercise did not facilitate executive function processes involved in the reconfiguration of working memory in young adults (mean age 22.2 years) who completed a 40-min treadmill test at moderate intensity. As mentioned previously, the CANTAB tests were originally designed to detect neuro-cognitive defects e.g. Alzheimer's. We know that the cognitive scores of the participants of this study were very positive, participants reported a mean score of 4.23, the scoring range is between 0 – 30 for this test, with a higher score indicating a weaker performance. For this reason, these tests may have failed to put a demand on their WM. This could be attributed to a ceiling effect with the test. Participants performed at a very high level making it very hard to discriminate between individual test scores. Scudder et al. (2014) supports this theory with their report that a higher VO2 max was associated with WM performance but only when WM demands increased. Cognitive results from this study for the SWM task were on the higher end of the scoring range indicating a highly functioning WM and executive function. Stroth et al. (2009) reported that 20 minutes on a stationary bike at MPA intensity level did not affect adolescents (aged 13 – 15 years) on an executive function task that included elements of working memory. Hillman et al. (2009) reported that treadmill walking at moderate intensity did effect executive function. In their study, Mucke et al. (2017) hypothesized that participants with higher MVPA would demonstrate a greater working memory then those with lower MVPA. Similar to this thesis they too found no significant relationship between the two. Application of different cognitive tasks and exercise procedures could contribute to the diversity of results. Booth et al. (2013) reported a positive relationship between MVPA and working memory.

4.2.3 Cognitive Flexibility

This study examined a general baseline performance of participants cognitive flexibility ability with respect to PA patterns and CVF. Significant results were seen for all participants between AST and CVF. Males and Females demonstrated no significant relationship. The AST test provides a measure of cued attentional set shifting and attention switching, both of which are components of Executive Function. A higher score indicates a poorer performance. Participants were examined on the median latency response (from stimulus to button press) in assessed blocks in which the rule is switching i.e. how long it took the participant to respond to the command given on screen.

4.2.3.1 Time spent in sedentary, LPA, MPA, VPA and MVPA.

There was no significant relationship found between AST and time spent in sedentary, LPA, MPA, VPA and MVPA. It must be noted that it has been stated that not all cognitive functions will respond to PA in the same way or as expected due to different cognitive demands and capacities (Chang et al. 2014). Piepmeier et al. (2015) argue that compared to simple processing speed, attentional set shifting necessitates a greater amount of cognitive capacity. Mucke et al. (2017) equally found no relationship between cognitive flexibility and MVPA. Cognitive flexibility is related to activities that occur in the frontal lobe of the brain. This is the area that has been reported to be most responsive to exercise. This may explain why there was no relationship between time spent in sedentary and cognitive flexibility. Time spent in sedentary may have no relationship and indeed no effect on cognitive flexibility. As mentioned previously this could be due to the nature of the CANTAB tests used. These tests were originally designed for the adult generation in order to test for neurocognitive deficiencies.

4.2.3.2 Cardiovascular Fitness (CVF)

Multiple regression results suggest that CVF was a significant predictor of AST scores for all participants. A participants' score on the AST task decreased 4.878 for every ml/g/min of VO2 max. A lower score on the AST task indicated the ability to switch between task demands. This result indicated that CVF had a positive effect on an individual's ability to switch between tasks.

Pontifex et al. (2011) reported that higher fit children i.e. those with a higher VO2 max were better able to maintain a higher level of accuracy when switching between task conditions. This would suggest that both children in the study conducted by Pontifex et al. (2011) and in this thesis, with a higher VO2 max had a greater ability to control cognitive processes. Children with a lower VO2 max, in comparison, had higher scores in the AST task, demonstrating a decreased capacity to allocate attentional resources (Pontifex et al. 2011).

This is backed up by Barnes et al. (2003) who states that it is the frontal lobe activities related to cognitive flexibility that demonstrated the greatest response to aerobic exercise. Adolescents are particularly susceptible to these changes throughout the later stages of child development where cognitive flexibility is not yet fully developed (Benzing et al. 2016).

4.3 Conclusion

This chapter gave a comprehensive and detailed overview of the different PA intensity levels that effect neuro-cognitive function in pre-adolescent Irish youth sampled in this study.

This study first examined two components of attention; (1) reaction time and psychomotor speed (RTI), and (2) sustained visual attention (RVP). Reaction and psychomotor speed was associated with CVF for all participants and MPA for males only. Sustained visual attention was associated with CVF for all participants and VPA, MVPA and CVF for females only. Visuospatial working memory and executive function were assessed using the SWM task.

All participants demonstrated relationships between the SWM task and LPA, similar results were seen in females only. Finally, this study examined the association between participants cognitive flexibility or attention set shifting (AST) and exercise intensities. Cognitive flexibility was associated with CVF for all participants and boys in particular.

The relationship between exercise and cognition is multifaceted. This current study has demonstrated that PA intensity and fitness level will interact with different types of cognitive processing tasks through different physiological mechanisms in order to enhance task performance (Lambourne & Tomporowski 2010). Fitness correlated with three out of the four tests used. Males demonstrated relationships with RTI task only i.e. attention, processing and psychomotor speed. Etnier, Nowell & Landers (2006) propose the CVF hypothesis which explains that physiological changes in the brains structural network occur as a result of the changes in CVF due to participation in MVPA. Males spent significantly more time in MVPA in this study compared to females and subsequently demonstrated higher VO2 max scores. Males had superior performance to females in both the AST and RTI tasks, which could be due to enhanced changes in brain structure as a result of them being significantly more physically active overall.

Different areas of the brain are associated with specific cognitive functions. For example, the cognitive measures that both RTI and AST measure are located in the frontal lobe of the brain and the cognitive measures associated with RVP and SWM are located in the parietal lobe. Specific cognitive functions require certain exercise intensities to function optimally. This study reported that the RTI and AST benefited the most from time being spent at a certain exercise intensities. RVP and SWM required the least amount of exercise intensity in order to function optimally.

This study has demonstrated that being physically fit is typically associated with enhanced cognition, in particular processing and psychomotor speed (RTI), and the ability to switch between tasks (AST). Future research should focus on interventions aimed improving and/or maintaining CVF and promoting participation in MVPA that will ultimately improve overall fitness level and subsequent cognitive function. Neuro-imaging has shown for in depth results for exercise and cognition and one that should be pursued to gain a comprehensive understanding of the exercise cognition relationship on a neural level.

4.4 Link Section Chapter four to Chapter five

Purpose of Chapter four:

To give a comprehensive and detailed overview of the different PA intensity levels that effect neuro-cognitive function in pre-adolescent youth. Multiple regression revealed significant contributions of the independent variables on the dependent variables. VO2 max was a significant predictor of AST scores for all participants. MPA was a significant predictor of RTI scores for boys. MVPA and VO2 max were significant predictors of RTI scores for females. MVPA was a significant predictor of RVP scores for all participants. VPA, MVPA and VO2 max were the strongest predictors of RVP scores for females. LPA was the strongest predictor of SWM scores in all participants.

Purpose of Chapter five:

There is a noticeable lack of research relating to the holistic approach of child development and the importance of it. Chapter 5 will examine relationships between NCF and HW and AA. The four NCF test scores (AST, RTI, RVP and SWM) will be correlated with five HW components (physical wellbeing, psychological wellbeing, autonomy and parents, social support and peers and school environment) and two components of AA (Reading and Maths). This information will assist in the development of a path model, using AMOS, demonstrating the interaction effect of all variables previously discussed. This model will highlight the importance of examining all variables and all areas of a childs life i.e. physical, cognitive, mental, social and academic as they grow and develop. It will also highlight the importance of a holistic approach to their development, that is, no one area should be overlooked when developing policies, programs, interventions and curriculums that seek to develop and educate the child.

Chapter Five: The importance of holistic development in pre-adolescent Irish youth.

The aim of this chapter is to identify a pathway model to illustrate the importance of taking into account all variables i.e. neurocognitive function (NCF), physical activity (PA), cardiovascular fitness (CVF), health and wellbeing (HW) and academic achievement (AA), in the development of preadolescent Irish youth and the importance of a holistic approach to their development and education. Specifically, this chapter looks to determine the key variables of this model and how they interact with one another. This chapter will examine the relationship between and NCF and HW and NCF and AA.

The purpose of providing a holistic education is to enable individuals to live their lives to the fullest and realize their potential as unique individuals. Holistic development encompasses cognitive, social and emotional development. The creation of an environment by educators, parents and guardians is vital to allow for this. Young children learn from a range of experiences in everyday life (French 2007). Children do not naturally compartmentalize learning instead they connect and intertwine items they have learned in the social, emotional, personal, physical and cognitive domain (French 2007). This holistic system of learning allows for the aforementioned domains to interact with each other in different ways.

5.1 Results

Descriptive and anthropometric characteristics of participants' HW and AA data are presented in Table 5.1. The available sample for each measure is shown in Table 5.1.

5.1.1 Descriptive Statistics

In total 262 participants took part in this portion of the study. Between 232 and 248 participants provided data on HW, and 131 – 132 participants provided data on AA. Independent samples t-tests were used to determine gender differences amongst HW and AA scores. Independent samples t-tests revealed significant gender differences for HW independent variable, autonomy and parental support, $t = -1.987$, $p = .048$, and social support and peers, $t = -2.935$, $p = .004$. There were no significant gender differences in AA scores.

Table 5.1 Descriptive statistics for components of HW and AA for preadolescent Irish youth.

	All		Males		Females	
	Mean	Std. Deviation	Mean	Std. Deviation	Mean	Std. Deviation
Physical Wellbeing	50.61	10.32	50.45	9.03	50.75	11.40
Psychological Wellbeing	53.99	10.02	53.81	9.96	54.15	10.12
Autonomy & Parental Support	51.37	9.88	50.07	8.86	52.57	10.62
Peers & Social Support	52.28	10.41	50.29	10.74	54.14	9.78
School Environment	53.32	9.66	52.61	8.98	53.97	10.25
AA Reading Sten score	5.98	1.86	5.95	1.71	6.00	1.98
AA Maths Sten score	8.03	10.90	9.10	12.91	7.14	8.88

5.1.2 Relationship between NCF, HW and AA

This thesis has previously reported relationships between NCF, PA and PF in Chapter four. Pearson product moment correlation (Table 5.2) revealed a small significant relationship between RVP and one component from HW, autonomy and parent relations, $r = .175$, $p < .05$. SWM had small significant relationship with 4 out of 5 HW components; psychological well-being, $r = .156$, $p < .01$, autonomy and parent relations, $r = .146$, $p < .01$, social support and peers, $r = .148$, $p < .01$ and school environment, $r = .138$, $p < .01$. There was a medium negative significant relationship between RTI and physical well-being for males, $r = -.210$, $p < .05$. Males also reported a medium positive significant relationship between SWM and social support & peers, $r = .248$, $p < .01$. In comparison to males, females demonstrated a medium relationship between RVP and autonomy and parental relations (r

= .207, $p < .05$), and social support and peers ($r = .209$, $p < .05$). Females also reported a small significant positive relationship between SWM and school environment, $r = .181$, $p < .05$.

Table 5.2: Pearson Product moment correlations – NCF and HW.

	All					**Males**					**Females**				
	Physical Wellbeing	Pyschological Wellbeing	Autonomy & Parental Support	Social Support & Peers	School Environment	Physical Wellbeing	Pyschological Wellbeing	Autonomy & Parental Support	Social Support & Peers	School Environment	Physical Wellbeing	Pyschological Wellbeing	Autonomy & Parental Support	Social Support & Peers	School Environment
AST	.017	-.003	-.023	.046	.002	.059	-.093	-.071	-.090	-.080	-.018	.082	-.025	.118	.046
	.803	.961	.725	.472	.969	.543	.317	.451	.330	.391	.843	.371	.784	.193	.611
RTI	-.032	-.008	-.120	-.091	-.046	-.210*	-.067	-.169	-.163	-.134	.093	.044	-.112	-.066	.008
	.637	.900	.063	.158	.478	.029	.472	.070	.078	.150	.319	.628	.217	.463	.931
RVP	.020	.026	.175**	.118	.090	-.018	-.027	.141	.035	.138	.068	.098	.207*	.209*	.027
	.763	.687	.007	.067	.164	.855	.773	.130	.704	.137	.470	.285	.022	.020	.770
SWM	.087	.156*	.146*	.148*	.138*	.101	.146	.159	.248**	.102	.078	.170	.160	.087	.181*
	.194	.016	.024	.022	.033	.298	.116	.088	.007	.273	.401	.061	.076	.334	.044

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

Using multiple regression analysis, HW predicted 2.7% of the variance of RVP in all participants ($r^2 = .05$, $F(5, 211) = 2.214$, $p = .05$, $p \leq .05$). The HW component, autonomy and parental support was statistically the strongest predictor of RVP scores for all participants ($r = .240$, $p = .01$, $p \leq .05$). RVP scores increased .001 for every one increase in autonomy and parental support score on the HW questionnaire.

There was no significant relationship between individual NCF components and reading scores (Table 5.3). There was a medium positive relationship between RVP and math scores, $r = .256$, $p < .01$. There was a medium significant negative relationship between SWM and reading scores for males, $r = -.273$, $p < .05$. There was no significant relationship between NCF and math scores. There was a medium significant negative relationship found between RTI and reading scores, $r = -.238$, $p < .05$ and a medium significant positive relationship was found between RVP and math scores, $r = .256$, $p < .05$ for females. These correlations are detailed in Table 5.3 below.

Table 5.3: Pearson Product moment correlations – NCF and AA.

	All		Males		Females	
	AA Reading	AA Maths	AA Reading	AA Maths	AA Reading	AA Maths
AST	-.034	-.023	.129	.085	-.152	-.110
	.709	.797	.344	.531	.210	.367
RTI	-.159	-.072	-.051	.038	-.238*	-.141
	.075	.426	.707	.776	.047	.247
RVP	.164	.256**	.124	.258	.195	.256*
	.067	.004	.362	.053	.108	.035
SWM	-.162	-.120	-.273*	-.233	-.086	-.029
	.069	.181	.042	.081	.481	.811

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

Multiple regression analysis revealed that AA predicted 5.5% of the variance of RVP ($r^2 = .071$, $F(2, 112) = 4.309$, $p = .02$, $p \leq .05$). Maths was statistically the strongest predictor of RVP score ($r = .27$, $p = .03$, $p \leq .05$). RVP score increased .006 every time a Maths score went up by one.

5.1.3 Pathway model

The chapter will now examine a potential pathway model that could be used to explain the relationship amongst the variables discussed thus far in this thesis, namely; NCF, PA, PF, HW and AA. The model proposed by this researcher is illustrated in Figure 5.1. The purpose of path analysis is to determine the sources of correlation between an independent and dependent variable (Carey 1998).

5.1.4 Pathway findings

Path analysis findings are outlined in Figure 5.1. CVF was negatively correlated with attention and psychomotor speed ($r = -.12, p < .05$) and cognitive flexibility ($r = -.16, p < .01$), and positively correlated with MVPA ($r = .46, p < .001$). MVPA was negatively correlated with cognitive flexibility ($r = -.10, p < .10$) and math ($r = -.20, p < .01$), and positively correlated with working memory and executive function ($r = .13, p < .05$). BMI was negatively correlated with both CVF ($r = -.29, p < .001$) and sustained visual attention ($r = .17, p < .01$). Working memory and executive function was negatively correlated with reading ($r = -.16, p < .01$). Attention and psychomotor speed was positively correlated with math ($r = .18, p < .01$) and negatively correlated with reading ($r = -.13, p < .05$). School Environment was positively correlated with psychological wellbeing ($r = .11, p < .10$). Physical wellbeing positively correlated with school environment ($r = .31, p < .001$), CVF ($r = .35, p < .001$) and negatively correlated with BMI ($r = -.24, p < .001$). Psychological wellbeing was positively correlated with physical wellbeing ($r = .459, p < .001$). Physical wellbeing was positively correlated with CVF ($r = .35, p < .001$). The values for NFI, TLI and CFI were 0.883, 0.976 and 0.988 respectively. The TLI and NFI values indicate that the measured variables are correlated while the CFI indicates the same taking into account sample size. The RMSEA was 0.018 indicative of a very good fit. Therefore, it indicates that the proposed model fits the data set well. From these value, we can conclude that the proposed model fits the populations covariance matrix.

There were a number of other paths (highlighted in blue in Figure 5.1) that were not statistically significant individually but were included in the model. These relationships are illustrated in Table 5.4. These relationships were removed from the original model and the path analysis was re-run. This revised model, shown in figure 5.2 proved to be a slightly better fit. The value for NFI dropped slightly to 0.863 but values for both TLI and CFI increased to 0.998 and 0.996 respectively. The RMSEA was .007 indicating a better fit than the original proposed model. These values indicate that the new model fits the revised data well. The strength of correlations between variables also changed slightly. These are illustrated in Figure 5.2.

Table 5.4: Relationships that were included in the original proposed model (fig. 5.1) but were not statistically significant.

Path	**Correlation**
CVF – Reading	.095
CVF – Math	.094
CVF – Working Memory & Executive Function	-.080
MVPA – BMI	.004
MVPA – Attention & Psychomotor Speed	-.095
Working Memory & Executive Function – Math	-.066
School Environment – Working Memory & Executive Function	.075
School Environment - CVF	-.036
Psychological wellbeing – BMI	.106
Sustained Visual Attention – School Environment	.078

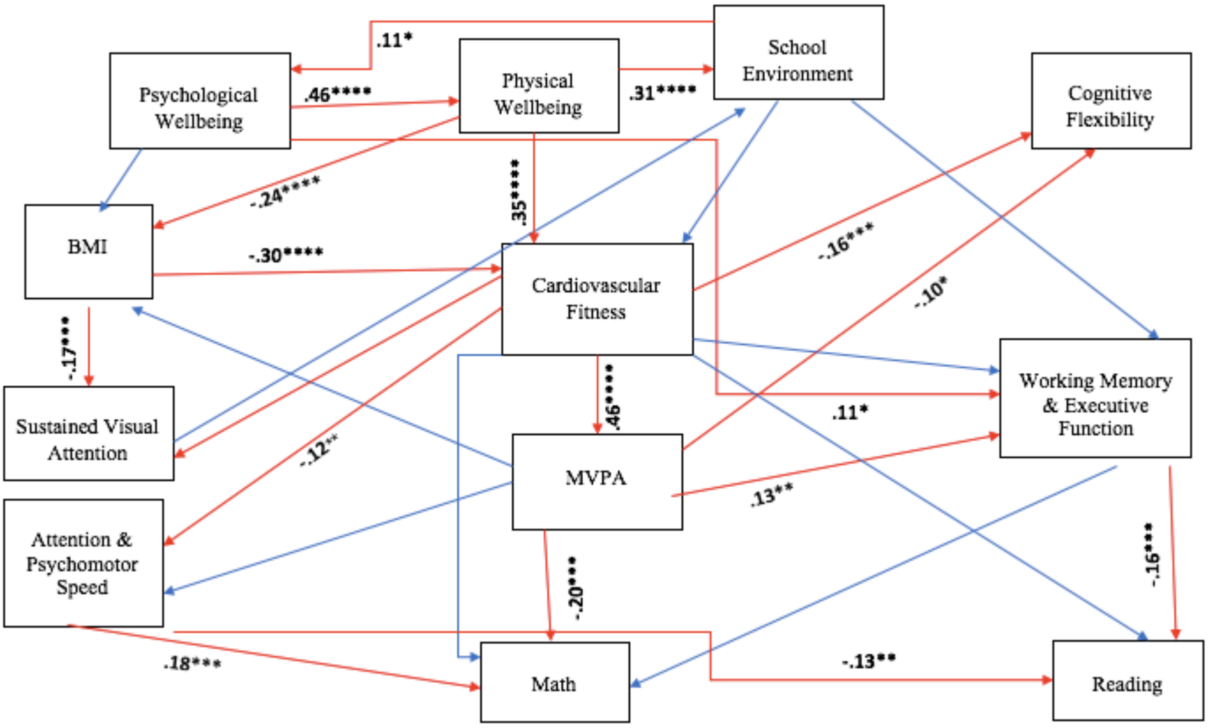


Figure 5.1: Potential model to demonstrate the importance of a holistic approach to the individual development of preadolescent youth.

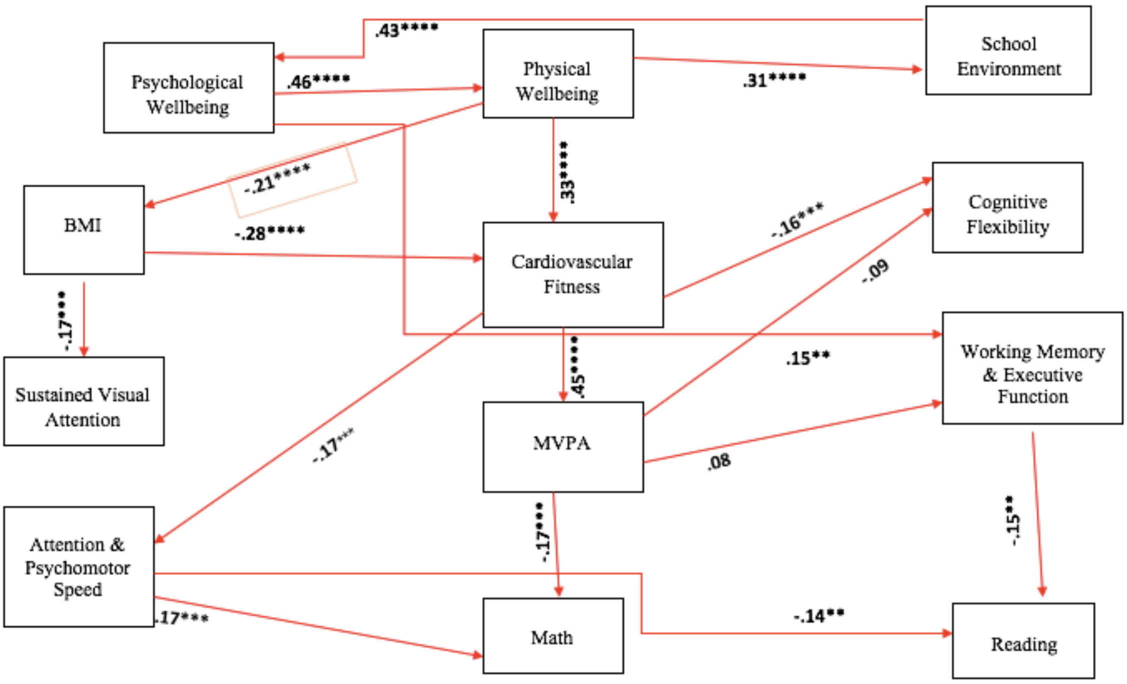


Figure 5.2: Revised potential model to highlight the importance of a holistic approach to the individual development of preadolescent youth.

Blue arrow = non-significant path, Red arrow = significant path, *= p<.10 ,** = p<.05, *** = p<.01, **** = p<.001.

5.2 Discussion

The purpose of this chapter was firstly to analyze the relationships between the following variables; NCF, HW and AA involved, and secondly identify a potential pathway model between all variables, to highlight the importance of a holistic approach to the individual development of preadolescent youth. This section will first discuss the correlation between variables NCF, HW and AA. This thesis has previously reported relationships between CF, PA and PF in Chapter four.

The relationship between NCF and HW

Multiple regression analysis revealed that HW predicted 3.1% of the variance of RVP. This model was significant (p = .037). Autonomy and parental relations made the strongest unique contribution (r = .225, p = .010). Both Pearson product moment correlations and multiple regression analysis have revealed evidence of a relationship between the autonomy and parental support component of HW with RVP. Girls also demonstrated a small relationship between RVP and autonomy & parent relations. There was a small negative significant relationship between RTI and physical well-being for boys. Satisfaction with autonomy and parental support was positively correlated with the ability to sustain visual attention in particular their ability to detect target sequences. Parents play an important role in shaping their child's development into adolescence an onto adulthood (Moretti & Peled 2004). The adolescent parent relationship has a profound effect on cognitive function (Moretti & Peled 2004). Moretti & Peled (2004) discuss Bowlby (1969) concept of 'attachment' or 'the attachment system'. Attachment or the attachment system is when children or adolescents relate to their parents as both an area where they feel secure from which then can explore and return and as a safe place where they can receive support and protection. Attachment or the parent child relationship has been shown to influence neurocognitive development (Carlson, 2003 & Allen et al. 2003).

Although preliminary Pearson product moment correlations revealed small correlations between SWM and HW, multiple regression showed no predictive power of HW on SWM. SWM had the most relationships with the components of HW, alongside RTI for boys and RVP for girls. SWM had small significant relationship with four out of five mental health components; psychological well-being, autonomy and parental support, social support and peers, and school environment. The positive correlations for SWM and HW could indicate that as scores increased in the SWM task (higher score indicates a worse performance), there MHW scores improved. On first glance, this result would appear puzzling. It has been argued amongst researchers that a positive mood would be expected to improve certain cognitive functions (Phillips et al. 2002). A healthy mind, is a term often used to denote both a health working mind and mood. There has been evidence however, that a positive mood may in fact damage some components of cognitive function, causing poor performance in working memory and executive function tasks (Seibert & Ellis. 1991). Martin & Kerns (2010) reported similar results for the effect of positive well-being on working memory. In their study, they reported that positive mood impaired storage and working memory. Seibert & Eillis (1991) reported that this could be due to the increase in load on working memory because being happy is inclined to increase the occurrence of mood related thoughts that interfere with the processing on a given cognitive task.

The relationship between NCF and AA

Good cognitive ability and function is of significant importance in predicting academic achievement (Rohde & Thompson 2007; Deary et al. 2007; Bull & Lee. 2014 & Finn et al. 2014). Further to this, Deary et al. (2007) attained significant correlations during their five-year longitudinal study on 70,000 British school children between cognitive function ability and academic achievement. Multiple regression and a Pearson product moment correlation have showed strong relationships and predictive power between NCF and AA. Pearson product moment correlations revealed a positive relationship between RVP and maths scores for all participants, a negative relationship between SWM and reading for males only and a negative relationship between RTI and reading for females and a positive between RVP and maths scores for females only again. Results indicate that as RVP scores increased so did scores in math for all participants. A higher score in the RVP task indicated an ability to detect target sequences and maintain visual attention. Anobile, Stievano & Burr (2013) investigated the relationship between mathematical performance and sustained visual attention in school children aged 8 – 11 years. They reported that attention and participants' perception of numeric numbers were a significant predictor of performance in math. SWM scores decreased as reading scores increased for males only. A lower score in the SWM task indicated an ability to retain and manipulate visual spatial information from working memory. WM plays a vital role in the many forms of complex cognition i.e. learning, reasoning, problem solving and language comprehension (Vuontela et al. 2003). WM is the most prominent predictor of AA scores (Lan et al. 2011) and the ability to solve mathematical problems (Beilock & Carr 2005). It is essential in making sense of written and spoken language and performing math equation in your head (Diamond 2013). WM ability has been correlated with math and reading ability amongst adolescents (Finn et al. 2014).

For females, their scores on the RTI task decreased as their scores for reading increased. A lower score on the RTI task indicated a sufficient reaction from the individual in question and the ability to respond accurately under impulses. RVP scores increased for those females who had achieved a higher maths score. This performance in the RVP would indicate an ability to sustain visual attention and detect target sequence sufficiently. Multiple regression analysis revealed, for all participants, that every time an individual's math score increased by one their score for the RVP task increased by .006. This would indicate that sustained visual attention and the ability to detect a target sequence influences math scores. These results are in line with previous research conducted by Lan and colleagues (2011) & Engle de Abreu et al. (2014). They reported that working memory, executive function and attention uniquely predicted academic achievement, both reading and math.

Pathway model

The model presented in this chapter proposes that there is a negative correlation between CVF and attention and psychomotor speed and cognitive flexibility, and a positive correlation with MVPA. A higher score in both the attention and cognitive flexibility tasks indicated a worse performance. CVF had a positive influential relationship with both attention and psychomotor speed and cognitive flexibility suggesting that a higher fit individual will have increased attention, psychomotor speed and cognitive flexibility. In a meta- analysis review, Smith et al. (2010) reported that aerobic exercise was associated with discreet improvements in attention and processing speed. Similar results were reported by Scudder et al. (2014) where greater aerobic fitness was significantly associated with shorter reaction time, superior accuracy in attention tasks and with aspects of cognitive flexibility. Masley et al. (2009) performed a study on 91 healthy adults who took part in a 10-week aerobic exercise intervention. They concluded that by increasing aerobic exercise over a 10-week period, participants performance on cognitive flexibility tasks was enhanced. The results from this study is consistent with previous authors (Barnes et al. 2003, Colcombe & Kramer 2003 and Churchill et al. 2002) who advocate that frontal lobe activities linked with cognitive flexibility and attention showed the greatest enhancements in cognitive performance with increasing aerobic exercise and fitness (Masley et al. 2009). CVF correlated highly with MVPA. This in line with previous research conducted by Prioreschi et al. (2017) who reported that MVPA significantly correlated with fitness level.

MVPA was negatively correlated with math scores. As time in MVPA increased, math scores decreased. Van Dijk et al. (2014) reported similar results in their study. Some researchers have suggested that too much time spent in MVPA could take time away from academic work such as homework and other academic pursuits (Van Dijk et al. 2014; Syvaoja et al.,2013; Esteben-Cornejo et al. 2014 & Owen et al. 2017). Van Dijk et al. (2014) and Tremblay et al., (2010) state that it is possible that MVPA could potentially benefit academic achievement so long as it does not detract from academic work.

MVPA was negatively correlated with cognitive flexibility and math and positively correlated with working memory and executive function. A higher score in the cognitive flexibility and working memory and executive function task indicated a poorer performance. MVPA positively influenced cognitive flexibility within the task however it negatively influenced working memory, executive function demands. This result is in contrast to that reported by Booth et al. (2013) reported that MVPA positively influence executive function. Mucke et al. (2017) on the other hand did not report any difference in performance in cognitive flexibility or working memory. These contrasting results could be due to the different measurement tools for cognitive function used by each study or as a result of a ceiling effect on tasks (Mucke et al.,2017).

BMI was negatively correlated with both CVF and sustained visual attention. In this case a higher score indicates a poorer performance in the sustained visual attention task. These relationships suggest that as BMI decreases CVF increase and as BMI increases the score in the sustained visual attention task increases indicating a poor cognitive performance in this task as a result of a higher BMI. These results would indicate that those with a lower BMI were more likely to be fitter and have improved ability to sustain visual attention than those that had a higher BMI. This finding reflects one that was reported by Bauer & Manning (2016), who reported that there were reductions in sustained visual attention performance in overweight/obese females who had elevated BMI levels. Zamzow et al (2014) reported similar findings for both genders aged 8 – 19 years of age. Araujo et al., (2015); Hsieh et al. (2014) and Joshi et al. (2012) all conducted separate studies to illustrate the relationship between BMI and CVF. They all reported an inverse relationship between BMI and CVF.

Working memory and executive function were negatively correlated with reading. This result indicates, that as working memory and executive function scores decreased (a higher score indicates a worse performance), AA reading ability improved. It is a widely known fact that working memory is associated with reading comprehension ability (Carretti et al. 2009). Gathercole et al. (2006) reported that working memory skill independently predicted achievement in reading in a sample of 46 6 – 11 year olds with reading disabilities. Cain, Oakhill & Bryant (2004) also demonstrated in their study, the link between working memory and reading comprehension skills in children aged 8, 9 and 11 years. They concluded that working memory was a predictor of the unique variance in reading comprehension. Both reading and executive function have been put forward as essential stepping stones for literacy development (Engel de Abreu et al. 2014). Engel de Abreu et al. (2014) reported two findings from their study on executive function and reading achievement in 106 school children aged 6 – 8 years old. The first, that individual differences in executive function components influenced early reading achievement, and secondly; children who's reading performances were classed as below par by classroom teachers demonstrated limitations in the working memory component of executive function.

Attention and psychomotor speed was positively correlated with math and negatively correlated with reading. A higher score indicates a worse performance in the attention and psychomotor speed task, therefore a poorer attention and psychomotor speed ability led to an improved math score and a worse reading score. Murrihy et al. (2017) reported no direct effect of psychomotor ability on math or reading ability in a study involving 133 8 – 12-year-old children. This could be due to the different measures used in studies and differences in population type (normal vs clinical) (Murrihy et al. 2017).

School Environment was positively correlated with psychological and physical wellbeing, indicating that if participants were happy in their school environment, they were also happy psychologically. The school environment is recognised as one of the most important settings for the promotion of a young person's mental health and well-being (Department of Education & Skills, 2015). The school environment component of the KIDSCREEN-27 questionnaire, explored participants awareness of his/her cognitive capacity, learning, concentration, feelings about school and their view on their relationship with their teachers (Ravens-Sieberer et al. 2014). Psychological wellbeing examined the psychological wellbeing of participants, including positive emotions, satisfaction with life and lack of feelings of sadness and loneliness (Ravens-Sieberer et al. 2014). If participants were happy in their school environment, they were intrinsically satisfied with themselves. In their construction of a questionnaire to capture young person's insights of how school as a learning environment effects their well-being. Schools play a vital role in the promotion of moral, spiritual, social and personal development of students (Government of Ireland 1998). Mental health and well-being should permeate all aspects of school life and should be incorporated into school policies in order to promote mental health and well-being in both staff and students (DES, 2015). Awartani et al. (2008) formulated a hypothesis that school learning environments influence youth well-being. They proposed 10 domains centered around the school environment that were hypothesized to effect psychological well-being; physical emotional safety, emotional well-being, satisfying relationships in school, confidence in capabilities, pleasure in learning, inner vitality, a sense of inter connection with all of life and finally overall satisfaction with life. Spratt et al., (2006) also examined ways in which school environment can impact children's psychological well-being. Both studies concluded that the school environment is a vital component in the development of children psychological well-being.

Physical wellbeing positively correlated with CVF and negatively correlated with BMI. These strong correlations would indicate that if participants were mentally happy with their physical health and wellbeing they were more likely to be fitter, happier in school and have a lower BMI. The physical well-being component of the KIDSCREEN-27 questionnaire examined that level of participants physical activity, energy, fitness and the degree to which a participant felt unwell enough and complained of poor health (Ravens-Sieberer et al. 2014). In a study conducted by Doll et al. (2000), to clarify the association obesity and well-being, they reported that physical well-being was significantly associated with BMI. As BMI increased, there was a deterioration in physical wellbeing. Physical wellbeing was strong positively correlated with CVF. This relationship would indicate that participants' physical wellbeing had a positive effect on their CVF level. Anderson et al. (2017) reported that physical wellbeing was strong related to CVF. The result of this study, and of the study in this thesis is not surprising as the physical well-being component has many similarities to fitness; feeling fit and well, being physical active, run well and full of energy (Anderson et al. 2017).

Psychological wellbeing was marginally positively correlated with physical wellbeing and working memory and executive function. Psychological wellbeing and physical wellbeing are both components of the mental health and wellbeing questionnaire completed by participants. This strong correlation would indicate that if participants were mentally happy that they would be physically happy with their health. Health can impact well-being and well-being can in turn effect health (Howell et al. 2007). Howell et al. (2007 meta-analysis review highlighted with complex interrelations between health and well-being. In a separate review Biddle & Assare (2011) reported that research has indicated that those who are more physically active are more like to be happier and suffer less with mental health problems and have improved cognitive functioning. This thesis reported a negative effect of psychological well-being on working memory and executive function (a higher score in the SWM task indicated a poorer performance). The capacity to regulate emotional information in working memory is discussed by Pe et al. (2013). The result presented in this thesis in contrast with results reported by Pe et al. (2013). A cohort of undergraduate students participated in this study. Pe et al. (2013) reported that participants who were able to retain and update positive information in working memory had higher levels of satisfaction and experienced more positive emotions throughout the day. Conversely Mitchell & Phillips (2007) discussed the negative impact of a positive mood on executive function, updating, planning and switching which would support the result presented in this thesis. These cognitive effects may be linked to increased levels of dopamine (Mitchell & Phillips 2007). A positive mood can lead to a heuristic style of processing (Bohner et al. 1994). Heuristic processing involves using shortcuts to reach an answer (Mitchell & Phillips 2007). This theory could explain the results of this thesis. Participants elevated mood may signify an absence of threat and a lack of motivation to alter the situation placed in front of them (Bohner et al. 1994).

5.3 Conclusion

This chapter has demonstrated the interaction effect between the variables, PA, PF, NCF, AA and HW and the importance of looking at all of these as whole when considering the development and education of preadolescent individual. The statistical significance of the model ($x2 = 49.706$, $df = 49$, $p = .445$) shows the importance of these variables as a model in the life of a preadolescent child. This model shows that we should not isolate one variable when seeking to improve the quality of life of a child or in research, but rather they should each be looked at collectively. Wellbeing is beginning to play a prominent role in Irish education and rightly so. This chapter demonstrated relationships between components of well-being and variables such as fitness level, working memory and executive function and BMI. An individual's HW has the potential to impact other aspects of their lives. It is extremely important that we provide continuous policies and research on how to improve and maintain a healthy HW status amongst preadolescent youth, particularly as they enter their adolescent years where a number of physiological, psychological and socioeconomic changes occur. The Department of Children and Youth Affairs (2012) maintains that youth should be active and healthy, with a positive physical and mental wellbeing. In Ireland, surveys have shown (this current study included), that youth in Ireland demonstrate a positive mental health and wellbeing status (Department of Health 2012).

Chapter Six: Conclusion

6.1 Summary Discussion

There has been substantial interest in the association between physical activity (PA) and cognition in recent years (Carson et al., 2016, Booth et al., 2013 & Vanhelst et al. 2016). It is important to determine what components of both cognitive functioning are affected by specific PA intensities and cardiovascular fitness (CVF). (Best 2010 & Booth et al. 2013). Childhood is a period of enormous growth and development (UNESCO, 2014). This thesis aimed to explore the relationship between PA intensity levels and CVF on cognitive functioning within the brain. This thesis has demonstrated that the moderate-vigorous PA (MVPA) intensity level along with a healthy CVF level will enhance neuro-cognitive function (NCF), in particular attention. Research has demonstrated that a holistic approach to a child's development and education will increase their chances of completing school and allow for experiences of good physical and mental health (UNESCO 2014).

Results presented in Chapter four demonstrated the relationship between PA intensity levels, CVF and cognitive functions with specific focus on attention, cognitive flexibility, working memory and executive function. Light PA (LPA), Moderate PA (MPA), Moderate-Vigorous PA (MVPA), Vigorous PA (VPA) and CVF all demonstrate relationships with individual components of neuro-cognitive function (NCF). These results are consistent with current literature and research on the relationship between PA intensity levels, CVF and NCF (Davis et al. 2011; Woods et al. 2010; Booth et al. 2013; Vanhelst et al. 2016 & Hillman, Castelli & Buck, 2005). In a meta analysis conducted by de Greeff et al. (2018), it is discussed that even a single bout of PA can increase the allocation of attention. Sustaining attention is a fundamental basic requirement for information processing (Luque-Casado et al. 2016). The ability at sustain visual attention is important in a classroom environment. This study along with previous research highlights the importance of being cardiovascular fit for optimal attentional control and functioning cannot be ignored (Geertson et al. 2016; Cooper et al. 2012; Ploughman, 2011 & Van der Niet et al. 2016). Higher fitness levels encourage elevated neuroelectric activity in the brain which allows for an improved ability to sustain visual attention (Luque-Casado et al. 2015). The ability to sustain attention is vitally important in all aspects of life, concentrating in school, driving, listening etc. (Hanania & Smith 2010). It has been noted that those who have a higher VO2 max as a result of team sports, may score higher in cognitive tasks due to increasing task demands during certain activities and a highly stimulating environment (Dalziell, Boyle, Mutrie, 2015 & Marchetti et al. 2015).

Results presented in Chapter five demonstrate a potential model highlighting the importance of a holistic approach in the development and education of a preadolescent individual. The model proposed in Chapter five encompassed neuro-cognitive function (NCF), physical activity (PA), cardiovascular fitness (CVF), academic achievement (AA) and health and well-being (HW). The statistical significance of the model ($x2 = 49.706$, $df = 49$, $p = .445$) shows the importance of these variables in the life of a preadolescent child. Offering holistic support and approaches for child development and education necessitates coordinated and collective efforts by researchers, policy makers, parents, guardians and educators (UNESCO, 2014). Development is holistic as it encompasses physical, social, emotional and cognitive domains (UNESCO 2014). These elements need to be taken into account together when assessing, measuring, intervening and researching child development and education (UNESCO 2014). Individually, the elements mentioned above play a massive role in a child's life as they grow and develop (UNESCO 2014). This philosophy of a holistic approach to a child's development has always been present (Bronfenbrenner 1974 & UNESCO 2014). The WHO definition of health encompasses this philosophy. They define health as *"A state of complete physical, mental and social well-being"* (WHO 2004, p1). To achieve this optimal health outcome, children must be given the opportunity to become physically active, achieve a healthy cardiovascular fitness level, develop a healthy functioning cognitive system, develop a positive state of well-being and achieve academic success (Woods et al. 2010; UNESCO 2014; DHC 2009; DES 2015; Awartani et al. 2008; Khan et al. 2014; Black et al. 2017 & Kohl & Heather 2013). This will ultimately come down to policy makers, researchers and educators undertaking a holistic approach to the development of policies and curriculums for children.

6.2 Research Strengths

This thesis has introduced the reader to the relationship of PA intensity levels and CVF on NCF and the importance of a holistic approach to the development and education of a child. While this thesis was not absent of shortcomings (which will be discussed later), there is strong evidence presented that the design and investigation of this thesis were based on thorough research consideration.

One of the immediate strengths of this thesis was the use of the CANTAB measurement tool for analyzing neuro-cognitive function. Research has shown it is a suitable tool to measure cognitive function in 4 – 90-year-old individuals (Syvaoja et al. 2015).

Another key strength of this thesis was the use of health and well-being questionnaires to collect rich meaningful data, relating to participants health and well-being (O'Brien, 2013).

The use of Actigraph accelerometer devices (GT1M, GT3X and GT3X+) (Freedson et al. 2005 & Trost 2007), provided appropriate rich information relating to PA intensity, duration and frequency. Additionally, the use of stringent inclusion criteria for the accelerometer data (minimum wear time, cut points, non-wear periods etc) (Trost et al. 2011) guaranteed strength within our PA methodology.

6.3 Research Limitations

1. *Physical Activity Inclusion criteria:* The stringent inclusion criteria (wear time, number of weekdays and weekend etc) was a strength of accelerometer analysis. These stringent inclusion criteria allowed for the collection of a detailed representation of objectively measured habitual preadolescent PA behavior and time spent in each PA intensity level. While this was significant strength of the study, these stringent inclusion criteria meant that some participants were excluded from the statistical analysis as they did not have the required minimum amount of accelerometer data.
2. *Physical Activity Compliance:* Participant compliance in wearing accelerometers was a limitation for the studies in this thesis. Many strategies were put in place to encourage participant compliance (reminder text message sent out each morning, lead researcher was present in school each morning to check monitor was being worn etc). Despite the application of these strategies there was still a large amount of data lost due to non-compliance.

3. *Neuro-Cognitive Measurement Tool:* The use of the CANTAB measurement tool for assessment of neuro-cognitive function can be seen as both a strength and a limitation. The CANTAB tests were originally designed for assessment in clinical settings. Some of the tests used may have been too easy for our healthy population of preadolescents resulting in unexpected or lack of relationships between NCF and PA intensity levels (Syvoaja et al. 2014).

6.4 Future Directions

Following the research presented in this thesis, the following are this researchers recommendation for future directions:

1. A longitudinal study is warranted to monitor and evaluate the development of NCF in preadolescence as the progress through to adolescence years. Adolescence is a time where a lot of change occurs with potential effects on NCF development.
2. A longitudinal study is warranted to monitor and evaluate the change in PA intensity levels as participants grow and develop and the relationship this has with NCF.
3. Research is needed on the effect of pre-and-post PA on NCF. This thesis along with previous research has demonstrated that there is a relationship between PA intensity levels, CVF and NCF.
4. There are many factors that influence the growth and development of an individual. This thesis has proposed a potential model that emphasizes the importance of a holistic approach to this development of an individual. Further research is needed in this area in the development of a concrete model that can be used to direct future policies and curriculum on the holistic approach of development in children.

6.5 Closure

The importance of being physically active cannot be ignored. The extent to which certain intensities of PA affect certain aspects of an individual's health is continually being researched (Hillman et al. 2017; Aadland et al. 2017; Donnelly et al. 2016 & Pindus et al. 2016). The health implications are endless. Research has shown that MVPA is the recommended PA intensity level to exercise at on a daily basis to counteract the detrimental effect of sedentary behavior (Tremblay et al., 2010). Time spent in both MPA and VPA can illicit health benefits for an individual (Owens, Galloway & Gutlin 2015). On their own, however, MPA my not be intense enough to cause a change in cognitive function performance (Felez-Nobrega et al. 2017 & Owens et al. 2017), and time spent in VPA may induce fatigue resulting in a poor cognitive performance on tasks (Vanhelset el. 2016). A healthy VO2 max is vital for both respiratory and vascular function e.g. the transport of blood around the body and brain (Armstrong 2006). Everything in the body is linked, with instructions and information, coming to and from the brain. The brain is an area bustling with activity; processing information, retention and manipulation of this information, switching and attending to multiple tasks at the same time, the list is endless. External factors along with internal ones can often influence the efficient functioning of the brain, factors such as: PA, CVF, AA and HW.

Childhood development is a maturational and interactive process involving physical fitness, cognitive, language, socio-emotional, perceptual and self-awareness skills (Black et al. 2017). Children develop optimally when they attain developmental competencies for academic, behavioural, socio-emotional and economic achievements (Black et al. 2017). There are multiple elements that influence the ability to acquire these competencies, such as, health (physical and mental), early learning and education that will benefit their cognition an academic performance (Black et al. 2017). It is the interaction of these elements, that will result in optimal development during childhood, into adolescence and onto adulthood. Future research should focus on longitudinal studies that will monitor and evaluate the development of NCF in preadolescence as they progress through adolescence and the relationship this has with a change in CVF and time spent at certain PA intensity levels. Further research is also needed in the development of a concrete model that can be used to direct future policies and curriculum on the holistic approach of development in children.

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Appendices

Appendix A – Procedures and Instructions for Accelerometer distribution

Prior to visiting the school (lead researcher):

- Ensure that all Actigraphs have been initialized.
- Ensure that the lead researcher had a master copy printout of the excel sheet identifying participant name, sub group of participant (1 - 5), student ID number, and associated accelerometer code.
- Ensure lead researcher had copy of the group names and ID codes for participant in each of the sub groups (1 - 5).
    - Codes = School, class, group, participant number
    - e.g. A1322 = Abbey, Class 1, Group 3, participant 1
- Ensure that accelerometers for each sub group (1 – 5) were held together by elastic band and sub group number clearly marked on attached label.
- Ensure lead researcher had labels for the sub groups with participant ID codes written on them.
- Ensure lead researcher had put 5 A2 posters up on wall identifying Sub group number and participant names.
- Folder ready for each <u>sub group leader</u> containing
    - Clip board with master copy excel sheet, ID labels, Assent forms
    - Accelerometers
    - Pencils

Below is set of exact instructions and procedures that were carried out by the research team at the time of data collection.

<u>Accelerometer protocol</u> - On the day of the visit:

Participants were instructed to line up in number order in their groups. Each group was assigned a sub group leader. Students were checked that they had been assigned to the correct group. Each participant received ID labels, it was explained to students that they will be using this same code every time we came to the school. It was explained that this was so no one will see their name on any of the information we had gathered. Each tester gave an accelerometer pack to each of the participants in their group. Accelerometer number was recorded beside each participants ID number.

Instructions to the Student for accelerometer given by Team leader:

- "The monitor, attached to the elastic waist belt should be worn on the center of the right hip. The belt can be worn under or over clothes". (Demonstrate)
- "The Actigraph should be positioned snugly against the body and not allowed to flop around".
- "It should be put on first thing in morning and taken off just before going to bed". Participants were informed that they should place the monitor somewhere where they will see it first thing in the morning. It was suggestedthat students set a reminder/alarm on their mobile phone (if they have one) in the morning so that they don't forget to put it on.
- Inform them that the Actigraph is **NOT** waterproof, it **CANNOT** be worn in the shower/bath or when swimming.
- Inform them that the Actigraph **CAN** be worn when playing sports (non-contact)
- Show participants the 'Record Card' and tell them they will all be given one to take home at the end of the class.
- Inform participants that should they need to remove the Actigraph for any period of time over the course of the week (other than when they are going to bed) that they **MUST** note this on their 'Record Card'.
- They should make note of the time it is taken off at, the time it is put back on at and the reason why they needed to take it off. This is particularly important if the Actigraph is removed because the student is playing a contact sport/swimming. They should also do this if they **FORGET** to wear the Actigraph for any period of time.

Questions (understanding check) to be asked of the students by the Sub group leader

- On what part of the body should you wear the accelerometer?
- When should you take the accelerometer off?
- What should you do if you take the accelerometer off during the day to take part in an activity?
- How are you going to remind yourself to put the accelerometer on first thing in the morning? (suggest setting reminder in phone).

Appendix B – Procedures and Instructions for Cardiovascular Fitness measurement.

The procedure was as follows:

1. Measure **<u>20m</u>** and mark a line at each end with cones.
2. Space 15 cones equidistance apart on each line – each participant was given a specific cone.

<u>Instructions were as follows:</u>

1. "This is a running endurance test. The aim of the test is to run for as long as you can, while keeping up with the beeps on the CD."
2. "Each person will start standing at a cone on the line"
3. "After a 5s countdown you will hear a **<u>triple beep</u>**. After the triple beep, there will be a single beep. On this beep, start running to the cone opposite your one, on the far line."
4. "The test starts **<u>SLOWLY</u>**. Try your best to keep in time with the beeps – <u>so start off slow</u>. If you do get to the line before the beep, wait at the line until you hear the beep. Then run back."
5. "Run continuously back and forth between the cones, keeping in time with the CD beeps."
6. "If you don't reach the line in time, we will give you a warning and tell you "**<u>You must make the next line in time with the beep"</u>**. If you don't make it in time, the test will be over for you and you can stop running".
7. "If you make the line after receiving a warning the test continues as normal, and you will receive a warning the next time you don't reach the line in time with the beep.
8. "The most important thing for this test is to try keep running for as long as you can and not stop until one of the testers tells you to."
9. "When you are finished running line up beside *TESTER* in the order you finished running."

Appendix C – Procedures and Instructions for height measurement using the Leicester Height Measure Kit show below

Instructions to participants was as follows:

1. Remove shoes
2. If the hairstyle affects their height, ask them to adjust it for the test
3. Stand with heels and toes together on the base plate
4. Arms loosely by their side
5. Back straight against the vertical measuring rods
6. Look straight ahead in a horizontal line
7. Take a deep breath and stand as straight as possible without their heels lifting off the ground.

Appendix D – Procedures and Instructions for weight measurement using the Secca scales shown below

Below is set of exact instructions and procedures that were carried out by the research team at the time of data collection.

Instructions to participant was as follows:

1. Wear only light garments
2. Remove items such as keys and money from pockets
3. Remove shoes.
4. Stand on the scales, with both feet fully on the weighing platform, heels towards the back edge, and their arms loosely by their side.
5. Remain as still as possible with their head facing forward (N.B. some children may not want to know their weight, record it without telling them unless they wish to see).
6. Step down from the scale.

Appendix E – Procedures and Instructions for CANTAB

The protocol used was as follows:

1. When the participants enter the room ask them do they need to use the toilet as they will be sitting down for a length of time.
2. Have a glass of water available at each iPad station.
3. Ask them if they need to wear glasses or use a hearing aid.
4. Make sure they are seated comfortably and within touching distance from the iPad screen which will be sitting on a stand.
5. Check participants date of birth and corresponding ID numbers is correct.
6. Give the participant a brief explanation of what will happen:
   - "You will do a series of touch screen tests".
   - "You will hear the instructions in your headphones. Listen clearly to them".
   - "The volume control button is located at the top of the Ipad on the left hand side".
   - "If you encounter a problem please raise your hand and a tester will come to your assistance" **.
7. Instruct students to put on headphones.
8. Press 'run test' when students are ready.
9. Record anything that happened. Any observations that may have a negative impact on results.
10. You will be asked to enter your password after the completion of each test.
11. Wipe the iPad screen with an alcohol wipe after each participant is completed.

**<u>Pausing/aborting a Test</u>

- Do not abort a test unless absolutely necessary
- If you need to pause or abort a test:
  1. Tap with 2 fingers simultaneously in the lower left and upper right corners of the screen.
  2. You will be asked whether you want to exit the test. The test is now **paused** and can be resume at any time by pressing **No.**

3. Tap **Yes** to abort.

- If aborted the data will be saved up until your last completed test. Data will not be saved for any tests that are aborted before completion. However, an aborted testing session can be resumed.
- Resuming a test:
- If a test follows on from an earlier interrupted testing session that was aborted, you will be asked whether you want to continue after the last completed test.
- Tap **Yes** to continue (or **No** to abort).

Appendix F – Procedures and instructions for the distribution and administration of the KIDSCREEN-27 QOL questionnaire

The procedure was as follows:

1. Students were seated in a normal classroom setting.
2. Each student was given a questionnaire and their name was checked on a list to make sure that consent forms had been signed by a parent/guardian.
3. The students were all given an individual ID number to be written on their questionnaire.
4. The students were given a brief outline of the aims of the questionnaire and a detailed instruction on how to complete the questionnaire.
5. Students were informed that the questionnaire was not a test, that there were no right or wrong answers, and that the responses they gave needed to be accurate and honest.
6. Students were encouraged to ask any questions that they may have by raising their hand and a researcher would come to their assistance.
7. Students were informed that their answers would be treated in strictest confidence and their ID numbers would be used in replace of their names.
8. Students were informed to take their time completing the questionnaire, read questions carefully and focus on themselves.
9. Once students reached the final question and reached a page with 'Take a Break", they were instructed to put down their pens and wait until further instruction.
10. An example question was written on the board in the classroom and the researchers explained each of the different answer options. Students were to tick the option that applied to them.
11. The students were instructed to tick only one box at each question.
12. Both researchers and the class teacher moved around the classroom asking students if they were able to understand the questions and had a quick check on students' questionnaires to see if they were being completed correctly.
13. Before handing up their questionnaires students were instructed to make sure their ID number was filled in correctly and all questions were answered.

14. Students handed up their questionnaires and were praised and thanked for their cooperation.

Appendix G – Coles & Lobsteins' (2012) BMI classification for boys and girls up to the age of 18 years

BMI (kg/m²) at age 18 years							
		Boys			**Girls**		
Age (months)	Age (years)	23 Normal Weight	25 Overweight	30 Obese	23 Normal Weight	25 Overweight	30 Obese
132	11	18.76	20.51	25.07	18.89	20.66	25.25
133	11.08	18.81	20.56	25.15	18.95	20.73	25.36
134	11.17	18.86	20.62	25.24	19.02	20.81	25.46
135	11.25	18.91	20.68	25.32	19.09	20.89	25.57
136	11.33	18.95	20.74	25.4	19.15	20.96	25.67
137	11.42	19	20.79	25.48	19.22	21.04	25.77
138	11.5	19.05	20.85	25.56	19.29	21.12	25.87
139	11.58	19.1	20.91	25.64	19.36	21.2	25.98
140	11.67	19.15	20.97	25.72	19.42	21.27	26.08
141	11.75	19.2	21.03	25.79	19.49	21.35	26.18
142	11.83	19.25	21.08	25.87	19.56	21.43	26.28
143	11.92	19.31	21.14	25.94	19.63	21.51	26.38
144	12	19.36	21.2	26.02	19.7	21.59	26.47
145	12.08	19.41	21.25	26.09	19.77	21.66	26.57
146	12.17	19.46	21.31	26.17	19.84	21.74	26.67
147	12.25	19.51	21.37	26.24	19.91	21.82	26.76
148	12.33	19.56	21.43	26.31	19.98	21.9	26.86
149	12.42	19.61	21.49	26.38	20.05	21.97	26.95
150	12.5	19.67	21.54	26.45	20.12	22.05	27.05
151	12.58	19.72	21.6	26.52	20.19	22.12	27.14
152	12.67	19.77	21.66	26.59	20.26	22.2	27.22
153	12.75	19.82	21.72	26.66	20.33	22.27	27.31
154	12.83	19.88	21.78	26.73	20.39	22.35	27.4
155	12.92	19.93	21.83	26.8	20.46	22.42	27.49
156	13	19.99	21.89	26.87	20.53	22.49	27.57
157	13.08	20.04	21.95	26.94	20.59	22.56	27.65
158	13.17	20.09	22.01	27	20.66	22.63	27.73
159	13.25	20.15	22.07	27.07	20.72	22.7	27.81
160	13.33	20.2	22.13	27.14	20.79	22.77	27.88
161	13.42	20.26	22.19	27.2	20.85	22.84	27.96
162	13.5	20.31	22.24	27.26	20.91	22.9	28.03
163	13.58	20.37	22.3	27.33	20.98	22.97	28.1
164	13.67	20.43	22.36	27.39	21.04	23.03	28.16