The Early Childhood Development of Inhibitory Control, Motor Control and Drawing Skills

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ABSTRACT

Research has broadly shown that Inhibitory Control and drawing skills are directly associated in early childhood development. The current study extends this in three studies investigating the role of Motor Control in this relationship, and the differences between three different drawing skills in their relationships with Inhibitory Control, Fine and Gross Motor Control, IQ, age and gender.

Study 1 found strong positive correlations in 3- and 4-year-old children (n=100) between Inhibitory Control, Fine Motor Control, age and two drawing skills (Figurative Representation and Detail). Mediation analyses however demonstrated that Fine Motor Control fully mediated the relationship between Inhibitory Control and these drawing measures. In contrast, the association of Inhibitory Control with Visual Realism of drawing was not mediated by Fine Motor Control, meaning that Inhibitory Control directly influenced Visual Realism (which is children’s tendency to draw what they see, rather than what they know is there). The relationship of Visual Realism with age was, however, surprisingly negative.

Study 2 (n=100) tested further the relationship between Inhibitory Control and Fine Motor Control to reveal any additional role played by Gross Motor Control or verbal IQ. The strong association between Inhibitory Control and Fine Motor Control in early childhood was confirmed: Inhibitory Control and Gross Motor Control were not directly linked, but Fine Motor Control mediated the relationship between Inhibitory Control and Gross Motor Control, while IQ played no major role.

Study 3 investigated whether the development with age of Visual Realism in fact follows a U-shaped pattern in children (n=233), accounting for the negative correlation between these among preschoolers. Such a pattern would indicate that children start drawing with visual

realism, then move to intellectual realism and then back to visual realism. Some support was found for this hitherto unreported pattern of development.

DEDICATION

I would like to dedicate this work to my parents. It is your dream for me, which has resulted in this achievement. It is your nurturing and loving upbringing that enabled me to become what I am today. This is such a small thing in comparison with what you have given me. Oh Mum, the greatest word in existence. You are Hope, Love and Life.

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In addition, I would also like to thank my second supervisor, Dr. Nicolas Geeraert, for his generous willingness to help me just when I needed it. Nicolas is a very cooperative and wonderful person in the way that he treats me as a student. He was very helpful in working with SPSS and I am very grateful for his extra efforts in helping me to analyse and understand my data.

I am also full of thanks to the children and their families who generously devoted their time to participate in the studies included in this thesis. I particularly wish to thank the participants in the longitudinal study, who willingly engaged in the tasks repeatedly over a period of one year.

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Abbreviations

BPVS-2: The British Picture Vocabulary Scale – Second Edition

EF: Executive functioning

FD: Figurative detail

FMC: Fine motor control

FR: Figurative representation

GMC: Gross motor control

IC: Inhibitory control

MC: Motor control

PDMS-2: The Peabody Developmental Motor Scale – Second Edition

SRC: Stimulus-response compatibility (task)

VR: Visual realism

IQ: General intelligence

DCD: Developmental Coordination Disorder

ASD: Autism Spectrum Disorder

ADHD: Attention Deficit Hyperactivity Disorder

Definitions of Key Terms

Drawing: This can be defined as the production of graphic shapes (other than those associated with written language), using a pencil or the like, not paint, which for a variety of reasons represent meaningful pictures or diagrams for people (Hope, 2008).

Executive functioning (EF): This is a person's level of higher order thinking, which is usually seen as having a number of components including: 1) working memory, 2) planning, and 3) response inhibition, also known as IC (Gross & Grossman, 2010). It is the last of these which the current study is mainly concerned with.

Fine motor control (FMC): Motor control (and associated skills) is subdivided into gross motor control and fine motor control (Gallahue and Ozmun, 2006). Fine motor control requires the skilful use of small muscles (e.g. in hands and fingers) to produce precise and refined movements required for daily activities, such as feeding oneself, dressing, and writing and drawing (Cools, De Martelaer, Samaey & Andries, 2009; Summers, Larkin, & Dewey, 2008). According to Diamond (2000) fine motor control relies on the prefrontal cortex and the cerebellum. It also involves incorporating visual stimuli from the environment (Korkman, Kirk & Kemp, 2007). Its development continues throughout a person's lifetime and includes not only physical growth, but also development of the motor and nervous systems (Gallahue & Ozmun, 2006). Children need to use visual information from their environment alongside their refined muscle control to complete complex tasks such as reproducing an image or figure (Sorter & Kulp, 2003). To measure fine motor skills, activities used in classroom setting are often measured, such as drawing, copying and block-building.

Gross motor control (GMC): This requires the use of large muscle groups (arms, legs and neck) and the involvement of bodily movements (Payne & Issacs, 2008) and is developed in early childhood for stability and control of the body to assist exploration (Cools et al., 2009; Gallahue & Ozmun, 2006; Haywood & Getchell, 2009; Schmidt & Lee, 2005). It is subdivided into locomotor skills and object control. Whilst locomotor skills involve movement from one place to another (walking, running, jumping etc.), object control skills involve the movement and coordination of body parts with objects – to either take action or receive a response from an object.

Inhibitory control (IC): This is the ability to stop an inappropriate response, especially a pre-potent one, or to ignore distracting information.

Human figure drawing: This can be defined as a task that requires someone (in the present case a child) to draw a whole person on a piece of paper.

Preface

Material from parts of this thesis has been or will shortly be presented at:

ICPCLS Kuala Lumpur 2016: 18th International Conference on Psychology, Cognitive and Linguistic Sciences.

ICCPN London 2017: 19th International Conference on Cognitive Psychology and Neuropsychology.

ICCPN London 2018: 20th International Conference on Cognitive Psychology and Neuropsychology to be held on Apr 24-25, 2 in London, United Kingdom.

Material from parts of this thesis is already being published as follows:

A paper based on chapters 2 and 3 is currently in press for Child Development: Simpson, A., Ruwaili, R., Jolley, R., Leonard, H., Geeraert, N., & Riggs, K.J. (2018, in press). Fine motor control underlies the association between response inhibition and drawing skill in early development. Child Development. DOI: 10.1111/cdev.12949

A paper on the results of chapter 4 is currently in preparation with A. Simpson, N. Geeraert, and others.

Chapter 1. Introduction

1.1 Overview

Executive Functions (EFs) are the cognitive abilities which coordinate information to produce goal-directed actions (Anderson, 2002; Fuster, 1997; Miller & Cohen, 2001). These functions are important for planning, reasoning, and integrating thoughts and actions (Shallice, Burgess & Robertson, 1996). EFs, at a fine-grained level, include the cognitive processes of working memory, inhibitory control, and mental set shifting or mental flexibility (Garon, Bryson & Smith, 2008), as first revealed by the factor analysis of Miyake, Friedman, and colleagues (2000). It is argued that EFs are crucial in just about every area of people's lives (Diamond, 2013), from school readiness as a child (Cameron, Brock, Murrah et al., 2012), to marital harmony as an adult (Eakin, Minde, Hetchtman et al., 2004). EFs have become an important subject of study in young children due to their influence on learning and social cognition: hence studying their development in childhood and adolescence provides a better understanding of the development of crucial mechanisms involved in controlling and organising behaviour.

Currently, developmental research is showing that one of the EFs, inhibitory control (IC), has a special part to play in a number of intellectual and academic abilities. According to Simpson and Riggs (2006), IC is the ability to stop an inappropriate response or ignore distracting information and suppress thinking. This EF is important to support other cognitive abilities which are needed in order for individuals to demonstrate flexible goal driven thinking and behaviour (Montgomery & Koeltzow, 2010; Chevalier, Sheffield, Nelson, Clark, Wiebe & Epsy, 2012). These include children's self-regulation and their understanding of others' minds, the physical world, text, and mathematics.

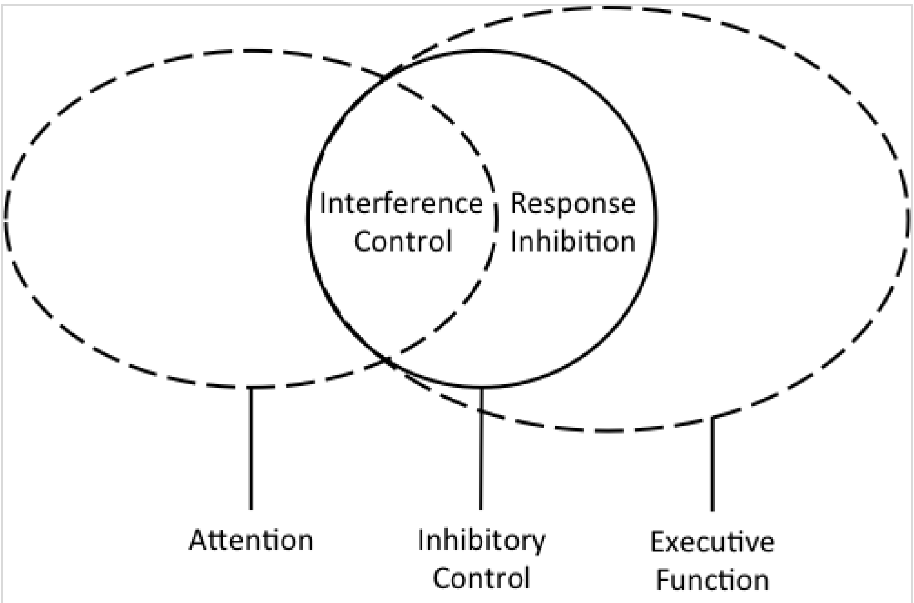
The development of IC in early childhood is of particular interest for two reasons. The first reason is that, although there is evidence to suggest that IC develops from infancy to early adulthood, the most dramatic change occurs in early childhood. According to several researchers, accuracy of 3-year-olds on a variety of inhibitory tasks is poor, but improves dramatically over the next year (Gerstadt, Hong & Diamond, 1994; Jones, Rothbart & Posner, 2003; Simpson & Riggs, 2005a; Wiebe, Sheffield & Espy, 2012; Willoughby, Wirth & Blair, 2011). The second reason for focusing on the development of IC in early childhood is that there is evidence to suggest that this dramatic improvement of IC is linked to other changes in young children's cognition (Apperly & Carroll, 2009; Beck, Carroll, Brunsdon, & Gryg, 2011; Benson, Sabbagh, Carlson & Zelazo, 2013). Carlson and Moses (2001) found a strong correlation between a battery of theory of mind tests and a set of IC tasks, even when other factors were controlled for (age, vocabulary and gender). Beginning with this study, correlational evidence has further suggested that improvement in IC is linked to the development of a wide range of important reasoning abilities (Apperly & Carroll, 2009; Beck, Carroll, Brunsdon et al., 2011; Benson, Sabbagh, Carlson & Zelazo, 2013; Sabbagh, Moses & Shiverick, 2006), as well as to the development of academic abilities more generally (Gilmore, Attridge, Clayton, Cragg et al., 2013). Relationships even extend to areas such as health (Moffitt, Arseneault, Belsky, Dickson et al., 2011), school readiness (Blair, 2002), and psychopathology (Dale & Baumeister, 1999).

For the remainder of chapter 1, I follow up on these themes in depth, drawing on relevant literature. I consider in more detail the nature of IC and how it can be measured, I describe its relationship with various childhood skills and abilities, including drawing, and I briefly examine how it may connect with motor control. I conclude with an account of the research focus of my thesis, and its three related areas of interest (covered in Chapters 2, 3, 4).

1.2 What is Inhibitory Control?

IC is seen as a key component of the executive function. It embraces control of visual attention (Frank, 2006) as well as control of manual and locomotor behaviour. Diamond (2013) in fact distinguishes these two components of IC (Figure 1.1): IC which controls attention, sometimes called 'interference control'; and IC which controls behaviour, sometimes called 'response inhibition'. Of these, the present study is concerned more with IC in the latter sense. IC is also regarded as an important component of the human ability for self-regulation (Kochanska, Murray, Jacques, Koenig & Vandegeest, 1996). Self-regulation, in turn is a rather wider construct with the role of promoting goal-directed or adaptive behaviour (Berger, 2011; Calkins & Fox, 2002). It embraces self-regulation not only of cognitive but also of physiological, attentional, behavioural and emotional processes.

Figure 1.1. Summary of the relationship between attention, inhibitory control and executive function (based on the analysis of Diamond, 2013).



Studies of IC often use a battery of behavioural tasks which are believed to require the exercise of IC, in a way that excludes excessive dependence on other abilities. I will pursue the kind of measures used for IC in more detail in section 1.3. A key issue in child development research is that of when in fact IC first develops. This will be pursued in section 1.4. Measures of IC are also found to relate to many important aspects of child development, as noted in 1.1. These will be pursued in more detail specifically for IC in section 1.5.

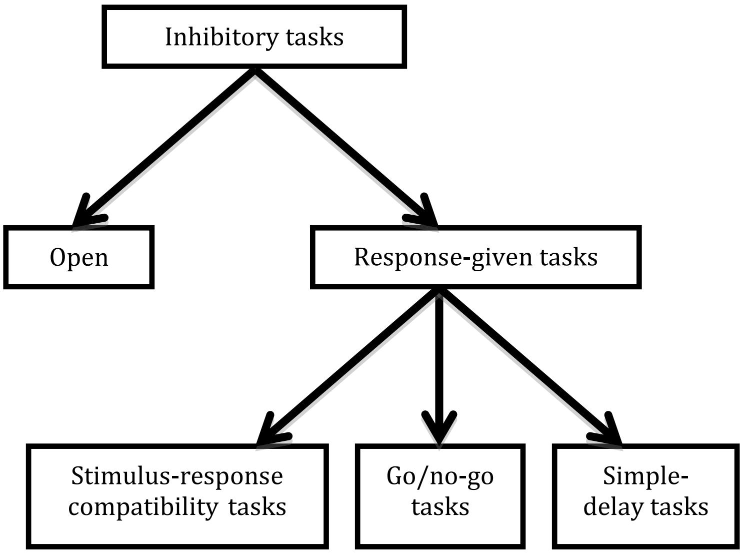
Finally, it is worth noting that IC, or some very similar construct, is often referred to by other names such as self-control, executive control, effortful control, behavioural regulation (all broad terms), and response inhibition, executive attention and interference control (more specific terms). It is argued, however, that such different terms, used for what are often similar measures, should be seen as more the product of differences in research tradition rather than reflecting real construct differences (Zhou, Chen & Main, 2012). I will follow Petersen and colleagues (2016) in adopting the term IC, regarded as a key component of self-regulation in longitudinal research in many research traditions, and as one of the distinct cognitive processes seen as part of the EF construct. It remains possible, however, that IC does have distinctive internal components, with response inhibition and interference control constituting the most likely candidates (Bunge, Dudukovic, Thomason, Vaidya & Gabrieli, 2002; Caughy, Mills, Owen & Hurst, 2013; Gandolfi, Viterbori, Traberso & Usia, 2014). However, at present I consider there to be insufficient evidence to justify the use of these more specific terms, particularly as it is unclear at what age these potential components become distinct.

1.3 The Measurement of IC through Response-Given and Open Tasks

Since IC is the key concept in my thesis, I look more closely here at how it is measured. All tasks used to measure IC in young children rely on the existence of what are called 'pre-potent' responses. These are responses that children will spontaneously choose or prefer when performing a task. For example, if children are presented with a task that involves the option of eating a sweet or not eating a sweet, the pre-potent response is to eat the sweet. Inhibitory tasks require children to resist the pre-potent response in some way so as to demonstrate their IC.

According to Simpson, Simon and Riggs (2004), there are two types of developmental task that require IC: these they term 'response-given' tasks and 'open' tasks (Figure 1.2). In response given tasks, children are directed simply to choose from a limited number of specific responses usually by following simple rules (e.g., 'if the stimulus is A, then respond B'). The exercise of IC is inherent in following the task's rule. By contrast, in open tasks children are allowed to respond in any way that they choose, while still following the task's constraints. Usually open tasks require children to answer a question (e.g., 'where does character A think object B is?'). Open tasks may seem to offer a limited number of choices, just like response-given tasks, but they differ in that they often require the exercise of some quite sophisticated kind of reasoning in order to make that choice, while also exercising IC. Any such tasks of course measure the child's ability to understand the task instructions as well as their ability to actually perform the required task itself.

Figure 1.2. Classification of developmental tasks that require IC.



I suggest that there are three main types of response-given task: stimulus-response compatibility (SRC) tasks, go/no-go tasks, and simple delay tasks (Figure 1.2). SRC tasks require children to withhold a pre-potent response while making an alternative, less obvious, response (sometimes called a 'conflicting' response – e.g. Carlson & Moses, 2001). In go/no-go tasks children are required to give the pre-potent response on the go trials, and withhold it on the no-go trials. Here IC is needed only on no-go trials, and, unlike in SRC tasks, a pre-potent response must be inhibited without an alternative response being produced. In simple delay tasks, the child is required to delay their pre-potent response for a set period. SRC and go/no-go tasks involve multiple trials, whereas simple delay tasks usually involve just a single trial. It is assumed, in the absence of evidence to the contrary, that these three types of response-given task measure the same inhibitory process. There is, however, some recent evidence to suggest that responses may be pre-potent in different ways in these tasks (Simpson, Upson & Carroll, 2017). However, the question of what makes responses pre-potent is outside the scope of this thesis.

The grass/snow task is an example of an SRC task, where children are shown two coloured cards, one white and one green (Carlson & Moses, 2001). The objective of the task is for children to point to the opposite coloured card in comparison to what is said. For example, when the researcher says *grass*, the child is required to point to the white card. According to Simpson and Riggs (2009), 3-year-old children perform poorly on this task due to their weak IC, and point to the green card if the researcher says *grass*. A recent meta-analysis suggests that this type of task is ideal for testing 3- to 5-year-olds (Petersen, Hoyniak, McQuillian, Bates & Staples, 2016). Since the parts of this thesis that investigate IC (Chapters 2 and 3) tested this age range, this type of task has been used.

The box-search task is an example of the go/no-go task. Children are asked to open boxes that have a certain cue on the lid, and leave other boxes unopened if another cue is shown. According to Simpson and Riggs (2007), opening a box is considered a pre-potent response and therefore young children will find it hard to inhibit. As for the simple delay task, an example of this is the delayed gratification task (Mischel, Shoda & Peake, 1988). A sweet is placed in front of a child and they are told that they can eat it now if they want, but if they wait they could have two sweeties instead of one. Once again, young children find waiting difficult since it is a pre-potent response to take a sweet at once. In all IC tasks, then, inhibitory demands are created because children are told, through the task rules, to do things counter to their normal behaviour.

Response-given tasks have good internal validity, having been specifically designed to measure IC in a direct way, and the results of several studies provide evidence for this (Congdon, Mumford, Cohen et al., 2012). Furthermore, the simplicity of the tasks allows them to be easily manipulated to demonstrate the IC of children. These advantages of response-given IC tasks have allowed direct investigation of the development of IC and how inhibitory demands can be created.

One way in which some studies have directly demonstrated the validity of SRC tasks, as measures of IC, has been through the comparison of performance in the standard inhibitory condition with that in a control condition (Gerstadt, Hong & Diamond, 1994). Some examples of SRC tasks in which children perform well in control conditions can be found in Table 1.1. The control conditions require children to remember two rules, but not to inhibit pre-potent responses, as the stimuli used have no prior associations. Young children perform substantially better on the control condition than the inhibitory version of such a task (Gerstadt et al., 1994; Simpson & Riggs, 2005a, 2009; Simpson et al., 2006). Such results strongly suggest that children are able to remember associations between particular stimuli and particular responses in the control condition, so their poor performance in the inhibitory condition must be due to the additional requirement for inhibition, making that condition a good measure of IC. This is one of the reasons that SRC tasks are used as the measure of IC in this thesis.

In contrast to response-given IC tasks, open tasks require the child to respond not just by selecting a response, but first by exercising some reasoning in order to determine how to go about selecting it. An example of such a task is the reverse contingency task, where children are presented with two windowed boxes, where they can see that one box has a treat in it, whilst the other is empty. Russel, Jarrod and Potel (1994) instructed children that they were to try to win the treat, but that the contents of the box which they chose would be given to an opponent. Children had to infer that, in order to obtain the sweet, they had to resist the pre-potent response, which was to point to the box containing the sweet, and point instead to the box that was empty. Three-year-old children had the opportunity to win treats across a number of trials (Apperly & Carroll, 2009; Carlson, Davis & Leach, 2005), but performed poorly, consistent with weak IC (i.e., a failure to inhibit pointing to the desired treat). Better performance usually develops by the age of five years (Russell et al., 1994).

Table 1.1. Examples of SRC tasks in which children perform well on the control condition.

Tasks	Experimental condition	Control condition	References
Day/night	See day picture, say 'night'	See abstract picture 1, say 'night'	Gerstadt et al., 1994;
	See night picture, say 'day'	See abstract picture 2, say 'day'	Simpson & Riggs, 2005
Grass/snow	Hear green, point to white card	Hear green, point to abstract picture 1	Simpson & Riggs, 2009
	Hear white, point to green card	Hear white, point to abstract picture 2	
Hand game	See finger picture, make a fist	See abstract picture 1, make a fist	Simpson et al., 2006
	See fist picture, point a finger	See abstract picture 2, point a finger	

Whilst response-given tasks have strong internal validity, open tasks are argued to have stronger external, ecological, validity. Open tasks more closely resemble real world activities, where IC usually comes into play in situations which require everyday reasoning, rather than in the context of arbitrary rules such as those used in response-given tasks. Open tasks involve theory of mind reasoning (Carlson & Moses, 2001), strategic reasoning (Apperly & Carroll, 2009), counterfactual reasoning (Beck, Carroll, Brundson & Gry, 2011) and also reasoning with symbolic understanding (Sabbagh, Moses & Shiverick, 2006; Bialystok & Senman, 2004).

Correlational analyses between response-given tasks and open tasks do however provide evidence for a link between such reasoning abilities and IC (see section 1.5 – Beck, Riggs & Gorniak, 2009; Bialystok & Senman, 2004; Benson, Sabbagh, Carlson et al., 2013; Carlson & Moses, 2001).

1.4 When does Inhibitory Control Develop?

Next, I consider what the literature tells us about the development of IC in typical children. It is suggested that IC develops in a roughly linear fashion, or at least monotonically, during early childhood (Willoughby, Blair, Wirth et al., 2012). There is however no clear consensus as to the age at which IC reaches full maturity. Initial research (Passler, Isaac & Hynd, 1985; Becker, Isaac & Hynd, 1987) suggested that the development of IC is ongoing between the ages of six and 12 years, while research by Welsh, Pennington and Groisser (1991) suggested that IC reaches maturity at the ages of either nine or ten years. Other early research (Levin, Culhane, Hartmann, & colleagues, 1991) suggested that IC does not reach maturation until the age of 12.

It is of course possible that the different measures used in each of these studies caused the differences in findings, suggesting that it is appropriate to use several measures to quantify IC (Bedard, Nichols, Barbosa et al., 2002; Christ, White, Mandernach & Keys, 2001). Indeed, Willoughby and colleagues (2012) later demonstrated that the test-retest reliability of a battery of EF tasks was much better than that of an individual task, especially in the three to five year range. For this reason, the current study employs more than one task wherever IC is measured (two in Chapter 2 and three in Chapter 3).

The first study to design a task to investigate the development of IC in young children was Gerstadt and colleagues (1994). This was the day/night task, which, as described in 1.3, follows the SRC paradigm. Children are instructed to say *night* when shown a picture of day time with the sun, and to say *day* if shown a picture of night with the moon. This study found that most young 3-year-olds either would not play, or failed a pre-test (being unable to respond correctly on any practice trials). Development was however clearly demonstrated in older age groups, through both increasing accuracy and decreasing response time. Several variants of this task have been devised to investigate IC in children (Carlson & Moses, 2001), as well as in adults (Brass, Bekkering, Wohlschlager & Prinz, 2000), including the grass/snow task, and both are employed in my thesis. The SRC paradigm can be viewed as a variant of the colour-conflict Stroop task (Stroop, 1935), which involves participants reading a list of words written in different coloured ink from their names (e.g. the word *blue* is written in the colour red). The colour-conflict Stroop task however is a measure of interference control (as the task has an attentional component), while SRC tasks are the most popular measure of response inhibition, which is the kind of IC targeted in my study.

Another SRC task used to measure IC is the tapping task, which has demonstrated similar results to the day/night task (Diamond & Taylor, 1996). Children are required to tap once with a rod when the tester tapped twice, and to tap twice if the tester tapped once. These studies showed that, between the ages of three and five years, young children increased their response accuracy and approximately halved their response times. Following this initial research, using an improved version of the day/night task, Simpson and Riggs (2005b) showed that the most dramatic development occurs between the age of 3½ years and 5 years. This is another reason why SRC tasks were deemed the most suitable for use in this thesis, given my target age group.

Montgomery and Koeltzow (2010) reviewed evidence for the improvement of IC in 3- to 7-year-olds. Not all studies found that IC improved with age. Out of 21 studies, only 12 studies showed a correlation between IC and age. The reason for the inconsistency may be explained by differences in the precise age ranges tested. Most studies which included young 3-year-olds in their sample showed a correlation between IC and age (83%), but when an older age range was examined only 22% of studies showed a correlation between IC and age. It seems again, therefore, that correlation between IC and age is seen with younger children rather than older children. This further supports the finding of previous studies which suggest that IC dramatically improves at the beginning of the fourth year, but after that the improvement is more modest (Diamond & Taylor, 1996; Gerstadt et al, 1994; Simpson & Riggs, 2005a). The same pattern of improvement appears in more recent studies such as Wiebe, Sheffield and Espy (2012), Willoughby and colleagues (2012), and Garon, Smith and Bryson (2014).

Aside from the precise task used to measure IC and the precise age group targeted, there are numerous other details of how IC is measured which may have an impact on the results obtained, and so on the age at which IC appears to develop most strongly. Earlier studies, for instance, used pre-tests to exclude those who could not produce any accurate responses (e.g., say *night* to a day picture) in practice trials (Diamond & Taylor, 1996; Gerstadt et al, 1994; Simpson & Riggs, 2005a), and relied more on reaction times of those who were able to respond relatively accurately, rather than just their overall accuracy, to measure IC. The majority of more recent research however has not employed such pre-tests, and has relied only on accuracy (hence no exclusion of participants has occurred). This option is clearly best for correlational studies, since there is no loss of data, and hence it was adopted in the research presented here. However, it is still unknown which methodology provides the most accurate measure of IC (e.g. pre-test pass-rate, accuracy of all participants, or reaction time of those who respond correctly).

Other differences of methodology used in SRC tasks measuring IC include the type of stimuli used, the number of practice trials, number of test trials and how instructions are given, as well as the use or not of reminders/feedback during test trials. Some researchers have observed that performance on SRC tasks deteriorates over 10 to 20 test trials (e.g., Gerstadt et al., 1994; Diamond et al., 2002). However, there was no observed deterioration in performance across 16 test trials of the day/night task, according to Simpson and Riggs (2005a, 2011). The reason for this result could be that Simpson and Riggs gave feedback to the participants during the test trials, whereas other studies did not correct the errors of the participants during the test itself. It is possible therefore that such feedback, when provided, may help children to remember the rules better throughout the duration of the task, and so maintain their performance.

Despite the variations in performance found in relation to the detailed way in which tasks are implemented, such as those described above, SRC tasks do generally provide strong evidence for considerable improvement of IC in early childhood. Clearly however there still needs to be more research conducted to define which task properties produce the best possible measure of IC (Vendetti, Kamawar, Podjarny et al., 2015). Based on the above findings, and in the absence of definitive research resolving all these issues, I did not exclude participants based on a pre-test, but aimed to explain the rules as clearly as possible in the introductory phase of each SRC task. After that no further feedback was given during the test itself, and accuracy alone was used as the measure of IC (See further 2.2.5.2).

Most recently Petersen and colleagues (2016) conducted a meta-analysis of 198 child development studies of IC. They focused not on the age at which IC develops, but on the question of which tasks were most appropriate to test children of different ages (from 20 to 100 months). If a measure is not age appropriate, it may lead to an over or under estimate of how strong a child’s IC is, and, as seen above, the estimate may not agree with that derived from other measures. While the study did not consider possible effects of the precise instructions, procedures and conditions accompanying each task, it showed in broad terms the age range appropriate for the use of 14 widely employed tasks (of the SRC and go/no-go types). Petersen and colleagues (2016) suggest that the suitable age range for any one task is usually not more than three years – meaning that multiple tasks must be used if the whole of childhood is to be studied.

The approach of Petersen and colleagues (2016) does to some extent question the whole enterprise of establishing any particular age when IC could be said to have ‘matured’. They make the valid point that IC is, in a sense, not quite the same thing for a young child as for an older one, since what constitutes a pre-potent response may differ, and the kinds of situation in which IC is employed in everyday life are different at different ages. Nevertheless, it is necessary to make some assumption about what is called 'heterotypic continuity' meaning "the manifestation of the same underlying process through different behavioural presentations at different developmental periods" (Cicchetti & Rogosch, 2002, p. 13). Petersen and colleagues then outline the statistical procedures by which results from different tests, each applicable to a different age range, may be synthesised into one scale covering a very wide age range (1 to 9 years). Such a scale, however, while suitable to track change in IC very accurately, and indeed to detect whether development speeds up or slows down at any age, does not admit of any absolute answer to the question, 'When has IC matured?' As Asato, Sweeney and Luna (2006) note, inhibitory control improves not only through the teenage years, but into adulthood as well, so it would require a scale to be established founded upon tasks with overlapping ranges of applicability all the way from age 1 to 20 years in order to comprehensively map inhibitory development.

In the present study, however, only IC development within a restricted age range needed to be considered (from 3 to 5 years). The use of SRC tasks is consistent with Petersen and colleagues' suggestions for tasks appropriate for this age range.

1.5 The role of Inhibitory Control in Child Development

In this section I pursue in more detail the different kinds of ability with which IC has been found to be related during child development, so as to contextualize the current study which specifically researches the relationship between IC and drawing skills. Although there is clear evidence to support the improvement of IC in early childhood, researchers are less certain about how this improvement relates to the development of other abilities (Montgomery & Koeltzow, 2010).

1.5.1 Theory of mind reasoning

Since the ground-breaking studies of Adele Diamond (starting with Diamond & Taylor, 1996), researchers have investigated the impact of maturing executive function on cognitive development. Within this large literature there has been a particular focus on the developmental relationship between IC and 'theory of mind'. Theory of mind is a complex set of skills and knowledge. It includes the understanding that others have internal mental states such as emotions, desires and beliefs, and that these mental states drive human behaviour. Evidence for the link between IC and theory of mind has been found in a wide range of studies in different disciplines within psychology.

First, early brain-imaging studies provided evidence that the frontal lobes are involved in both theory of mind and IC (Baron-Cohen et al., 1994; Fletcher et al., 1995; Goel, Grafman, Sadato, & Hallett, 1995; Sabbagh & Taylor, 2000), although these studies were conducted on adults. The left frontal lobe, however, has been shown to relate to preschool children's social competence, which may be considered in part a product of theory of mind (Fox, Schmidt, Calkins, Rubin & Coplan 1996). Furthermore, it has been known for some time that autistic individuals, who have theory of mind deficits, also show impairments in tasks involving EFs and particularly IC (Hughes & Russell, 1993; Ozonoff, Pennington, & Rogers, 1991).

Furthermore, there is evidence that IC is particularly important for the development of children's understanding of others' beliefs, which constitute a key aspect of theory of mind. This research began with the realisation that both understanding of beliefs (for a review see Wellman, Cross & Watson, 2001), and IC (Gerstadt et al., 1994), appear to improve dramatically between the ages of three and five years. Beliefs are 'symbolic' or 'representational' mental states: they symbolise or represent a relationship between the mind and the world, an expectation about how the world is, and thus to an extent bear a distant resemblance to more concrete non-mental representations of the world such as drawings. In consequence, it is possible to recognise that beliefs can be true or false (unlike most other types of mental state which cannot be false – so long as the individual holding the mental state is authentic). For example, if a child has seen his mother place smarties in a cupboard, he may falsely believe that another child, who did not see that action, will also think that there are smarties in that cupboard.

In order to perform successfully on tasks that test understanding of others' beliefs, there is evidence that typically-developing children need to have effective IC. It is suggested that, in order to demonstrate understanding of another's beliefs, children often need to inhibit their own knowledge of current reality, which is more salient than another's belief. According to Carlson and Moses (2001), as children's IC develops, they are better able to inhibit this kind of pre-potent response (such as reporting their own beliefs, rather than those of others), and so their performance on representational theory of mind tasks improves.

The procedures used in theory of mind studies are therefore sometimes adapted to reduce the inhibitory burden on children, so as to measure theory of mind independently of IC (Freeman, Lewis, & Doherty, 1991; Mitchell & Lacohée, 1991; Moses, 1993; Robinson & Mitchell, 1995; Wellman & Bartsch, 1988). Russell, Mauthner, Sharpe and Tidswell (1991), for example, showed that 3-year-olds performed badly when they had to deceive by means of pointing with their finger to an empty location. It could be that this act of pointing to an object's true location constitutes a pre-potent behaviour; hence it is difficult for young children with their weak IC to resist (Carlson, Moses & Hix, 1998). Children using a novel method of deception, pointing with an arrow rather than their finger, were however able to deceive at moderately high levels (Carlson et al, 1998), arguably because this method imposed fewer inhibitory demands.

Carlson and Moses (2001) were the first to perform a correlational study to investigate the relationship between IC and theory of mind. Their first study tested 10 response-given tasks which were divided into two groups by a factor analysis. One group, which they called 'conflict tasks', contained SRC tasks (e.g., the day/night task) and go/no-go tasks (e.g., the bear/dragon task), while the other group contained simple-delay tasks (e.g., the gift delay task). Performance on the conflict tasks correlated with several measures of representational reasoning. These tasks, such as the false belief task (Wellman, Cross & Watson, 2001) and the appearance-reality task (Flavell, 1986), can all be classified as open tasks (that is, they involve both high reasoning and high inhibitory demands). For instance, in a typical false belief task, the participant observes a character seeing a coin placed in a blue box. This character then leaves, and a second character arrives and moves the coin to a red box. The first character returns and the participant has to indicate which box that character will look in to find the coin. The participant must inhibit their own knowledge of the current location of the coin, while engaging in theory of mind reasoning. In a typical appearance-reality task, the child is shown a picture of red car. The researcher then places a filter over the picture so that the colour appears black, and asks the child what colour the car really is. The participant must inhibit their knowledge of the current colour of the card, while engaging in representational change reasoning.

Since false belief tasks are today widely accepted as unambiguously a test of theory of mind understanding, I will refer to studies using it below. In contrast, the appearance-reality task is not generally regarded as a test of theory of mind, but of the wider domain of 'symbolic understanding'. I address that kind of task in the following section.

Since Carlson and Moses' original study, attempts to replicate the relationship between IC and theory of mind with various tasks have not always been successful (for a review see Montgomery & Koeltzow, 2010). Nevertheless, some carefully conducted longitudinal research does suggest that response-given task performance predicts later theory of mind ability (Carlson, Mandell & Williams, 2004; Flynn, O'Malley & Wood, 2004; Hughes & Ensor, 2007). More recently, a training study has found that individual differences in response-given task performance predict theory of mind learning (Benson, et al., 2013). These data provide the most convincing evidence to date that effective IC promotes theory of mind development.

While a relationship between IC and children's false belief task performance has often been found, the precise mechanism which produces the relationship has been the subject of considerable debate. Two prominent accounts which have been suggested are the Expression and the Emergence accounts (Moses, 2001). The former suggests that children require a threshold level of IC in order to solve such tasks, because of the high demands that those tasks place on IC. In this view, children may in fact possess an understanding of false belief, but are unable to demonstrate it due to the demands on IC. Evidence for this comes, for example, from the fact that 3-year-olds fail false belief tasks not by responding at chance levels, but by consistently reporting their own knowledge (i.e., the current location of the object). That is, the Expression account proposes that children with poor IC simply cannot resist the urge to refer to what they know to be true (Carlson & Moses, 2001). The false belief task thus requires the child to suppress a pre-potent response, which is exactly what SRC measures of IC involve.

By contrast, the Emergence account proposes that the child cannot acquire the concept of another's' false beliefs until a certain level of IC has already emerged. In this view, EFs such as IC actually contribute to the development of theory of mind knowledge, and children first need a certain level of inhibition in order to then consider any form of representational relation (Carlson & Moses, 2001). IC then plays a role not just in helping children to inhibit pre-potent responses in specific tasks (as described above), but in a more general way, by enabling children to suppress their own perspectives and so better consider the mental states of others, and so develop theory of mind in the first place (Carlson & Moses, 2001). Benson and colleagues' (2013) data support the view that IC influences theory of mind in an indirect way, consistent with an Emergence account. Good IC helps pre-schoolers to develop the reasoning ability they need to succeed in the open tasks that are used to test theory of mind.

The Emergence account explains results from some studies where IC correlates with performance on false belief tasks that do not require the inhibition of a pre-potent response. Such a task is that of Perner, Lang, and Kloo (2002), who presented children with a false belief task of the type described above, which ended with the other person searching for the object in the wrong place. Children however were then asked to explain the person's actions, a task which did not require them to resist any pre-potent response, but just explain what happened, after the event. Although demands upon IC were therefore reduced, scores were still strongly correlated with IC. This therefore suggests that the relationship between IC and false belief performance is not due simply to the fact that standard false belief tasks involve a pre-potent response which must be inhibited.

Summing up, it may be said that simple correlations between IC and theory of mind measures are consistent with both those accounts. They are also consistent with yet other proposals, such as that theory of mind development leads to better IC. However, more recent research tends to support the Emergence account more than the Expression account (Benson et al., 2013; Perner et al., 2002), and suggest that efficient IC supports learning.

1.5.2 Symbolic reasoning

As I noted in the previous section, others' beliefs are symbolic or representational in that they encode a relationship between the mind and the world. Besides others' beliefs, however, there are many other kinds of non-mental representation used by humans: spoken and written words, photographs, figurative and non-figurative art, maps, clocks and calendars, and a wide range of signage and symbols. Since my study is concerned with children's drawing, rather than understanding of others' beliefs, research involving such non-mental kinds of representation is especially relevant. Interest has particularly focused on whether the relationship between children's developing understanding of beliefs and improved IC is restricted to mental representations, or extends to non-mental representations as well. That is to say, is the role of IC specific to the development of belief understanding, or does it have a more domain-general role, which also affects children's understanding of non-mental representations?

Such questions essentially involve the concept of 'domain-specificity' which has long been central to theorising about human development (for a review see Karmiloff-Smith, 2015). Are the cognitive processes which underpin development specialised to enable children to learn about specific 'domains' – such as language, theory of mind, and mathematics – or are these cognitive processes more domain-general, so that they equally benefit learning across domains? The question of domain-specificity has also long been applied to theory of mind development. Broadly the argument goes that we have excellent theory of mind skills, so there must be specific learning mechanisms, or even innate knowledge, to support development in this domain. This then extends to the question of what kinds of representations are subject to these domain-specific processes, 'Does the ability to understand mental and non-mental representations develop together, or is theory of mind development in some way unique?' In particular the further question, 'What is the relationship between IC and representation?' is relevant to my thesis. IC could be specifically related to the development of belief understanding (a domain-specific position), or IC could be associated with the development of non-mental representations as well (a more domain-general position).

Unfortunately, the literature is quite ambiguous on the question of whether the role of IC in representational development is domain-specific or domain-general. Carlson and her colleagues (Carlson & Moses, 2001; Carlson, Moses & Breton, 2002) treated both the false belief task and the appearance-reality task (described in the previous section) as 'tests of theory of mind'. Both the false belief and appearance-reality tasks 'look like' tests of children's representational understanding, but the appearance-reality task does not seem to test mental state understanding in the same clear-cut way that the false belief task does. As noted previously, these are both open tasks. In open tasks the participant is free to approach the task in whichever way they wish, and so it can be difficult to determine what kind of reasoning is being used. It seems likely that a false belief task can only be tackled with *mental state reasoning* (which is why I focused attention on it in the section above concerned with development of theory of mind understanding). Notwithstanding, it has been questioned whether children performing such tasks actually need to understand others' false beliefs. That is to say, it is less clear whether those children actually need to understand that beliefs are representational.

Fabricius, Boyer, Welmer and Carroll (2010), for example, propose that children may pass the false belief task using a simple kind of mental state reasoning, which they call 'perceptual access reasoning'. This strategy assumes that, when a person cannot see something concerning an event, their judgement about that event is bound to be wrong. Thus, when children first pass the false belief task, they may do so by assuming that the character in the task simply does not know where the object is, and so picks the wrong location, rather than that this character thinks that they do know its location, but are wrong because of their false belief. In contrast, it seems unlikely that mental state understanding of any kind is central to passing the appearance-reality task. Indeed, it can also be questioned whether children need symbolic understanding in order to succeed in that task. It may be that good performance depends more on their understanding of the language and discourse conventions involved in the task (See Deák, 2006, for discussion).

Overall, evidence that performance on inhibitory tasks correlates with performance on the false belief and appearance-reality task does support the proposal that IC's association with reasoning *is domain-general*. Effective IC aids the development of both mental state and non-mental state reasoning. The exact role of IC in the development of symbolic reasoning, domain-general or otherwise, is however still unclear.

Carlson and other researchers may not have distinguished between mental and non-mental representations, but one line of developmental research has aimed to do this. This concerns studies using non-mental state versions of the false belief task. In particular, an early attempt was made to replicate the standard false belief task with a version that involved visual representation, rather than others' beliefs. This study (Zaitchik, 1990) used a photograph in place of the character who sees where something is placed, before leaving, only to return after it has been moved. Where, in the standard task, the child is asked where the other character *thinks* the object is located, in a false photo task the child is asked where the object is located in the photograph. It was found that young children performed poorly on both the false photo and false belief tasks.

However, no correlation was found between children's performance on the false photo task and false belief task. Perner and Leekam (2008), in a comprehensive review of these tasks, suggests that this lack of correlation occurs because the two tasks are not in fact comparable. In the false belief task, the character has a *false* belief because they think the object is currently in a certain location, when it has in fact been moved. By contrast, when a photo shows an object in its original location, after it has been moved, it cannot be said to be *false*. It is in the nature of a photograph to record the world at the time when the photo is taken, not at the later time when the photograph is viewed, and the photo does not become *false* because the world changes. It would only be false if, at the time it was taken, through some failure of its lens or mechanism, it somehow made the object appear to be somewhere where it was not. Photos are true representations of the past.

In place of the false photo task, a false sign task has therefore later been used (Parkin, 1994). The latter, by its nature, does correctly parallel the false belief task, but uses non-mental representations. The person with the belief in the false belief task is replaced by a signpost which initially points to a hidden object, and then fails to move when that object's location is changed. The false signpost is truly false, in the same way as a false belief, since signposts are expected to reflect *current* reality and not the location of things only when they were first erected. The difference is, however, that signposts are non-mental while beliefs are mental. Later studies, such as Sabbagh, Moses and Shiverick (2006), then went on to show that performance on the false belief and false sign tasks correlated, while performance on neither of these tasks correlated with that on the false photo task. Finally, and crucially for the issue of the domain-specificity of IC's role in representational development, Sabbagh and colleagues (2006) further showed that IC was linked both to the false sign and false belief tasks, but not the false photo task.

Overall then, there is an indication that IC is involved in symbolic understanding in a domain-general way, spanning both mental (belief) and non-mental (sign-post) representations, which can be genuinely false. At the same time, IC does not appear to be involved in the understanding of all kinds of representation – as the lack of correlation between IC and the false photo task shows.

1.5.3 Other kinds of reasoning – counterfactual, deductive and strategic

In addition to symbolic reasoning, IC has been implicated in other kinds of reasoning. For example, when an individual misses their bus, they might imagine what could have happened if they had got to the stop on time. This is considered to be counterfactual thinking, where people put aside what they know is true about the current world, so as to imagine how it might have been (Roese & Summerville, 2005). According to Epstude and Roese (2008), counterfactual thinking assists people in learning from their mistakes in order to avoid negative situations in the future. It has been suggested that, from a very young age, children are able to entertain and even create fictional worlds (Kavanaugh & Harris, 1999; Leslie, 1987). However, according to several studies, it is only around the age of four years that children begin to think counterfactually, and this ability continues to develop through childhood (Kuczaj & Daly, 1979; Riggs, Peterson, Robinson, & Mitchell, 1998; Beck, Robinson, Carroll, & Apperly, 2006; Rafetseder, Cristi-Vargas, & Perner, 2010; Weisberg & Beck, 2010).

Riggs and colleagues (1998) tested 3- to 5-year-olds on stories similar to those used to test false belief. For example they were told a story of a mother making a cake. In the story, the mother took some chocolate from the drawer and moved it to a different location: the cupboard. Later, the children were asked, “What if Mum hadn’t made a cake, where would the chocolate be?” Children of five years of age usually gave the correct counterfactual answer (in the drawer), whereas younger children often responded with their own understanding of the current situation (in the cupboard). This study is further supported by other researchers such as Harris, German and Mills (1996) and Guajardo and Turley-Ames (2004).

EFs, especially IC, may play a role in children's performance on counterfactual reasoning tasks because they find it difficult to suppress reporting the world as it is (their pre-potent response), rather than as it could have been. One may need the capacity to suppress what one knows to be true about the world, in order to give a counterfactual answer. This need to ignore what they know to be true about how the world is what potentially creates demands on children's IC.

As with false belief understanding, it has been established that IC develops over preschool years alongside the improvement in children's performance on a range of counterfactual tasks (Davidson, Amso, Anderson & Diamond, 2006), although such parallel development does not in itself demonstrate a link between them. More convincingly, brain-imaging evidence from adults has suggested that the orbito-frontal cortex is involved in counterfactual thinking as well as IC (Camille et al., 2004; Coricelli et al., 2005; Ursu & Carter, 2005). Furthermore, there have been correlational studies which show that effective IC, along with other skills such as vocabulary ability and working memory, is associated with the development of counterfactual thought. Beck, Riggs and Gorniak (2009), for example, tested 3- and 4-year-olds on a battery of counterfactual tasks, and that found IC, along with vocabulary knowledge, was associated with counterfactual thinking. Along with IC, effective working memory may also have a role in counterfactual reasoning: thinking about alternative states of affairs requires children to generate new information about the counterfactual world, while retaining information about the real world (Drayton, Turley-Ames, & Guajardo, 2011).

Similar effects are found with deductive reasoning tasks which contain counterfactual premises. In these, instead of having to imagine what the world would be like if something different from reality had occurred, children are told, as if it is a fact, something which is empirically false, and are required to make a deduction from it. For example, in Hawkins, Pea, Glick and Scribner (1984), 4- and 5-year-olds were given premises which were incongruent with their world knowledge, such as that certain birds have wheels. They did very poorly on reasoning tasks using such premises, tending simply to report the truth about the world (e.g., by saying, “No, birds have wings”). On the other hand, they did very well when premises were congruent with their real-world knowledge or with fantasy worlds. Both Dias and Harris (1988, 1990), and Richards and Sanderson (1999), also reported such findings. Once again, the findings are consistent with the child participants having immature executive functions, especially IC. The pre-potent response which has to be inhibited is again that of resorting to reality (Riggs & Beck, 2007). IC, and working memory, have been further found to play important roles in deductive reasoning in late childhood and in adults (Markovits & Doyon, 2004; De Neys & Everaerts, 2008).

Other evidence for the role of effective IC in reasoning development comes from studies which involve strategic reasoning. This differs from the kinds of reasoning described above in that the reasoning is focused on what others might be thinking, with the strategic aim of deceiving or outmanoeuvring them. Hence it may also involve theory of mind understanding (1.5.1), as seen for example in one of the tasks used by Sher, Koenig and Rustichini (2014). In this study, children aged between three and nine years had to play a stickers game, in which the child and researcher simultaneously chose between one and five stickers without seeing each other’s choice until after it was made. The player who chose fewer stickers got to keep their stickers, while the other player received none. If there was a tie between the numbers of stickers chosen, neither player kept any. Each player needed to use a mixture of reasoning and counterfactual thinking of a more imaginative type in order to win the most stickers. For instance, a child might judge, based on past choices, that the researcher might on the current turn choose three stickers. In that case she should reason that, in order to get the most stickers herself, she must undercut the researcher by as little as possible and choose two. The strategic reasoning required is clearly more demanding than the theory of mind task which I described in 1.5.1 which required simple deception. Once again, however, there are pre-potent responses that need to be inhibited, such as that of simply choosing the largest number of stickers, which was the pattern of behaviour seen in the youngest participants.

Indeed, the link between strategic reasoning and IC has been supported by studies such as Hala and Russell (2001). Hala and Russell (2001) additionally suggested that alternative response modes, such as playing with a partner, allow 'cognitive distancing' which enables children to separate the task goal from the means of responding. This in turn can prevent children with low IC from responding impulsively with the pre-potent response, and enable them to come up with an alternative response strategy (Apperly & Carroll, 2009). In other words, a different response mode may result in the same core task making different demands on IC.

1.5.4 Academic abilities

There have also been a number of studies which have considered the role of EFs in relation to academic learning. It has been found that EFs contribute to a child's performance in both mathematics and reading tests (Steele, Karmiloff-Smith, Cornish, et al., 2012; Thorell, 2007; Welsh, Nix, Blair, Bierman & Nelson, 2010). Indeed, it is very possible that EFs are important for learning and performance across all academic subjects. Importantly with my focus on IC, Blair and Razza (2007), in a study of nursery children, report separate results for IC: significant positive associations were found with math ability (r=.44), phonemic awareness (r=.35), and letter knowledge (r=.25).

Moreover, both IC and working memory predict examination performances in English, mathematics and science later at the age of eleven years (St Claire-Thompson & Gathercole, 2006) and fourteen years (Nunes, Bryant, Barros & Sylva, 2012). They also predict both mathematics and reading scores across a range of developmental ages (Yeniad, Malda, Mesman et al., 2013). Geary (2011), on the other hand, found differences in the relationships between working memory and mathematics and reading over time. This study tracked performance every year from kindergarten to grade five (ages five to ten years), and found that the link between working memory and reading decreased with age, whilst it increased with age for mathematical ability. Such a study has not been undertaken for IC, however, so although it seems important for academic achievement across a range of academic domains, we cannot be sure if the precise relationship of IC with each domain over time is the same.

It is perhaps particularly important to understand in detail the importance of IC and other processes involved in the learning and performing of mathematics because of the impact this has on success in Western societies. It is suggested that poor mathematical skills have an even greater effect on life chances than poor literacy (Parsons & Bynner, 2005). Furthermore, 21% of UK 11-year-olds leave primary school without sufficient knowledge of mathematics, and 5% even fail to achieve the mathematical skill levels expected of 7-year-olds (Gross, 2007). This problem follows through into adulthood and, according to Williams, Clemens, Oleinikova, and colleagues (2003), a fifth of UK adults have numeracy skills below the basic level needed for everyday situations.

There are, of course, many factors that play a part in mathematics achievement, such as attitudes (Ma, 1999), motivation (Steinmayr & Spinath, 2009), general intelligence (Mayes, Calhoun, Bixler & Zimmerman, 2009), and educational factors (Nunes, Bryant, Sylva & Barros, 2009), quite apart from a child's underlying cognition. Within cognition, IC plays a key role (Bull & Scerif, 2001; Gilmore, Attridge, Clayton et al., 2013; Kroesbergen, Van Luit, Van Lieshout et al., 2009; St Clair-Thompson & Gathercole, 2006). However, it is not the only relevant EF, since working memory (Raghubar, Barnes & Hecht, 2010) and shifting (the ability to switch attention from one task to another – Yeniad et al., 2013) are also important. Although there are some inconsistent findings, the majority of studies do demonstrate that IC predicts mathematical performance (Brock, Rimm-Kaufman, Nathanson, & Grimm, 2009; Bull & Scerif, 2001; Espy, McDiarmid, Cwik, et al., 2004; Gilmore et al., 2013; Kroesbergen et al., 2009; Lee, Ng, Pe, Ang, et al., 2010; St Clair-Thompson & Gathercole, 2006). Nevertheless, it is still not fully understood exactly *why* IC might play a special role in the development of math ability, compared with that of other academic skills (Keller & Libertus, 2015).

It might well be considered that mathematical skills appear to be somewhat distant from drawing skills, which are the main focus of my thesis. Nevertheless, I would argue that, at a fundamental level, both drawing and mathematics involve children operating with symbolic representations of real objects in place of the real objects themselves (Bruner, 1966). At least at a basic level, for young children aged two, for example, a number stands symbolically for a quantity of real objects, somewhat in the way that a picture stands for its subject matter (Piaget's sensorimotor stage: Ojose, 2008). Indeed, the connection is clear in studies where very young children are asked to represent the quantity of a number of objects. Often the children use drawings of the objects for this purpose (Hughes, 1986). Young children are also found to be able to make simple mathematical computations using non-canonical representations of number quantity, which resemble drawings rather than numbers, such as unstructured arrays of dots, before mastering the conventional number symbols (Mussolin, Mejias & Noël, 2010). For such reasons, although I have not found this precise connection made in the literature, I would suggest that if IC has an impact on young children's achievement in mathematics, it might be expected also to have an impact on their drawing skills, which is what I directly examine next.

1.5.5 Drawing skills

From about the age of 12-18 months, the typical child will be making marks on paper (Cox, 1993). At first children may not intend their scribbles to represent anything, but this changes with age. As the child becomes older, the marks become more meaningful and often more ‘figurative’ (i.e., readily interpretable by an adult as resembling their subject matter). It should be noted that figurative representation which my study is largely concerned with is one subtype of the symbolic representation which we have widely referred to above. As Simeonsson and Rosenthal state (2001, p. 87), symbolic representation is "the ability to mentally represent an object or experience distant in time or space", and such representation may either be figurative, where "meaning and knowing are based on a correspondence of features or characters, the signifier (e.g. outline of a cat) and the signified object (cat)" or it may take other forms, termed "operative", such as the representation of a cat by the word *cat*. In the domain of children's drawing skills, therefore, we are concerned with symbols which are both non-mental (i.e. not purely mental representations like beliefs), and figurative (i.e. look like what they represent).

Drawing, in the widest sense, plays a valuable role in child development because it helps improve their cognitive abilities when they discuss and reflect on what they have drawn. This is supported by Brooks (2003), who showed that talking with children aged five and six years as they drew, encouraging them to give meaning to their creations, helped promote their mental functions, such as their ability to identify geometric shapes in what they had drawn, or to realise that a standing figure threw a larger shadow than a sitting one. This therefore suggests that when children are given the opportunity to think deeply and reflect on their drawings and share their understanding of them, their intellectual abilities are enhanced. Hence, such drawing activities are considered to be intimately connected with their cognitive abilities, as first suggested by Piaget and Inhelder (1956).

While some cognitive abilities may be affected by drawing, for many researchers a key issue is rather whether drawing skill may itself be considered to be a product of the EF. Indeed a number of EFs have been implicated in figurative drawing development. Empirical research however has tended to focus either on the role of the EFs in general, or on working memory in particular, without singling out IC (e.g. Kibby, Cohen & Hynd, 2002; Panesi & Morra, 2016).

Indeed, the degree of connection which has come to be accepted by researchers between executive function in general and drawing skill is such that drawing tasks (either productive or interpretational) are sometimes included in batteries of tests used to measure EFs (e.g. Fuhs, Nesbitt, Farran & Dong, 2014; Traverso, Viterbori & Usai, 2015). It could be argued, perhaps, that the tendency to include drawing tasks among measures of EF has discouraged research on the relationship between components of EF and drawing skill, by taking attention away from the fine grained differences between the separate constructs involved.

With reference to IC in particular, it has been suggested that 'suppression' (in a broad sense) is indeed needed for drawing skill to develop, but this suggestion has not typically been accompanied by empirical studies, performed to confirm this specific relationship. Miyake and colleagues (2000) for example proposed that when children learn to draw, a number of individual EFs play a role, including IC, working memory and attention shifting. Barlow, Jolley, White and Galbraith (2003) further suggested how IC might play a role in drawing development alongside working memory. They proposed that, in order to improve the figurative realism of their drawing, children need to inhibit their habitual way of drawing the target, such as a human figure, as well as to continually monitor the process of making changes in their habitual way of representing that target. Essentially children need to inhibit their immature drawing style, in order to advance to more sophisticated forms of drawing. Hence, working memory and IC need to work together to yield development in measured drawing skill.

Morra (2005, 2008) present similar ideas using somewhat different, neo-Piagetian, terminology. Initially Morra highlighted the role of young children's 'M operator' (his term for working memory), which only allows them to activate a few 'graphic schemes' at a time. By the term graphic schemes, he refers to children's stored representations of pictures or parts of pictures which they have previously drawn. That is "…the visual aspect of a previously attained solution to a graphic problem…" (Morra, 2005, p319). As children age, their M capacity increases, which allows for development of drawing skill, due to the simultaneous activation of more schemes while drawing a new picture. Morra then later suggested an ‘I operator’ (his term for IC), which again develops with age, and enables children to gain more drawing knowledge and skills. Consistent with Barlow and colleagues (2003), in Morra's terms, the I operator enables the child to develop new schemes and not simply to continue to draw based on existing ones.

At first sight, some studies which we discussed earlier which use non-mental symbolic representations suggest an empirical link between the development of IC and such non-mental representations. One such is Sabbagh and colleagues (2006), described in 1.5.2. This revealed an association between effective IC and performance on the signpost task, which involves a non-mental representation broadly similar to a drawing (i.e., a street sign). However, I suggest that there are many differences which mean that we cannot take this study as providing evidence of an association between IC and drawing in the sense discussed in the current section. First, we are concerned here primarily with the possible impact of IC on the process of a child creating a drawing product, not on the child's interpretation of a drawing product made by others. Furthermore, we are concerned with the development of children’s figurative drawing skill, in the sense of how well their drawing accords with the subject matter which they are asked to draw. We are not concerned with their understanding of any form of ‘false representation’ like that in the study of Sabbagh, and colleagues (2006). Finally, a signpost is not in fact fully comparable with a drawing because it is not figuratively symbolic: it does not look like what it points to. The false photo task is in that respect closer, but that did not yield a relationship with IC.

Overall, with respect to the role of IC in drawing skill development, studies such as those above only make proposals based primarily on *plausible* arguments, or offer empirical work conducted with different aims, which has uncertain implications for the relationship between IC and drawing skill development. A study which comes closer to directly researching the relationship between EFs and drawing skill, however, is that of Panesi and Morra (2016). This considered the relationship in 3- to 5-year olds between age, working memory, and what they termed EFs, on the one hand, and drawing a dog on the other. Working memory was measured from the Mr Cucumber, backward word span and direction following tasks. (In the Mr Cucumber test the child is shown an outline shape of a strange person with between 1 and 8 stickers placed on it in various positions. That is then removed and the child has to place stickers from memory in the correct places on a new blank outline shape.)

However, the measure of EF was close to being a measure of IC, since it was derived from performance on four tasks, three of which were inhibitory tasks (the day/night task, bear/dragon task and a dimensional change card sort task). Only one, the magic house task, was a measure of something else, 'updating', the ability to constantly update the contents of working memory (concerning what animals were in a house).

Notably also, in this study, the dependent measure of drawing skill for the dog differed from being a simple measure of figurative representation or detail such as I, like many researchers, use. Panesi and Morra (2016) aimed to utilize the proposal (e.g. Silk & Thomas, 1986) that young children (3–6 years old), after acquiring a schematic way to represent a person (their human figure scheme), develop a graphic scheme for a dog simply by differentiation from the human figure. Hence children in the study were asked to draw a man first, before the dog, and were scored for inclusion of 13 features of a dog, chosen to exclude any that would be the same for drawing a man. The researchers thus conceptualised the study as being focused on drawing 'flexibility', in the light of the fact that children are found in other studies to have well established schemes for drawing human figures, which affect their drawing of animals (Silk & Thomas, 1986). Correlation and regression analysis, controlled for the effect of age, showed that while working memory had the stronger correlation with the drawing measure, it was closely followed by the measure of EFs. The same was the case for drawing a man with the effects of age, motor coordination and score all partialled out. This therefore provides quite strong evidence for an independent effect of IC on drawing skill in young children, which cannot be explained away as simply due to its correlation with working memory capacity.

It could be argued, however, that due to the chosen nature of the drawing task and the way it was scored, an influence of IC was especially favoured in this study. Panesi and Morra (2016) were arguably not so much measuring effects of various EFs and other variables on ability to draw a dog, as on ability to resist the temptation to draw a dog like a man (i.e. the ability to inhibit the man drawing scheme). The fact that the children had to draw a man just before drawing the dog could have increased the inhibitory demands of the task, so favoured the likelihood of an association emerging between a measure of, EF which was close to being a measure of IC, and drawing skill. The researchers in effect primed the pre-potent response of drawing a human, thus making its inhibition even harder than usual when drawing the dog. Panesi and Morra's (2016) study does however suggest that drawing flexibility depends on the development of a variety of components of the cognitive system, including IC, which provides support to both Barlow et al.'s (2003) and Morra's (2005) suggestions. Nevertheless, for my purposes in the present study I will instead use a clearly distinct measure of IC, separate from other components of the EF, and measures of drawing skill based simply on the qualities of the drawings per se, not in contrast with drawing of anything else, so as not to specially favour an effect of IC.

Although Panesi and Morra come close to investigating the separate effect of IC on children's drawing skill, to my knowledge, the specific relationship between IC and drawing skill has only been tested separately and explicitly in just one study: Riggs, Jolley and Simpson (2013). This study investigated the associated of IC and human figure drawing in 3½- to 5½-

year-olds. The bear/dragon task was used to measure IC, and the classification system of Cox and Parkin (1986) was employed to measure quality of human figure drawing. Regression analysis showed that IC predicted development in human figure drawing even with the effect of age excluded, and, in reverse, ANOVA showed that the ability to draw recognisable figurative pictures was associated with higher IC scores. Thus, although this study was limited in using a single measure of IC and of drawing, it did support the proposal that IC, considered separately from other components of EF, plays a role in the development of the representational realism of children’s drawing.

Riggs and colleagues (2013) also importantly mentioned two alternative ideas about how IC might enter into the relationship which they found, which I will refer to as the ‘Symbolic Competence’ and the ‘Behavioural Inhibition’ accounts. The former draws attention to the obvious visual similarities in figurative drawings between the drawing itself and the subject matter it depicts in the world. In order for a child to draw figuratively, it is therefore argued that an understanding of this representational relationship, i.e. symbolic competence, needs to be present.

Symbolic competence or understanding is an understanding of symbolic representation, which is essentially a link between a mental entity (e.g., the category |dog|) and an entity in the real world (a physical dog). This ability can be measured in children through, for example, the use of a model of a room along with a real room. Children first observe the researcher hiding a model of a toy in the model room, and are subsequently required to find the real toy in the real room. If children achieve this, they display symbolic understanding (Kuhlmeier, 2005). As we saw earlier (1.5.2), studies have shown that IC in children is correlated with the ability to perform tasks which require such understanding (Benson et al., 2013; Sabbagh et al., 2006). There is a possibility therefore that the development of figurative drawing can be underpinned by understanding of symbolic representation, which in turn is associated with good IC (Benson et al., 2013). According to Riggs and colleagues (2013), if IC is connected to the development of symbolic understanding, then that can possibly explain the correlation between IC and figurative drawing.

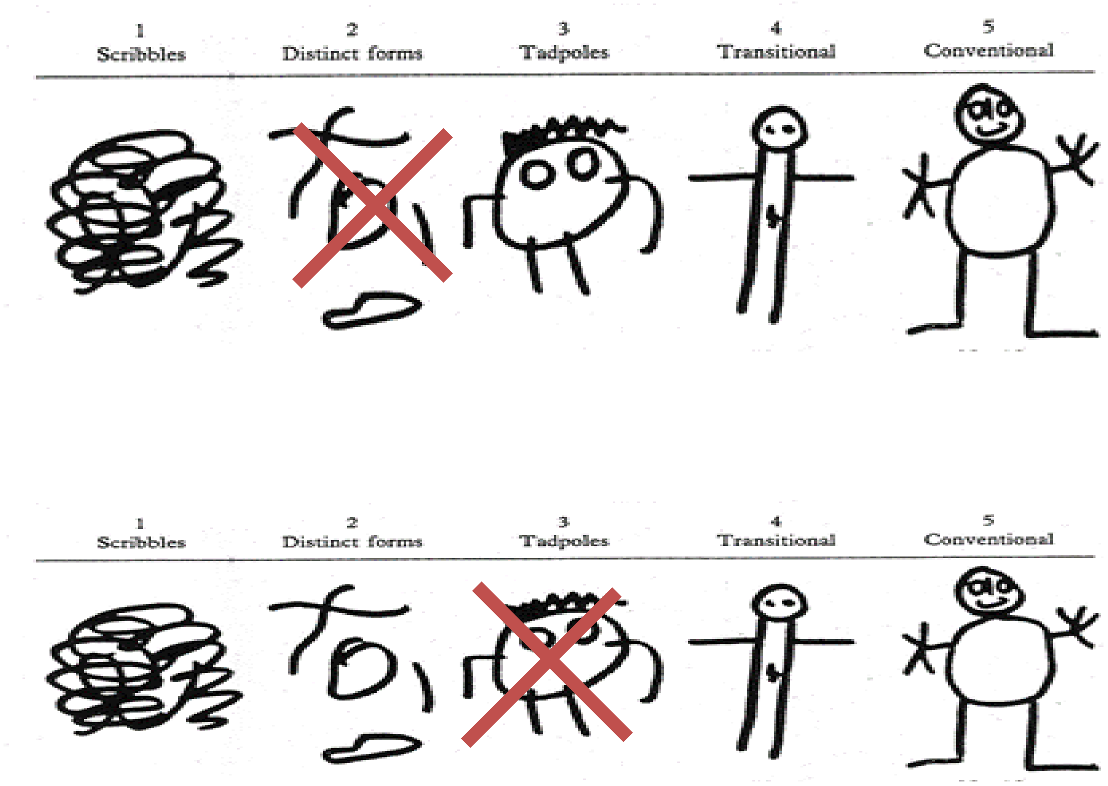
The ‘Symbolic Competence account’ is therefore based on findings that the development of such understanding is connected with the development of IC, around the age of three years (e.g., Apperly & Carroll, 2009; Beck et al., 2011; Benson et al., 2013; Sabbagh, et al., 2006). When producing a figurative drawing, clearly a child must exploit symbolic understanding so as to generate visual similarity between the drawing they envisage in their mind and the object in the world that the drawing is expected to depict. Since IC is associated with the development of symbolic understanding, then this connection may explain the relationship observed between IC and figurative drawing skill (Riggs et al., 2013). In short, following this account, the effect of IC on drawing skills would be partially or wholly mediated by symbolic insight/understanding.

The second idea of Riggs and colleagues (2013), which I term the 'Behavioural Inhibition account', relies on the indirect evidence that IC plays a role in drawing development arising from the fact that these abilities develop side-by-side during preschool years. This is combined with the suggestion that a number of improvements in the early development of children’s drawing skills can readily be interpreted as requiring inhibition of earlier behaviours.

In order to draw a picture and continue to improve in drawing, a child must inhibit immature drawing behaviour (Cox, 1993; Ebersbach, Stiehler & Asmus, 2011; Morra, 2008; Panesi & Morra, 2016; Riggs et al., 2013). For example, scribbling may need to be inhibited in order to draw enclosed shapes, which help to improve figurative drawing (Golomb, 1992; Barlow et al., 2003). The young child’s open-ended lines and shapes must be inhibited to produce enclosed shapes and these must in turn come to represent a recognizable contour of the referent. This is most easily seen in children’s outline drawings of a human figure. It could be that the development from drawing distinct forms to figurative forms (e.g., the tadpole shape –

see Figure 1.3) entails children inhibiting drawing disjointed lines and shapes. Furthermore, when drawing human figures, at three years of age, they tend to draw a ‘tadpole’ representation and then, by the age of five, begin to draw ‘conventional’ human forms (Cox, 1993) – again IC may be required to suppress the tadpole representation. Finally, in order to be ‘visually’ rather than ‘intellectually’ realistic, drawings of more than one object need to depict depth and partial occlusion of one object by another, when real objects are presented to the child overlapping or partly hidden. This requires ‘hidden line elimination’ (Freeman, 1980), and again the earlier tendency to draw complete objects at all times (intellectual realism) has to be inhibited so as to draw only what is actually visible.

Figure 1.3. Illustration of how children need to inhibit prior immature drawing schemata (those marked X, and to the left of X), so that they can move on to a more mature drawing style (Riggs et al., 2013).



IC also develops within the same age range as previously mentioned (e.g., Carlson, 2005; Simpson & Riggs, 2005). This then provides a rationale for how a child's ability to draw their first human figure representation may actually be aided by IC development, rather than just develop alongside it, without a connection. Inhibition may play a facilitative role in the graphic transition of children's depiction from earliest drawing behaviours up to age seven at least (Lange-Küttner, Kerzmann & Heckhausen 2002). Riggs and colleagues (2013) rely on the above reasoning as the basis for their second idea as to why IC and drawing skill might be correlated, which I refer to as the 'Behavioural Inhibition account': a direct relationship between IC and drawing skill not involving symbolic competence as an intermediary. Thus, following the Behavioural Inhibition account, IC and drawing skill would be associated directly, rather than mediated through other variables, because drawing skill develops straightforwardly through the suppression of immature drawing behaviour.

1.6 The Current Study

The current study, which embraces three separate studies, aims to build on existing work in several ways, not all of which have yet been fully introduced above. The literature relevant to certain parts of my study will instead be considered in detail in the separate chapters devoted to each study (chapters 2, 3 and 4).

The focus of the first study may be summed up in the following question: What is the relationship between IC and fine motor control (the coordination of muscles, nerves and bones to make small, precise movements), along with age and gender, on the one hand, and drawing skills during preschool development on the other? As I mentioned in 1.5.5, Riggs and colleagues (2013) offered two accounts for how IC and picture drawing skills could be associated – Symbolic Representation and Behavioural Inhibition. In Study 1 I will not only test how well the data gathered fits these accounts, but also consider a third possibility, termed the 'Motor Development account'. This has only very recently been formulated along with the current PhD research, and is being published in Simpson, Al Ruwaili, Jolley, Leonard, Geeraert & Riggs (in press). This takes into consideration that, in order to draw skilfully, a child also requires good fine motor control (FMC), as has previously been demonstrated in preschool children (Lange-Küttner, 2008; Toomela, 2002). If IC is then shown to affect FMC, this suggests that IC might impact on drawing skill not only directly, but also mediated via FMC. Evidence of such a relationship is limited in early childhood, but there is, on the other hand, a known relationship between the EFs and FMC in older children and adolescents (Riggs et al., 2013).

Since IC involves slowing down and monitoring performance, it is reasonable to propose that the development of IC may involve the reduction of impulsivity, which in turn improves FMC. This again would be expected to occur especially during the preschool years when IC is developing particularly strongly. Much remains uncertain, however, especially at the young age which Study 1 addresses. It could be the case that IC and FMC are associated simply due to them both developing strongly alongside each other within individuals over the age range 3 to 5 years (Thelen et al., 2001). Alternatively it could be that IC is indeed essential to the progress of FMC, and that the latter even mediates the effect of IC on drawing skill development (as predicted by the Motor Development account). The full literature and argumentation with respect to this will be presented in chapter 2.

Besides adding a third account of the relationship between IC and drawing skills to the other two accounts to be considered, Study 1 will also deal with drawing skill in a more refined way than has often been the case in previous studies. While considering the literature reviewed above in this chapter, it came to my attention that, although 'drawing skill' is sometimes referred to as if it was a unitary phenomenon, clearly it is not. In 1.5.5 I showed that its development goes through various stages, as described by Luquet (1927/2001). Hence, a number of different measures of drawing skill exist, quantifying different aspects of drawing, such as whether it represents something (i.e. is in fact figurative) rather than being a meaningless scribble, the degree of figurative detail present in the drawing, and the extent to which visual rather than intellectual realism is evidenced in a figurative drawing: again, this will be tested in more detail in chapter 2. For this reason, it was considered important in Study 1 not just to pick one of these measures, nor combine them into one overall measure, but to consider how the three accounts of the relationship between IC and drawing played out for each of them separately. In this way again I hoped to add significantly to knowledge in this research area.

In particular I wanted to know whether IC is linked to the development of visual realism in the same way as to the development of figurative skill more generally. As we noted in 1.5.5, visual realism is the term used for drawing aspects of an item as actually seen, in contrast with intellectual realism which refers to drawing features which are not seen at the time of drawing but known to exist (like the handle of a mug where the handle is turned away from view). These two types of figurative drawing realism (intellectual and visual), originally noted by Clark (1897, cited in Freeman & Janikoun, 1972), have been extensively described by Luquet (1927/2001) and more recently summarised by Jolley (2010). Luquet (1927, 2001) put forward a theory of drawing development that includes stages the child goes through in their depiction, and many researchers are interested in the shift between two of these stages, intellectual realism and visual realism.

Studies 2 and 3 (in chapters 3 and 4) to a considerable extent constitute follow-up studies of different aspects of the findings from Study 1. Hence it is not appropriate here to detail their scope, nor to review all the relevant literature. Briefly, Study 2 follows on from evidence obtained in Study 1 that IC and motor control are tightly linked in early childhood, regardless of their specific relationship with drawing skill. Study 2 attempts to disentangle the relationship between FMC, gross motor control (the coordination of muscles, nerves and bones to make larger movements with the arms, legs, feet, or entire body) and IC, controlling for both age and general intelligence. Study 3 follows up on an intriguing finding which emerged in Study 1, concerning the pattern of development of visual realism. I obtained an unexpected result which potentially challenges the accepted view that children start drawing with intellectual realism and simply progressive to visual realism. Hence it investigates the precise nature of the relationship (linear or quadratic) between age and the development of visual realism in drawings between the ages of two and eight years.

Chapter 2. How are Inhibitory Control and Fine Motor Control related to the Development of Preschool Children's Drawing Skills?

2.1 Introduction

As highlighted in the previous chapter (1.5.5, 1.6), it has already been shown that inhibitory development is related to the development of drawing skill in children. Many details of this relationship, however, remain unclear. It has long been known (since Luquet, 1927/2001) that drawing skill progresses through a number of stages, including the onset of drawing distinct forms, in contrast with scribbling, then the move to drawing more conventional forms with less or greater detail, and then, within figurative or representational drawing, the progression from intellectual to visual realism, when attempting to draw specific objects or people directly seen in the environment (as against drawing entirely from memory). Intellectual realism shows itself when children draw features which they know the object possesses, even though they cannot be seen at the time, such as the handle of a mug when in fact the handle is turned away from view. Visual realism is demonstrated by drawing just what can be seen at the time of drawing. While there is some research that considers the relationship between IC and the emergence of figurative drawing (Riggs et al., 2013), to date there is no research examining the relation between IC and the transition from intellectual to visual realism. One possibility is that the inhibition of intellectual realism is required to produce a visually realistic drawing (Crook, 1985; Freeman, 1980; Luquet, 2001): this possibility has been raised but not previously empirically tested (Ebersbach et al., 2011; Riggs et al., 2013).

Furthermore, there are a number of possible mechanisms by which IC might be related to drawing skill during development. As outlined in section 1.5.5, two accounts have been proposed, to which I added a third. These I refer to as the Symbolic Competence, Behavioural Inhibition, and Motor Development accounts. The first two of these were proposed by Riggs and colleagues (2013), though not explicitly named in that study. The third is a new proposal made by a research group of which I am a member, and it is a specific aim of the present study to assess it.

Under the first of these accounts, it is argued that IC is primarily related to the domain-general understanding of symbolic representation, as shown for example by research in the field of theory of mind and false signs (e.g., Apperly & Carroll, 2009; Benson et al., 2013; Sabbagh et al., 2006). Extending this argument, it is proposed that symbolic understanding would also play a role in the production of figurative drawings. The symbolic understanding that children require in order to draw a figurative picture is essentially an understanding of the relationship between a mental construct (e.g., the category |house|) and something in the world (an actual house). If IC is associated with the development of this symbolic understanding, then it can explain the observed association between improvement in IC and the emergence of figurative drawing from scribbling, and the subsequent development of its elaborative detail (Riggs et al., 2013). The claim of the Symbolic Competence account then is that the link between IC and figurative drawing skill is indirect, occurring through the mediating variable of symbolic understanding, which is the ability which is directly associated with IC.

An account could in principle be true or not at any stage of drawing development, whether that of moving from scribbles to distinct forms, from distinct forms to figuratively representational forms, or, within the latter, from intellectual to visual representations. If it is shown to apply at certain stages, however, I argue that cannot be taken as confirmation that it applies at all stages of drawing skill development: each must be separately tested. In fact, when it comes to the Symbolic Competence account, one would not expect it to explain the third transition (intellectual to visual), since this is not a transition from non-figurative to figurative, but just between two versions of figurative representation. The findings of Riggs and colleagues

(2013) are consistent with this account applying at the first two of those transitions (the third was not measured). However, these findings are also consistent with the predictions of the other two accounts, as symbolic competence was not included as a measured variable in their study.

Under the Behavioural Inhibition account, IC is seen as having a simpler and more direct role in drawing development. This account holds that many advances in drawing skill require the direct intervention of IC to suppress a previous, less mature drawing behaviour. Scribbling, for example, must be inhibited in order for children to produce enclosed shapes, and to move from those to fully figurative drawing (Riggs et al., 2013). The oversimplistic drawing of these shapes must in turn be inhibited, so that pictures which represent detailed outlines and other features of objects or people can be produced (Lange-Küttner, Kerzmann, & Heckausen, 2002).

Finally, when asked to draw a specific object in view while they are drawing, children may have to inhibit their earlier habit of drawing a part of that object which is occluded (Freeman & Cox, 1985). It seems likely that intellectual realism must in some sense be 'rejected' in order to produce a visually realistic drawing (Crook, 1985; Freeman, 1980; Luquet, 2001). Indeed, although I have not found this argument in the literature, it might even be suggested that a close parallel exists here with the role of IC in the development of counterfactual reasoning (see 1.5.3). Glick and Scribner (1984) found that IC was needed to enable 4- and 5-year olds to successfully inhibit reasoning based on the reality that birds always have wings and instead to entertain the idea presented to them that some birds have wheels. Analogously, when drawing, we might expect children with low IC to have difficulty inhibiting what for them is the 'reality' that a mug always has a handle, and manage to draw a mug without a handle where that handle is not visible in a particular exemplar presented to them in the immediate context. However, any role of IC in suppressing intellectual realism in order to enable visually realistic drawings to emerge has not been investigated empirically.

In this account, therefore, the relationship between IC and drawing skill is direct, and not mediated through any other ability. The results of Riggs and colleagues (2013) are consistent with this view as much as with the prediction of the Symbolic Competence account, at least for earlier stages of drawing skill development. As stated above, the authors however did not include the transition from intellectual to visual realism in their study. Hence the present study extended the Behavioural Inhibition account to test the relationship between IC and drawing skill at this level.

The ideas behind the above two accounts are not new (Riggs et al., 2013). The current study however investigates an additional account, the Motor Development account, as outlined in section 1.6, which proposes that the relationship between IC and drawing skill is mediated by fine motor control. In other words, it sees well developed fine motor control as a prerequisite for drawing development, especially for the emergence of figurative drawing from scribbling, and for increasing use of figurative detail in these drawings. IC in turn is seen as associated with the development of fine motor control, which involves controlling smaller muscles in order to grasp and manipulate objects (Wells, 2006) and requires precise visuomotor coordination, especially in movement of the hands. Hence it is required for skilled drawing (e.g., Lange-Küttner, 2008; Toomela, 2002). There also exists some evidence linking IC and motor control in development more generally (Diamond, 2000; Koziol, Budding & Chedekel, 2012). There is, however, less evidence for an association between IC and motor control in young children, especially 3-and 4-year-olds, although this age group is of particular interest because IC improves most rapidly at this age (see section 1.4).

In the current study, I will not only consider the power of the Motor Development account in explaining the emergence of figurative representation from scribbling, and in the increase of representational detail in children's drawing, but also in the shift from intellectual to visual realism. It is possible that, even if the relationship between IC and figurative drawing skill development is mediated by FMC at earlier stages, as suggested in the Motor Development account, it could still also be the case that IC acts *directly* to suppress a specific drawing behaviour at other transitions, such as the shift from intellectual realism to visual realism, as suggested in the Behavioural Inhibition account. After all, it is unclear whether there are differences in motor control demands between drawing intellectually and visually realistically, in the way that there appear to exist such differences in demand between scribbling and figurative drawing. While IC and symbolic understanding have already been extensively reviewed in chapter 1, I did not give the same attention to motor control, which I therefore review next.

2.1.1 Motor control and its relationship with IC

The development of motor skill in general is a process which continues throughout a person's lifetime. This not only includes physical growth, but also development of the motor and nervous system (Gallahue & Ozmun, 2006). Overall motor skills are conventionally further subdivided into gross motor skills and fine motor skills, each with their own control mechanism.

Gross motor control (GMC) manages skills which require the use of large muscle groups (arms, legs and neck) and the involvement of large scale bodily movements (Payne & Issacs, 2008). GMC is developed in early childhood for stability and control of the body in order to facilitate exploration (Cools, de Martelaer et al., 2009; Gallahue & Ozmun, 2006; Haywood & Getchell, 2009; Schmidt & Lee, 2005). These skills are subdivided into locomotor skills and object control. Whilst locomotor skills involve the movement from one place to another (e.g., walking, running, jumping), object control skills involve the movement and coordination of body parts with objects – to either take action or receive a response from the object (e.g., throwing a ball, climbing on a climbing frame).

Fine motor control (FMC) manages fine motor skills which require the use of small muscles (e.g. hands and fingers) to produce precise and refined movements, required for daily activities, such as feeding oneself, dressing, writing and drawing (Cools, De Martelaer, Samaey

& Andries, 2009; Summers, Larkin & Dewey, 2008). FMC also involves incorporating visual stimuli from the environment (Korkman, Kirk & Kemp, 2007). Children need to use visual information from their environment alongside their refined muscle control to complete complex tasks such as placing jigsaw pieces in the right position with others or cutting and gluing paper (Sorter & Kulp, 2003). According to Diamond (2000), fine motor skills, like gross motor skills, rely for their control on the prefrontal cortex and the cerebellum.

FMC is especially relevant to the present study because, according to Toomela (2002), greater FMC improves drawing skills. Thelen, Corbetta and Spencer (1996, p.1074) stated that good motor control requires “learning to maintain a smooth, straight reach under various speed and load conditions and from many locations in the reaching space”. Furthermore, von Hofsten (1993) and Jeannerod (1997) described development of this skill as progressing from movement that was less continuous and less straight, to straighter, more controlled and more direct movement. In fact, children’s drawing skill involves more sub-movements, referred to as ‘movement units’, than do many other motor activities (von Hofsten, 1979). Movement units are actions, such as reaching for something with the hand, or drawing a line on paper, which are distinct from other previous or later movement units by having their own separate acceleration and deceleration phases: each one is seen as being separately planned or ‘prospectively controlled’ (von Hofsten, 1979). Hence for my study, which is focused on factors affecting development of children’s drawing skills, FMC is of more central concern than GMC.

Drawing places heavy cognitive demands on young children, to control their fine motor skills, both because of the inherent complexity of the task and also because their limited experience at performing it. Indeed, according to Toomela (2002), drawing is also considered one of the best ways to study children’s sensorimotor skill. Furthermore, just as it was remarked in Chapter 1 that drawing tasks are sometimes used as measures of IC, so also we find them used in standardised measures of young children’s FMC. For example, the Peabody Developmental

Motor Scales – second edition (PDMS-2) battery of tests includes, in its Visual-Motor Integration subsection, drawing tasks (e.g. copying a circle). Once again, in my study, however, I will not use such tasks to measure FMC, so as not to confound my measures of drawing skills with those of FMC.

As noted in section 1.5, previous research has shown that development of IC in early childhood is linked to the development of a whole range of other cognitive skills, including the understanding of symbolic representation (Apperly & Carroll, 2009; Beck et al., 2011; Benson et al., 2013; Sabbagh et al., 2006). The evidence below further shows some, albeit fragmentary, evidence of an association between IC and motor control. IC and FMC are usually studied separately in young children, but there is an increasing awareness and understanding of the close relationship between these abilities in the process of child development. Something that remains unclear, however, as the rest of this section will show, is the precise underlying mechanism of the connection. Does FMC lead to IC? Or is the reverse true? Or do both simply develop together dependent upon some third ability? There are then at least three possible positions which may be adopted concerning the precise relationship between IC (or EFs in general) and FMC (or other forms of motor control).

One kind of evidence which lends support to the possibility of a link between motor control and EF is neuroscientific, often based on studies of adolescents with Attention Deficit Hyperactivity Disorder (ADHD). Barkley (2012), for example, shows that there exist large overlaps in neural structures, mainly in the cerebellum and prefrontal cortex, both of which are linked to controlling action and to EFs (including IC). Wang, Kloth and Badura (2014) further claim a strong association between motor skill, cognitive skill and cerebellum development. Davis, Pitchford, Jaspan and colleagues (2010) also found a correlation between motor and cognitive skills in children with cerebellar tumors. Thus, there is support for the proposal that abilities such as FMC and IC occupy a similar location in the brain, and so are intimately connected. Moreover, there is an association between increased grey-matter density in the frontal lobes and cerebellum and the early onset of walking and standing in infancy and executive functions in adults (Murray, Jones, Kuh & Richards, 2007).

While this evidence of location in the same parts of the brain is consistent with the proposal that IC and FMC simply develop together, work by Duque, Mazzocchio and colleagues (2005) suggest a key role for IC in relation to lateralization of brain functions which could provide an explanation of why IC and FMC are intimately connected in the brain, and even be taken to suggest that IC leads to FMC. Many successful actions require communication between the hemispheres, and this in turn involves a mechanism of functional inhibition as well as facilitation: inhibitory involvement is believed to be critical in the preparation of unilateral actions so as to counteract the production of default mirror movements.

Turning now to developmental psychological studies of typical children, there are only a few relevant studies of infants. Gottwald, Achermann, Marciszko and colleagues (2016) for example found an association between IC and motor planning (though not wider aspects of motor control) in 18-month-old children. There also exists one study that found a link between IC and FMC in 12-month-old children, and a link between IC and both FMC and GMC in 24-month-old children (St. John, Estes, Dager et al., 2016). In 5- and 6-year-olds, Livesey, Keen, Rouse, and White (2006) measured both FMC and IC (using Stroop and stop-signal tasks). They found that motor performance significantly correlated with Stroop performance. The relationship with the stop-signal task scores was in the expected direction, but did not reach significance. However, Roebers, Röthlisberger, and colleagues (2014) also found significant correlations between FMC, IQ and EF (in which IC was included) in typical 5- and 6-year-olds. While evidence suggesting that IC is related to FMC is limited in early childhood, it is more strongly evidenced in older children and adolescents. Rigoli, Piek, Kane and Oosterlaan (2012), for instance, found a significant positive correlation between an IC measure and FMC in 12- to 16-year-olds.

It is notable that most evidence for the relationship between IC and FMC in fact comes from individuals diagnosed with conditions such as Developmental Coordination Disorder (DCD) (Leonard and Hills, 2015), Autism Spectrum Disorder (ASD), and Attention Deficit Hyperactivity Disorder (ADHD – Sugden, Kirby & Dunford, 2008). These all tend to exhibit deficits both of motor and inhibitory functions, thus implying a connection between the two, though not what kind of connection.

DCD is diagnosed specifically on the basis of difficulties found in acquiring and executing motor skills which affect daily living as well as academic achievement, difficulties which cannot be explained by other medical conditions. The motor characteristics of DCD are however almost always accompanied by behavioural and attention problems, reflecting poor development of IC, according to Henderson, Rose and Henderson (1992). Hence, there is a large body of evidence demonstrating that poor EFs are associated with this disorder (Leonard, Bernardi, Hill & Henry, in press; Mandich, Buckolz & Polarajko, 2002; Piek, Dyck, Francis & Conwell, 2007).

The three main components of executive function with which individuals with DCD have difficulties are IC, working memory and switching (Mandich et al., 2002; Alloway & Archibald, 2008; Michel, Roethlisberger et al., 2011), the same being true in individuals with ASD and ADHD (Miyake, Friedman, Emerson et al., 2000). Such difficulties can be seen in children as young as three years (McEvoy, Rogers & Pennington, 1993), though not all studies support this finding (Griffith, Pennington, Wehner & Rogers, 1999). On-going development of EFs with age is also not guaranteed in individuals with these disorders. For example, whilst typically developing individuals did improve on a computerized task measuring working memory, an ASD group did not (Luna, Doll, Hegedus, Minshew & Sweeney, 2007). Similar findings were found in a study by Solomon, Ozonoff, Carter and Caplan (2008), who even observed a slight decrease in performance over time in individuals with ASD. This pattern of deficits may well further extend to IC. There is however not much information on EFs before the unfolding of ASD symptoms, since studies are usually undertaken on individuals who already have ASD.

Furthermore, motor difficulties in children with ADHD are now widely documented in the literature (Barkley, DuPaul & McMurray, 1990; Piek, Pitcher & Hay, 1999; Pitcher, Piek, & Hay, 2003). By comparing motor performance between children with ADHD and non-clinical control children, Piek and colleagues (1999) found a link between motor ability and inattention, which can be interpreted as a relationship between FMC and IC (although the kind of inhibition which my thesis is concerned with is in fact the behavioural rather than the attentional type, see section 1.2). This was further supported by a follow-up study, which compared children with ADHD with non-clinical controls using the Movement Assessment Battery for Children (a standardized assessment of motor ability to identify children with motor coordination deficits). A relationship between motor ability and inattention was again found (Pitcher et al., 2003).

Although empirical evidence for a relationship between IC and FMC, and for the directionality of any relationship, is limited in early childhood for typical children, there are a number of evolving theories which support an association between EFs and motor control, such as the Embodied Cognition and Dynamic Systems theories. Embodied Cognition is defined by Thelen and colleagues (2001) as a cognition which emerges from the interaction of the body with the world, as well as depending on the body with its specific perceptual and motor abilities. This means that this approach does not consider the body and its physical actions as being somehow distinct from the mind and its cognitive processes, as do some approaches to psychology (Wilson, 2002). Consequently, a link between a human capability that is more manifest physically, such as FMC, and one that is more mental, such as IC and other EFs, is seen as entirely natural and to be expected.

According to the Dynamic Systems theory of development, on the other hand, all aspects of a human being develop together and mutually affect each other bi-directionally, within a scenario in which a vast number of factors at many levels are at work. In such a view, the EFs, including IC, can emerge from what is called prospective motor control, the ability to plan motor activities and adapt them to different goals, which itself arises through exploratory actions and cycles of perception and action which are the defining characteristics of motor control itself (Thelen et al., 1996; Thelen & Smith, 1994; Thelen, 1992). Von Hofsten (2014) in fact considered prospective motor control to involve implicit knowledge concerning fundamental physical principles, and so to be, in effect, embodied action control. This therefore provides a potential way in which the development of aspects of motor control such as FMC could lead to development of EFs such as IC. Indeed, according to several researchers (Van der Meer, Van der Weel, Lee et al., 1995; Von Hofsten, 2004; Zoia, Blason, D'Ottavio, et al., 2007), prospective motor control develops during the first few months of life, but EFs emerge later on in infancy (Diamond, 2000), implying perhaps that it is the former that leads to the latter. Whilst the executive functions involve multiple processes and act upon ideas, they also, like motor skills, act upon the outside world (Willingham, 1998). Hence, it is entirely possible that EFs can be derived from prospective motor control as described above.

Further evidence for the idea that EFs develop from motor processes comes from a study by Murray and colleagues (2007), which showed correlations between the onset of standing and walking in infancy and EFs in adulthood. This study, as well as previous work by Thelen and colleagues (1996, 2001), again suggests that prospective motor control is important in the development of EFs. Infants who develop motor control abilities such as standing, walking and reaching early, develop better executive function skills.

Gottwald and colleagues (2016) also found that, at 18 months, simple inhibition (in tasks with low working memory demand such as the day/night task), together with working memory, emerged as positively related to prospective motor control. By contrast, complex inhibition (in tasks with higher working memory demand, such as a Stroop task) and control variables were not. Gottwald and colleagues however argued from this that in infancy, with simple inhibition tasks such as are used in the present study, both prospective motor control and EFs including IC could develop from the one need to control action, with neither having priority. This contrasts with studies cited above which suggested that the EFs might actually be the product of prospective motor control.

In short, we may conclude that while available studies and relevant theories are often interpreted as supporting the idea that motor control skills (such as FMC) and EFs (including IC) simply develop together, or that the former lead to the latter, there has been little attention to the possibility that the latter might in some sense lead to the former, especially in typical children in early childhood. However, the Motor Development account which we described at the start of 2.1, and which it is a prime purpose of Study 1 to evaluate, incorporates the idea that IC leads to FMC, rather than the reverse. It predicts that IC would impact on FMC which in turn (as a mediator) would be associated with drawing skills: it does not propose that FMC is mediated by IC in its effect on drawing skills. Hence, aside from its concern with the three accounts of how IC might affect drawing skill, Study 1 may additionally be seen as a contribution to our understanding of how IC and FMC are related to each other. In particular it explores the neglected possibility that IC in some sense has priority over FMC rather than the reverse.

2.1.2 Overview of Study 1

In order to properly evaluate the three accounts described in 2.1, it was necessary to measure more than one dimension of drawing skill. Thus two of the measures used in the current study focused on the emergence of children's ability to draw something that an adult could recognize as an object or person (the measures of figurative representation and figurative detail). The measure of figurative representation (FR) targeted the transition from scribbling to some kind of figurative drawing in the four drawings elicited in this study: of a person and a house from memory, and of a mug and two balls from models in view. Each was scored 1 for figurative and 0 for non-figurative, so the overall scale ran from 0 to 4. A measure of figurative detail (FD) quantified the amount of detail in the drawings of a person and of a house. This employed an overall scale of 0 to 16 based on the Cox and Parkin Human-figure scale (1986) and 12 common features of a house that could be included (based on Barrouillet, Fayol, & Chevrot, 1994).

Since these scales did not quantify the kind of realism involved, I also measured the child's progression from intellectual realism to visual realism, through a task where children had to make two drawings of objects as they were seen in front of them: first a mug with the handle turned away (Freeman & Janikoun, 1972), and then two balls where one was partly hidden behind the other (Cox, 1978). The children were scored for whether they drew them precisely as seen (visual realism, +1 for each drawing) or how they knew them to be, including parts that were hidden (intellectual realism, -1 for each drawing).

In order to assess the three accounts, in the current study, I further needed to measure IC and FMC. The former was achieved through two age-appropriate tasks, which were selected from the range usually used to measure IC in children, as recommended by Petersen and colleagues (2016). These two tasks, the grass/snow and day/night tasks, were chosen for their minimal motor demands (verbal response or just pointing at pictures), so as to avoid any confounding of the measure of IC with the measure of FMC.

FMC was measured using eight age-appropriate tasks selected from the Peabody Developmental Motor Scale (PDMS-2 – Wang, Liao & Hsieh, 2006). They involved folding and cutting, putting laces through holes, and building with wooden blocks: tasks which required drawing were omitted, so as to avoid any confounding of the measure of FMC with the measures of drawing skills.

Based on the literature reviewed above and arguments set out here, I formulated a number of hypotheses concerning the findings of my study. These fall into three areas: background variables (age and gender), predictors of figurative representation and detail, and predictors of drawing realism. First, on the basis of much previous research which shows that age-related development occurs in the abilities which are of current concern, age was expected to be associated with improvement in performance on drawing ability of all types, as well as with improvement in IC and FMC. Hence age had to be included in all analyses so that its effects could be controlled for. In particular, the age-related transition from intellectual realism to visual realism, which occurs in middle childhood (Clark, 1897; Freeman & Janikoun, 1972), is in fact one of the oldest findings in cognitive development. Overall, the use of visual realism is usually seen as increasing monotonically during childhood (Cox, 2005; Golomb, 2002; Jolley, 2010). Gender was also included in the study, but on the basis of previous research was not expected to associate with drawing skills.

Next, all three of the accounts predicted a relationship between IC and figurative representation and figurative detail. The difference is that while under the Behavioural Inhibition account this relationship would be direct, under the Motor Development account the relationship would not be direct, but mediated through FMC. The Symbolic Competence account predicts a link mediated through symbolic understanding, but, since I did not measure symbolic understanding, in the context of this study the link would appear to be also direct. A relationship between IC and figurative representation was deemed particularly relevant to the Symbolic Competence account, however. If the strongest direct relationship were found between IC and figurative representation that would suggest that the mediating role of symbolic understanding should be explored further.

Third, only the Behavioural Inhibition account predicted a relationship between IC and drawing realism (visual versus intellectual). It further predicts that this link would be direct, not mediated through FMC, and, given the usual development of realism in the literature, from intellectual to visual, positive. The other two accounts do not appear to predict such a relationship. One might speculate that since the motor demands of drawing a visually realistic picture do not appear to exceed those of drawing an intellectually realistic picture, the Motor Development account would predict no impact of FMC on this measure. Furthermore, since arguably visual and intellectual realism are equally the product of symbolic understanding, the Symbolic Competence account does not appear to predict a relationship between IC and change between these drawing styles.

2.2 Method

2.2.1 Participants

One hundred children (55 girls and 45 boys) participated in this study, with age range from 3 to 4 years (mean age = 44.2 months, SD = 6.77 months). These children were recruited from nurseries and preschools in Bury St Edmunds and Colchester. All spoke English as their first language, and none were reported as having any behavioural or learning difficulties (based on teachers' reports). The sample was of mixed social background and was predominantly white.

One hundred was selected as a suitable sample size since I wished to perform multiple regression and had been advised that 100 was a suitable minimum number for this. In order to obtain this number I began with a larger number but had to eliminate some 12 children who either could not or were not willing to participate in one or more of the IC or FMC tasks. For instance, one child declared that he did not know the names of the sun and the moon. I provided the names and then administered the IC day/night and grass/snow tasks which required knowledge of these words. To my surprise the child performed perfectly, but I excluded him since I supposed that his perfect performance was not due to his high rate of IC but rather to the fact that he had no established knowledge of the words *sun* and *moon*. Hence the association of the word *sun* with a picture of the sun was not for him an established prepotent response which had to be inhibited at all. Children who produced a scribble rather than a drawing were not excluded, however, since this provided measurable information about their figurative drawing ability (2.2.4.1).

2.2.2 Design

In the current study, a within-subjects correlational design was used. The three drawing measures: figurative representation (FR), figurative detail (FD) and realism (intellectual vs visual) were the dependent variables. The independent variables were IC, FMC, age and gender.

2.2.3 Materials

The following materials were used for the tasks involved in the study.

Drawing tasks: plain A4 paper, pencils, a mug (height 12cm, diameter 6cm) and two balls (diameter 9cm). IC grass/snow task: two pictures: one of the moon in a night sky, and the other of the sun in a day sky (height 12cm, width 12cm – See Figure 2.1). IC day/night task: a flip-book, which contained 16 pictures, half of the sun in a day sky and half of the moon in a night sky. FMC motor control task: materials from the Fine Motor Quotient of the Peabody Developmental Motor Scale – Second Edition (PDMS-2, Wang et al., 2006). The materials included two sheets of A4 paper: one with a black circle and the other with a black square, in the centre of each sheet. These were photocopied for each child. In addition to this, there were blunt scissors, ten coloured square blocks made of wood, a strip of card with 6 holes in it and a shoe lace (See Figure 2.2).

Figure 2.1. The day/night task[1].

[1] Images from Simpson and Riggs (2010)

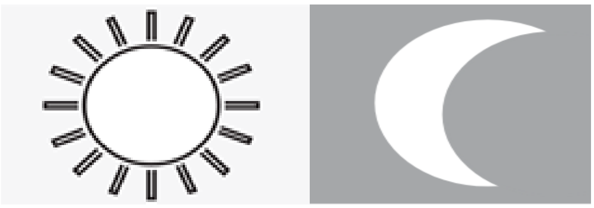


Figure 2.2. PDMS-2 test materials[2].

2.2.4 Procedure and scoring

Informed consent was first obtained from the parents of participants and the school authorities. The measurement sessions involved two people, the researcher (E1) and a Master's student with experience of these tasks (E2). E1 was responsible for the administration of the tasks and E2 recorded the children's responses. All the children were tested individually, in the morning, either in a separate room from their classroom, or in a quiet corner of their classroom. E2 sat next to the child to record the responses while E1 sat across the table. The children were asked for their help, and told that they were going to play some fun games.

Table 2.1. Task order of Study 1.

Session 1	Session 2
1. Draw human figure	1. Draw a house
2. Grass/snow	2. Day/night
3.Draw mug (handle occluded)	3. Draw balls (overlapping)
4. Lace a string	4.Cut a circle

[2] Image from publisher's website

5. Cut a square	5. Fold paper
6. Build a pyramid	6. Build diagonal-pyramid
7. Button strip	7. Touch Fingers

There were 14 tasks in all, which were administered over two sessions to each child, on different days, each session lasting about 20 minutes, and which followed a fixed order, shown in Table 2.1. In each session drawing tasks, starting with the most demanding (human figure or house), came first, and the purely motor tasks later.

2.2.4.1 Drawing tasks. Four tasks were administered over the two sessions. In each session a plain A4 paper and a pencil were placed on the table in front of the child.

In Session 1, for the Human-figure task, children were asked to draw themselves with the instruction, "Can you draw a picture of yourself?" The drawing in this task was therefore totally based on the children's memory. For the Occluded-handle task, a mug was placed on the table in front of the child in such a way that the handle was not visible. Children were then asked to "Draw what you see". If they asked any questions about how to draw it they were asked to "…Just do your best drawing". The drawing in this task was therefore instructed to be based on representing the objects in view.

In Session 2, for the House task, children were asked, "Can you draw a picture of your house? (Or *a* house, if they said they did not live in one)". The drawing in this task was therefore based on the children's memory of houses. For the Occluded-ball task, two balls were placed on the table in front of the child so that one ball was half-hidden by the other. Children were asked, "Can you draw a picture of these two balls?"

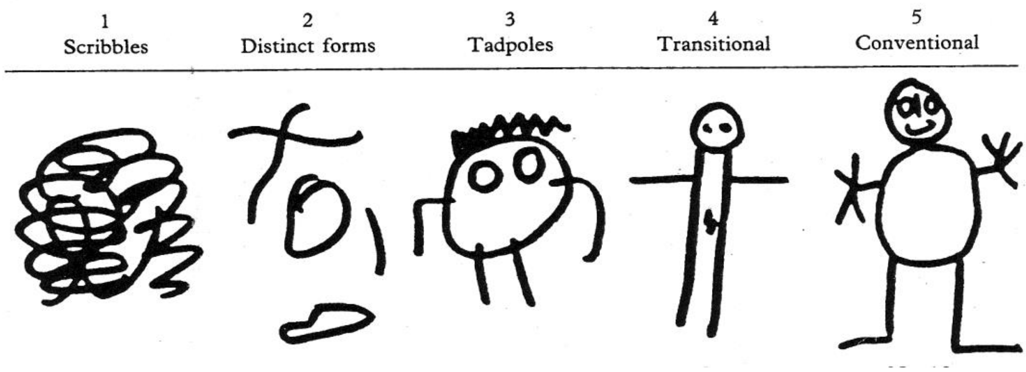
The drawing tasks were scored as follows. For figurative representation, E1 and another expert independently scored each of the four drawings as either showing figurative representation or not (figurative representation scale scored from 0-4). Drawings were assigned to the figurative category if the two raters were able to identify the drawing as resembling the object in the real world. Drawings were assigned to the non-figurative category if the raters were unable to identify them. Where there was disagreement, the drawing was discussed until agreement was reached.

In order to measure figurative detail, just the human figure and house drawings were scored by two measurers, as follows. The human figure was scored according to the Cox and Parkin (1986) Human-figure scale (See Figure 2.3). It is scored in detail as follows: 1. Scribbles – 0 point (Abstract, nonrepresentational. No distinct forms or strokes); 2. Distinct forms – 1 point (Some distinct forms or strokes); 3. Tadpoles – 2 points (Has only one enclosed head/body area. All figures have legs attached to lower part of this closed area. May have facial features. May also have arms attached to side of head/body area); 4. Transitional figures – 3 points (Shows some definite separation of the head and body features. May have arms and facial features. Arms may be attached to legs); 5. Conventional figures – 4 points (Drawings include a separate head and body, i.e., two distinct enclosed areas. Usually have facial features, legs, and arms) (See Figure 2.3).

The house task was scored using a revised version of the house scale of Barrouillet, Fayol and Chevrot (1994), and identified 12 features of a house to look for in the drawings. Each item was given 1 point providing a maximum score of 12. This revised scale was taken from Brechet and Jolley (2014) who excluded certain features from the longer list of 22 items in Barrouillet and colleagues (1994) because none of their children drew them ('chimney', 'vertical chimney', and 'folding out of house elements'). The item 'at least a window' was also excluded because it was considered repetitious of the 'two or more windows' item. Three additional items related to windows were also excluded. 'Two high windows' was omitted because it would have disadvantaged children who drew bungalows, 'alignment of windows' because it was too similar to 'position of windows', and 'texture/shape of windows' because the criteria were not sufficiently clear. ‘Attic’ was excluded because it was unrelated to the representational quality of a house drawing. Finally, the two items ‘path’ and ‘other buildings attached’ were relabelled as a single item ‘extraneous’. The revised list of items used in the scale was therefore: ‘outline of house’, ‘roof’, ‘roof shape’, ‘door’, ‘door handle’, ‘base of the house’, ‘two or more windows’, ‘position of windows’, ‘proportion of windows’, ‘curtains’, ‘extraneous items’ and ‘perspective’. The scores for the human-figure task and house task were added to produce the overall figurative detail scale score (scored 0-16).

In order to measure realism, just the occluded-ball and occluded-handle drawings were used. The drawings of the mug and ball were scored on the realism scale (scored -2 to 2) as follows. A score of -1 was given if the handle of the mug was included, or both balls shown in full (intellectual realism), and +1 if the handle was omitted, or the balls shown with one partly hidden (visual realism). Thus higher scores reflect greater visual realism.

Figure 2.3. Cox and Parkin’s (1986) classification system for human figure drawing.



2.2.4.2 IC tasks. IC was assessed with the day/night task and the grass/snow task, which were adopted from Simpson and Riggs (2009). The grass/snow task was in fact implemented with day and night pictures in the present study: it is referred to as the grass/snow task because that is the form it originally took in earlier studies (see chapter 1.3) and to distinguish it from the day/night task which requires speaking rather than pointing by the child.

In Session 1, for the Grass/snow task, E1 explained that they were going to play a ‘silly game’ in which the child had to point to two pictures. Children were shown the sun and moon pictures and asked to name them. E1 then explained that in the game they had to point to the sun picture when she said, *moon,* and to the moon picture when she said *sun.* The child was explicitly told not to point to the named pictures. E1 then ‘talked children through the rules’ by saying the two names and getting them to point to the appropriate picture (e.g., “…so when I say *sun* can you show me which picture you have to point to” confirming that they were correct or correcting them if necessary by referring to the rules. Children then received four practice trials (order: sun, moon, sun, moon) with feedback. If, for example, the child pointed to the moon when the researcher said *sun,* E1 confirmed that this was the correct response. If, however, the child pointed to the sun, E1 said that this was wrong because moon was correct. Children next received 16 test trials in the same pseudorandom order (ABBABAABBABAABAB) and with no feedback. E2 coded children’s responses.

In Session 2, for the Day/night task, the procedure was identical to that for the grass/snow task except that children in the day/night task were asked to say *sun* when they see the moon card and to say *moon* when they see the sun card, so the day /night task required a verbal response. E1 first explained the rules using the sun and moon pictures. The four practice and 16 test trials were presented using a flip-book, which contained 16 pictures. E2 again recorded responses. A total score out of 32 was given to each child depending on the number of correct responses given in both IC tasks.

***2.2.4.3 FMC tasks*.** This included eight tasks from PDMS-2 (See Figure 2.2), which were presented in a fixed order (See Table 2.1). The tasks were administered as follows.

In Session 1, the first task was Lacing a string (item 58 in PDMS-2). E1 placed a string on the table and showed the child a strip consisting of 6 holes. E1 asked the child to "watch me lace", then E1 held the string and strip clearly so that the child could see exactly what she was doing. E1 began to lace by placing the string top down through the first hole, and up through the second hole, and down through the third hole. E1 showed the child the final result, and then removed the string from the strip, and placed these two items on the table in front of the child. Children were instructed to "Do it like I did". Children were allowed to take as much time as they needed to complete the task.

The second task was Cutting a square (item 68 in PDMS-2). Children were given a piece of A4 paper with a square depicted on it and a pair of scissors, and instructed to cut out the square along the line. The third task was Pyramid building (item 69 in PDMS-2). E1 used six cubes to build a pyramid. E1 placed three cubes next to each other, then two cubes on top and one cube on top of the two cubes. The pyramid was kept in front of the child and six additional cubes were provided with the instruction "build a pyramid like mine". The fourth MC task in session 1 was the Button strip (item 24 in PDMS-2). E1 placed a button strip on the table and unbuttoned all of the buttons. The E1 then asks the child to "button and unbutton this one as fast as you can" whilst pointing at one of the buttons.

In Session 2, the first FMC task was Cutting a circle (item 65 in PDMS-2). Children were given a piece of A4 paper with a circle depicted on it and a pair of scissors, and instructed to cut out the circle along the line. The second task was Folding paper (item 72 in PDMS-2). Here children were shown a folded piece of paper. They were then given two pieces of A4 paper and instructed to "fold your paper to look like this one". Third came Diagonal-pyramid building. This task was a modification the Pyramid building task that increased its difficulty. The pyramid was constructed with edges adjacent (rather than faces as in the original task). There was also a distance of a few millimetres between each block (rather than the faces being in contact). E1 used six cubes to build a pyramid. E1 placed three cubes next to each other, then two cubes on top and one cube on top of the two cubes (with a distance of a few millimetres between each block). The pyramid was kept in front of the child and six additional cubes were provided with the instruction "build a pyramid like mine". Finally came Finger touching (item 26 in PDMS-2). E1 demonstrated touching her thumb with each finger successively at a rate of one touch per second. Children were then instructed to do the same thing.

The MC tasks were all scored by E2. The PDMS-2 scoring criteria were used to assess the motor tasks for each child. A score ranging from 0 to 2 was given for each task and these scores were then added together to form the total FMC score for each child (maximum of 16 for all tasks).

2.2.5 Choice of Statistics

Pearson correlation was chosen to initially explore the relationships between the variables of the data, in a simple pairwise fashion. In order to answer the research questions realistically, however, it was important to be able to distinguish between predictors and dependents, and to be able to assess the strength of relationships between variables in the presence of the full set of variables included in the design, not just in isolated pairs. Hence multiple regression was the central form of analysis deemed appropriate since it takes into account the inter-correlations between predictors in assessing their relationship with any dependent. Finally, since the key question to be answered in order to assess the three accounts of the relationship between IC and drawing skill turned on whether IC affected drawing skill directly, or via some other variable such as FMC, we adopted an enhancement of multiple regression known as mediation analysis. This adds to conventional multiple regression, as implemented in SPSS and other packages, the capability of assessing not only the strength of direct relationship between a predictor and a DV (such as IC and a drawing skill measure), in the presence of other inter-correlating variables, but also the strength of indirect relationships via a third, mediating, variable (e.g. IV with a drawing skill via FMC).

2.3 Results

Table 2.2 summarises descriptive statistics for age and gender, as well as the five performance variables, IC, FMC, Figurative Representation (FR), Figurative Detail (FD), and Visual Realism (VR). The last was on a scale where negative scores reflect high intellectual realism and positive ones higher visual realism.

Table 2.2. Descriptive statistics for Study 1.

Variables	*N*	Minimum	Maximum	Mean	*SD*
Inhibitory control	100	0	32	18.3	11.4
Fine motor control	100	0	16	9.14	4.77
Figurative representation	100	0	4	1.91	1.46
Figurative detail	100	0	15	4.67	4.52
Visual realism	65*	-2	2	0.58	1.31
Age (in months)	100	36	54	44.2	6.77

- Number of children who produced at least one figurative picture in the realism drawing tasks.

2.3.1 Correlation Analyses

Initially, bivariate correlations were computed for the total sample of children to assess the relationships among the 7 variables, without considering any possible mediation effects: age, gender, IC, FMC, FR, FD, and VR. As seen in Table 2.3, all variables were correlated highly significantly with each other, except gender, which correlated significantly with none of the other variables, though descriptively it showed a low correlation with FD (r=.238; girls scoring slightly higher than boys: girls 5.64, boys 3.49).

Table 2.3. Correlations between the seven variables of Study 1.

		1	2	3	4	5	6	7
1	Age	-						
2	Gender	.023	-					
3	Inhibitory control	.470**	-.003	-				
4	Fine motor control	.577**	.031	.635**	-			
5	Fig. representation	.597**	.151	.565**	.735**	-		
6	Fig. detail	.544**	.238	.456**	.683**	.844**	-	
7	Visual realism	-.540**	-.047	-.574**	-.530**	-.567**	.466**	-

(* *p*<.05, ***p*<.01, *** *p*<.001)

2.3.1.1 IC and other variables. Analysis showed that there was a moderate positive correlation between IC and age, as would be expected, $r(98) = .47$, $p < .001$. When examining the relationship between performance on FMC and IC, I also expected based on all three accounts that the correlation would be in the positive direction, where children with higher inhibitory capacity performed better on FMC tasks. As expected there was indeed a strong positive and significant relationship between IC and FMC, $r(98) = .64$, $p < .001$. Moreover, it appears that IC and FR also had a moderate positive relationship with each other, $r(98) = .56$, $p < .001$, consistent with the Symbolic Competence account. Furthermore, IC showed a significant and moderate positive correlation with FD, $r(98) = .46$, $p < .001$, as predicted by the Behavioural Inhibition account.

With respect to the relationship between IC and VR, it was expected (e.g. from the Behavioural Inhibition account) that the correlation would be in the positive direction, where children who had higher scores on IC tasks would perform better on the VR scale, meaning that their drawing would be more visual than intellectual. However, the surprising finding was a significantly inverse relationship between IC and VR, $r(63) = -.574$, $p < .001$. Thus, better performance on the IC scale was related to a lower score for VR. This intriguing finding will be followed up in the Discussion.

Gender, which is not of prime concern in the current study, had a near zero correlation with IC. In fact only a few studies have considered the role of gender in the operation of the executive function, including IC. Raaijmakers and colleagues (2008) for example reported that four-year-old boys exhibited less successful deployment of the EFs than girls, who exhibited better IC and verbal skills, and so, arguably, greater maturation. Kochanska, Murray and Coy (1997) also reported girls as young as 22 and 33 months outperforming boys in IC. Olson, Sameroff, and colleagues (2005) again found that three-year-old girls exhibited significantly greater IC than boys. Keenan and Shaw (1997) suggest that faster developmental maturation of preschool girls could be responsible for their greater IC than boys, who manifest more aggressive behaviour. In addition, socialization practices have been suggested as a possible contributory factor: in general, greater encouragement is given to girls than to boys with respect to exerting self-control of their behaviour (Keenan and Shaw, 1997). By contrast Herba and colleagues (2006), in a study of adolescents with behavioural problems, found no gender differences in performance on a range of measures of specific types of IC. Closer to the age range of the current study, Overman (2004) and Thorell and Wåhlstedt (2006) reported no differences in EF performance of preschool boys and girls. Thus my gender finding is consistent with what is perhaps the minority finding in the literature.

2.3.1.2 FMC and other variables**.** The results of these correlational analyses indicated that all the four variables age, IC, FR, and FD were positively and significantly correlated with FMC. There was a moderate positive correlation between FMC and age, $r(98) = .58$, $p < .001$, which revealed that higher values on the FMC variable, as expected, were associated with higher values on the age variable (older children). Similarly, FMC had a strong positive correlation with both FR, $r(98) = .74$, $p < .001$, and FD, $r(98) = .68$, $p < .001$. Here again, children with higher levels of FMC tended to perform better on the FR and FD tasks. However, FMC, as found above, exhibited a significant and moderate negative correlation with VR, $r(63) = -.53$, $p < .001$.

2.3.1.3 Figurative detail and other variables. The results of the correlation analysis (Table 2.3) showed that there were significant positive relationships between FD and both FMC and IC, as already stated. Similarly, FD had a moderate positive and significant correlation with age, $r(98) = .54$, $p < .001$, and a very strong relationship with FR, $r(98) = .84$, $p < .001$. However, FD again recorded a significant and moderate negative correlation with VR, $r(63) = -.47$, $p < .001$. In this case, children with a higher level of figurative detail performance tended to perform worse on the VR measure, in the sense that they exhibited more intellectual than visual realism.

2.3.1.4 Figurative representation and other variables. FR had a significantly positive relationship with age, IC, FMC and FD as already indicated. The relationship between FR and age was also strongly positive, as expected, $r(98) = .60$, $p < .001$. The only surprising finding, similar to that which was obtained for realism above, concerns the negative association between FR and VR, where a moderate but significant negative relationship found, $r(63) = .57$, $p < .001$.

2.3.1.5 The visual realism scale and other variables. VR had a negative correlation with all variables, as seen above. For example, even VR and age had a moderate negative relationship with each other, which was significant, $r(63) = -.54$, $p < .001$. This indicates that older children tended to produce drawings showing more intellectual rather than visual realism. The negative association between VR and the other six variables was initially surprising, but I was able to find an explanation for it (See further Discussion, Section 2).

In summary, the results of the current study revealed that children's performances on IC, FMC, FR and FD were all linked moderately and positively to age, meaning that children's capacities on these traits rose with age. However, VR was negatively correlated with age, meaning that visual realism scores declined with age.

2.3.2 Multiple Regression Analyses

Since the data exhibited many moderate or strong pairwise correlations between all variables, excluding only gender, a multiple regression analysis was essential to explore the data further in a way that adjusted estimates of relationship in the light of all the inter-correlations among predictor variables. Therefore four separate analyses were conducted, with FR, FD, VR and FMC in turn as dependent variables.

2.3.2.1 Figurative representation as dependent. In the first analysis (See Table 2.4), multiple regression analysis using the standard 'enter' method was conducted, where age, gender, FMC, and IC were entered as predictor variables and Figurative Representation as dependent variable.

Table 2.4. Study 1, multiple regression with 3 drawing variables as dependent measures.

	Dependent variable								
	Fig. Representation			**Fig. Detail**			**Visual Realism**		
Predictor	*Beta*	*T*	*P*	*Beta*	*t*	*P*	*Beta*	*t*	*p*
Age	.239	3.01	.003	.222	2.59	.011	.269	2.12	.038
Gender	.188	2.03	.045	.216	3.12	.002	.018	0.18	.855
IC	.128	1.53	.130	.006	.064	.949	.364	3.11	.003
FMC	.511	5.63	<. 001	.545	5.56	<. 001	.164	1.23	.225
Model statistics									
F (df)	37.3 (4, 95)			28.7 (4, 95)			11.9 (4, 60)		
R^2	.611			.547			.442		
P	<.001			<.001			<.001		

The overall model explained 61% of the variance in FR, which was statistically significant, F (4, 95) = 37.3, p < .001, R = .781, R^2 *Adjusted* = .594. Among the individual predictors, FMC, with *Beta* = .511, t(99) = 5.627, p < .001, significantly predicts FR scores, consistent with the correlation analysis, with the highest beta of all the predictors. This result suggests an important link between FMC and FR in early childhood. IC, however, contrary to the correlation analysis, was not significantly related to FR so had no direct effect on the children's ability to move from non-figurative to figurative drawing when age and FMC are taken into account, *Beta* = .128, t(98) = 1.53, p = .130. Gender, *Beta* = .130, t(99) = 2.030, p = .045, and age, *Beta* = .239, t(99) = 3.010, p = .003, also significantly predicted FR scores. This suggests that age and female gender are associated with a higher level of figurative representation in drawing.

This analysis was followed by a reduced multiple regression still with FR as dependent variable, but entering just age, gender and FMC as predictors, excluding IC, the non-significant predictor. In that analysis gender emerged as non-significant so was also excluded, and the regression run only with age and FMC included (Table 2.5). 58% of the variance was accounted for by FMC and age alone, and this was revealed to be highly statistically significant, F (2, 97) = 68.314, p < .001, R = .765, R^2 *Adjusted* = .576. The result showed again that FMC, *Beta* = .585, t(99) = 7.301, p < .001, is more strongly related to FR than age, *Beta* = .260, t(99) = 3.249, p = .002. The result confirms that FMC and age both play a key role in children's success on the FR component of drawing skill (See Table 2.5).

Table 2.5. Study 1, multiple regression with three drawing variables as dependent measures (non-significant predictors removed).

	Dependent variable								
	Fig. Representation			**Fig. Detail**			**Visual Realism**		
Predictor	*Beta*	*t*	*p*	*Beta*	*t*	*p*	*Beta*	*t*	*p*
Age	.260	3.24	.002	.223	2.65	.009	-.351	-3.25	.002
Gender				.215	3.14	.002			
IC							-.413	-.3.82	<.001
FMC	.585	7.30	<.001	.548	6.52	<.001			
Model statistics									
F (df)	86.3 (2, 97)			38.7 (3, 96)			23.1 (2, 62)		
R^2	.585			.547			.427		
P	<.001			<.001			<.001		

2.3.2.2 Figurative detail as dependent. The second overall multiple regression (Table 2.4) followed the same pattern as above, but with Figurative detail as the dependent variable (children drawing themselves and a house). The four predictors of a child's FD, age, gender, IC and FMC, together explained 55% of the variance, F (4, 95) = 28.694, p < .001, R = .740, R^2 *Adjusted* = .528. In detail, the result indicated that the measure of FMC predicted FD significantly, *Beta* = .545, t(99) = 5.563, p < .001. Furthermore, the result revealed that both age, *Beta* = .222, t(99)

= 2.593, *p* = .011, and gender, *Beta* = .216, *t*(99) = 3.120, *p* = .002, were found to positively and significantly predict FD. Hence, FMC, age and gender act as strong predictors of FD. IC however did not significant predict FD, *Beta* = .006, *t*(99) = .064, *p* = .949.

These relationships were further analyzed (Table 2.5) using multiple regression omitting IC, which, as already shown, had no significant effect, but retaining FMC, age and gender as predictors of FD. The result revealed that even without IC, 55% of the variance was still accounted for by FMC, age and gender at a statistically significant level, F (3,96) = 38.659, $p < .001$, $R = .740$, R^2 *Adjusted* = .533. The result again showed that FMC, *Beta* = .548, *t*(99) = 6.519, $p < .001$, as well as age, *Beta* = .223, *t*(99) = 2.653, *p* = .009, and gender, *Beta* = .215, *t*(99) = 3.136, *p* = .002, all had positive and significant effects.

2.3.2.3 Visual realism as dependent. For the third overall analysis (Table 2.4), I examined the predictors of a child's representational drawing skill using the VR scale, measuring whether the child used intellectual realism or visual realism to draw their pictures.

FMC, IC, gender and age were entered as predictor variables and VR as dependent variable. The overall model explained 44% of variance in VR, which was revealed to be statistically significant, F (4, 60) = 11.886, $p < .001$, $R = .665$, R^2 *Adjusted* = .405. Considering each predictor separately, a significant negative relationship was observed between IC and VR, meaning that higher IC was associated with more use of intellectual realism in the drawing, *Beta* = -.364, *t*(64) = -3.114, *p* = .003. Similarly, age was found to be negatively and significantly correlated with VR, *Beta* = -.269, *t*(64) = -2.124, *p* = .038. FMC, *Beta* = -.164, *t*(64) = -1.226, *p* = .225, and gender, *Beta* = -.018, *t*(64) = -.183, *p* = .885, were also negatively correlated with VR but did not significantly predict it. The result suggested that all the predictors, FMC, IC, age and gender, were negatively correlated with visual realism.

I again followed up this analysis (Table 2.5) with a multiple regression omitting non-significant predictors. IC and age alone as predictors of a child's VR explained 43% of the variance, *F* (2, 62) = 23.094, $p < .001$, *R* = .653, R^2 *Adjusted* = .408, barely less than the 44% with all four predictors included. Again, IC and age showed a negative and significant correlation with VR: IC, *Beta* = -.413, *t*(64) = -3.824, $p < .001$; age, *Beta* = -.351, *t*(64) = -3.252, $p < .001$. I had expected all the drawing measures to positively correlate with IC: thus, the negative relation between one of the drawing measures (realism) and IC was initially surprising and not as yet clearly explicable.

2.3.2.4 Fine motor control as dependent. Finally, I investigated whether IC independently of age and gender predicted children's FMC (Table 2.6).

Age, gender and IC together accounted for 50% of the variance in FMC scores, *F* (3, 96) = 32.413, $p < .001$, *R* = .709, R^2 *Adjusted* = .488. The detailed result indicated that IC and age were both significant predictors of FMC: IC, *Beta* = .468, t(99) = 5.739, $p < .001$; age, *Beta* = .356, *t*(99) = 5.739, $p < .001$. Conversely, the result showed that gender, *Beta* = .024, *t*(99) = .332, *p* = .740, was not a significant predictor of FMC. As this study expected, IC was the key predictor of FMC, but leaves open the precise role of FMC in the development of children's skill in drawing tasks in early childhood.

This analysis was again followed up with a multiple regression including only the significant predictors, IC and age. These two predictors alone explained 50% of the variance in FMC, the same as before, *F* (2, 97) = 49.014, $p < .001$, *R* = .709, R^2 *Adjusted* = .492. The result showed that separately both IC, *Beta* = .467, *t*(99) = 5.761, $p < .001$, and age, *Beta* = .357, *t*(99) = 4.401, $p < .001$, were significant predictors of the children's FMC. Again, IC had the stronger effect (See Table 2.6).

Table 2.6. Study 1, multiple regressions with FMC as dependent measure.

	FMC			FMC (significant predictors only)		
Predictor	*Beta*	*t*	*p*	*Beta*	*t*	*p*
Age	.356	4.370	<.001	.357	4.401	<.001
Gender	.024	.332	.740			
IC	.468	5.74	<.001	.467	5.761	<.001
Model statistics						
F (df)		32.4 (3, 96)			49.0 (2, 97)	
R^2		.500			.503	
P		<.001			<.001	

2.3.3 Mediation Analyses

A primary hypothesis of the Motor Development account which I aimed to test in Study 1 was that FMC positively mediated the relation between IC and drawing skills. Although the analyses above are suggestive, in that in the multiple regression analyses IC is not always related to drawing skills in the presence of FMC, they do not precisely test this hypothesis. To better examine this precise hypothesis; I therefore followed the recommendations of Shrout and Bolger (2002), who suggest a mediation analysis, which includes a bootstrapping procedure to compute a confidence interval around the indirect effect (i.e., the path from the independent variable to the dependent through the mediator). If zero falls outside of this interval, significant mediation is said to be present. I used the SPSS macro designed by Preacher and Hayes (2008) to perform all the required analyses, both those using customary multiple regression and those using bootstrapping.

2.3.3.1 Figurative representation as dependent. The first mediation analysis was conducted with FR as dependent (Table 2.7). The multiple regression analyses showed that IC was positively associated with FR when the effects of other, possibly mediating, variables were not taken into account, $B = .047$, $t(99) = 4.409$, $p < .001$. That effect is commonly termed path c (see Figure 2.4). With all predictors taken into account it was also found that IC was positively related to FMC, *B* = .196, *t*(99) = 5.739, *p* < .001, on what is called path a. Thirdly, results indicated that the potential mediator, FMC, was positively associated with FR, *B* = .157, *t*(99) = 5.627, *p* < .001, on path b. Since effects on all three paths a, b, and c were significant, further analyses were used to test if FMC was truly mediating between IC and FR.

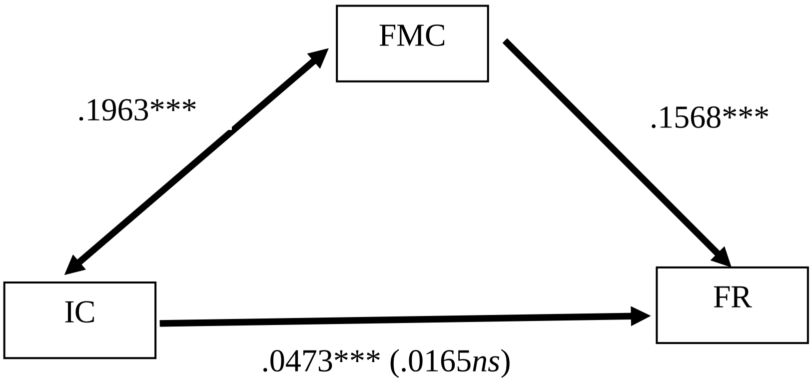
Table 2.7. Study 1. Mediation analysis with FR as dependent.

Effect and Path	**Variables**	***B* Coefficient**	***SE***	***t***	***p***
IV to MV (Path a)	IC → FMC	.1963	.0342	5.739	<.001
Direct Effect of MV on DV (Path b)	FMC → FR	.1568	.0279	5.627	<.001
Total Effect of IV on DV (Path c)	IC → FR (not considering FMC)	.0473	.0107	4.409	<.001
Direct Effect of IV on DV (Path c')	IC → FR	.0165	.0108	1.526	.1303
Partial Effect of Control Variables on DV	Age → FR Gender → FR	.0517 .3810	.0172 .1877	3.010 -2.030	.0033 .0451
				Bias corrected 95% confidence interval*	
Indirect Effect of IV on DV through MV (Path ab)	IC→ FMC → FR	.0308, .0302*	.0093*	.0157 to .0534	

*Bootstrapped estimates (1000 resamples)

Further multiple regression results indicated that the direct effect of IC on FR became non-significant, *B* = .016, *t*(99) = 1.526, *p* = .130, when controlling for FMC (path c'), thus suggesting full mediation of the effect of IC through FMC. The indirect path ab was also tested using the bootstrapping method with bias-corrected confidence estimates (MacKinnon, Lockwood, & Williams, 2004; Preacher & Hayes, 2008). In the present study, the 95% confidence interval of the indirect effects was obtained with 1000 bootstrap resamples (Preacher & Hayes, 2008). Results of the mediation analysis confirmed the mediating role of FMC in the relation between IC and FR, with *B* = .030, *CI* = .0157 to .0534: the confidence interval did not contain zero. Figure 2.4 displays the results.

Figure 2.4. Mediation model of IC and FR through FMC (*B* coefficients are shown with probabilities: *ns* not significant, * *p*<.05, ** *p*<.01, * *p*<.001).**



2.3.3.2 Figurative detail as dependent. Secondly, I performed the same analyses with figurative detail as dependent (Table 2.8). Multiple regression analyses were again used initially to assess each component of the proposed mediation model. First, it was found that IC was positively associated with FD, $B = .104$, $t(99) = 2.909$, $p = .005$, directly on path c when the effects of other, possibly mediating, variables were not taken into account (Figure 2.5). It was also found that IC was positively related to FMC on path a, $B = .196$, $t(99) = 5.739$, $p < .001$, and indeed that the potential mediator, FMC, was positively associated with FD on path b, $B = .516$, $t(99) = 5.563$, $p < .001$. Since effects on all three paths a, b and c were significant, I therefore next tested mediation.

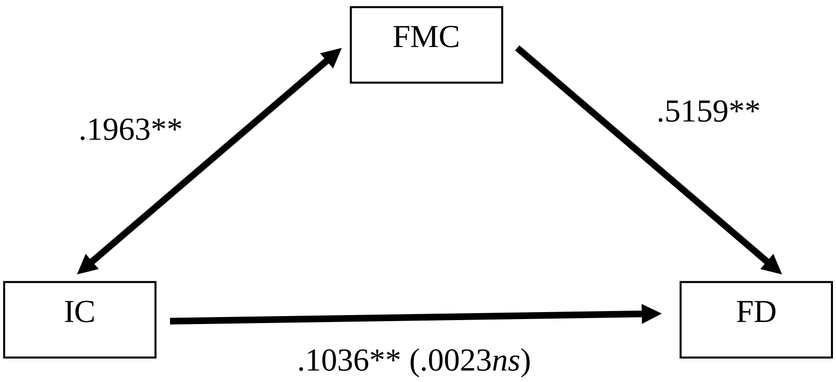
Table 2.8. Mediation analysis with FD as dependent.

Effect and Path	Variables	*B* Coefficient	*SE*	*t*	*p*
IV to MV (Path a)	IC → FMC	.1963	.0342	5.7387	<.001
Direct Effect of MV on DV (Path b)	FMC → FD	.5159	.0927	5.5631	<.001
Total Effect of IV on DV (Path c)	IC → FD (not considering FMC)	.1036	.0356	2.9099	.0045
Direct Effect of IV on DV (Path c')	IC → FD	.0023	.0360	.0645	.9487
Partial Effect of control Variables on DV	Age → FD	.1482	.0572	2.5925	.0110
	Gender → FD	1.9490	.6247	3.1201	.0024
				Bias corrected 95% confidence interval*	
Indirect Effect of IV on DV through MV (Path ab)	IC → FMC → FD	.1012, .1007*	.0328*	.0470 to .1824	

*Bootstrapped estimates (1000 resamples)

Further regression results indicated that the direct effect of IC on FD, path c', became non-significant, *B* = .002, *t*(99) = .065, *p* = .949, when controlling for FMC, therefore suggesting full mediation. Second, the indirect path ab was tested using the bootstrapping method as described above. Result showed that the indirect effect of IC on FD through FMC had a 95% confidence interval which did not include zero, *B* = .101, *CI* = .0470 to .1824. Thus the mediation role of FMC was again confirmed.

Figure 2.5. Mediation Model of IC and FD through FMC (*B* coefficients are shown with probabilities: *ns* not significant, * *p*<.05, ** *p*<.01, * *p*<.001).**



2.3.3.3 Visual realism as dependent. Finally, multiple regression analyses were again initially used to calculate each component of the proposed mediation model with visual realism of drawing as dependent (Table 2.9). First, it was found that a significant negative association existed between IC and visual realism when potential mediators were not considered, path c: *B* = -.051, *t*(64) = -3.814, *p* < .001. However, the result also showed that IC was significantly and positively related to FMC on path a: *B* = .133, *t*(64) = 3.077, *p* = .003. Thirdly, results indicated that the potential mediator, FMC, was negatively associated with visual realism on path b: *B* = -.049, *t*(64) = -1.226, *p* = .225. Statistically this was not significant, throwing doubt on the hypothesis that in this instance FMC played a mediating role.

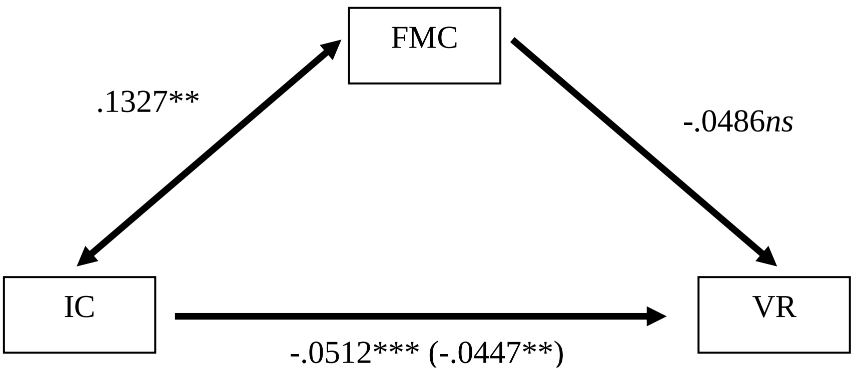
Testing the mediation more directly, it was first found that, when FMC was included in the analysis, the direct effect of IC on realism on path c' IC remained significant, with only a very small fall in the value of B: *B* = -.045, *t*(64) = -3.114, *p* = .003. This again suggests that FMC had little mediation effect on relationship between IC and VR. Finally, the test of path ab using bootstrapping as above yielded a 95% confidence interval, which included zero, showing that the effect of IC on VR through FMC was not significant. In other words, the result showed that the effect of IV on DV (c' path) controlling for the effect of FMC was statistically significant while the effect of IV on DV via the potential mediator was not. Hence, the influence of IC on VR is not mediated by FMC, meaning that IC has by far the majority of the influence on visual realism directly (Figure 2.6).

Table 2.9. Mediation analysis with visual realism as dependent.

Effect and Path	Variables	*B* Coefficient	*SE*	*t*	*p*
IV to MV (Path a)	IC → FMC	.1327	.0431	3.0775	.0031
Direct Effect of MV on DV (Path b)	FMC → VR	-.0486	.0397	-.1.2257	.2251
Total Effect of IV on DV (Path c)	IC → VR (not considering FMC)	-.0512	.0134	-3.8138	.0003
Direct Effect of IV on DV (Path c')	IC → VR	-.0447	.0144	-3.1136	.0028
Partial Effect of Control Variables on DV	Age → VR	-.0520	.0245	-2.1236	.0378
	Gender → VR	-.0470	.2568	-.1830	.8554
				Bias corrected 95% confidence interval*	
Indirect Effect of IV on DV through MV (Path ab)	IC→FMC→VR	-.0065, .0073*	.0068 *	-.027 to .0015	

*Bootstrapped estimates (1000 resamples)

Figure 2.6. Mediation model of IC and VR through FMC (*B* coefficients are shown with probabilities: *ns* not significant, * *p*<.05, ** *p*<.01, * *p*<.001).**



2.4 Discussion

Overall, the results show that there are widespread associations among IC, FMC and all three drawing measures (as well as age). Regression and mediation analyses further demonstrated that, when FR and FD were considered as dependents, the effect of IC was positive, and mediated through FMC. By contrast, when VR was taken as the dependent, the effect of IC was negative, and not mediated through FMC. This then suggests that it is indeed unwise to talk generally about factors affecting drawing skill without considering what particular skill is being referred to. We now discuss these findings.

2.4.1 Predictors of figurative representation and detail

In section 2.1.2 I made predictions which concerned the relationships between IC and FMC on the one hand and FR and FD on the other. The findings of Study 1 have provided strong evidence of relationships between IC, FMC and these drawing skills in early childhood. After controlling for age and gender, mediation analysis using regression indicated that the relationships between IC and FR and FD were completely mediated by FMC, which is consistent with the Motor Development account. Recall that (section 1.6) this account proposes that, in order to draw skilfully, a child needs good FMC (Lange-Küttner, 2008; Toomela, 2002). It further proposes that IC is related to FMC, something known to be the case in older children and adolescents (Rigoli et al., 2012). The combination of those two proposals yields an account where IC would predict drawing skill mediated through FMC, which is indeed what my findings have supported. By the same token this result does not support either the Symbolic Competence or the Behavioural Inhibition account, both of which predict a direct link between IC and one or the other or both of these drawing skills.

The Symbolic Competence account (section 1.5.5) proposes that the ability of children to make the transition from non-figurative to figurative drawing is linked to effective IC. In detail, this account proposes that IC is related to the development of symbolic understanding which in turn leads to the initiation of figurative drawing (Riggs et al., 2013). Thus it actually predicts that the effect of IC on drawing skill is mediated through symbolic competence, rather than any form of motor control. Since, however, in the present study symbolic competence was not measured and included in the models tested, this account would be supported by a direct relationship between IC and FR. However, the data did not support this account since there was no direct link between IC and children’s performance on the figurative representation scale, once FMC, gender and age were taken into account.

The Behavioural Inhibition account predicts that children’s drawing skill progresses by inhibiting more immature drawing behaviour. Hence it suggests a direct impact of IC on FR, not mediated by any other variable: children simply need the ability to directly inhibit drawing behaviour that was established before (Golomb, 1992; Cox, 1993; Ebersbach et al., 2011; Morra, 2008; Panesi & Morra, 2016; Riggs et al., 2013). My finding however was that there was no direct link between IC and FD or FR (once other variables were taken into account). The current result therefore again failed to support the Behavioural Inhibition account.

A different suggested explanation for a relationship between IC and FR is that FR measures such as that used in the current study, based on two types of drawing tasks (free drawing from memory and drawing from real objects), are in part assessing the child's ability to carry out a task according to the instructions given, which also needs IC for success. In any event, this direct connection of IC with FR was not supported by the finding of the present study. Indeed IC was not independently related to figurative drawing on FD either (the latter being in the present study measured from drawings produced exclusively from memory).

2.4.2 The relationship between IC and FMC

In Study 1 there is further an observed relationship between IC and FMC in the data, irrespective of drawing skill. This result constitutes an important finding in itself. In previous studies there was evidence for the relationship between FMC and aspects of the Executive Function, such as IC, in older children and adolescents who had been diagnosed with Developmental Coordination Disorder (Leonard & Hill, 2015). There is also some evidence that IC and FMC are related in typically developing infants (Gottwald et al., 2016; St. John et al., 2016), and in 5- and 6-year-olds (Livesey et al., 2006). The result of my study however offers the first evidence for a relationship between IC and FMC in typical 3- and 4-year-olds, i.e. in the period when IC is developing most rapidly (Garon et al., 2014; Johansson, Marciszko and colleagues, 2015; Petersen, et al., 2016; Simpson & Riggs, 2005; Wiebe et al., 2012).

As we outlined in section 2.1.1, while there are various sources of evidence for a relationship between EFs, such as IC, and motor control abilities, such as FMC, there is no agreement on the direction of any relationship between them. Some theories suggest that they simply develop together (Thelen et al., 2001), others that FMC leads to IC (Von Hofsten, 2004). There has been little attention to the third possibility that IC might lead to FMC, especially in typical children in early childhood. Yet the findings of Study 1 are consistent with this.

Study 1 is however correlational, so cannot definitively prove a direct effect of IC on FMC. One interpretation could be that better IC does indeed cause FMC to improve. A second explanation could be that the concept of 'embodied cognition' accounts for FMC and IC developing together in the one body of each child. It should be noted in this connection, however, that, as was seen in the regression results (Table 2.6), the relationship between IC and FMC is highly significant even when the effect of age on FMC is controlled for, and the betas for IC are greater than those for age. The relationship between IC and motor control is further explored in Study 2, and will be further discussed in the General Discussion in Chapter 5.

2.4.3 Predictors of visual realism of drawing

The third area of prediction presented in 2.1.2 concerned IC and FMC in relation to VR as the dependent variable. In this instance, it is the prediction of the Behavioural Inhibition account which is apparently supported, since a direct link was found between IC and VR, not one mediated through FMC. The relationship was however negative. While not strictly contradicting the Behavioural Inhibition account, this was counter to what we had expected given that the overwhelming burden of previous research suggested that VR exhibits progression from intellectual to visual realism with age, rather than the reverse. Hence IC was expected to show a positive relationship with VR, by enabling greater inhibition of the immature style (intellectual realism). This aspect of the result will be examined in detail later below.

With respect to the other two accounts, it should be recalled that the inclusion of VR was something of a novelty in the present study, so it was not entirely clear what precise predictions they would offer in relation to it. Based on the reasoning offered in 2.1.2, it could be argued that the Symbolic Competence account in this case would predict that, since the demands placed on symbolic understanding do not differ between drawing visually and intellectually, no relationship would be found between symbolic understanding and VR. Since symbolic understanding was not measured in the present study, however, this prediction becomes a prediction of a direct link between IC and visual realism, which indeed was found for VR as dependant (though not for FR, as we saw above). Once again, however, it is anomalous that the relationship between IC and VR is negative, for the same reason as stated above.

The finding of a direct link between IC and drawing realism must also be considered in relation to the Motor Development account. Again it is not entirely clear what this account predicts for VR. If it predicts a link mediated through FMC, as it does for FR and FD, then it is clearly not supported. It was argued in 2.1.2, however, that this account might not make that prediction for realism, since realism is not a drawing variable which entails obvious implications for motor skill demands in the way that FD and FR clearly do. Since it does not appear to require any difference of motor skill to draw an intellectually realistic picture or a visually realistic one, possibly this account would not expect FMC to be involved in this instance. In any event, it is clearly the latter position that is supported.

To my knowledge these are new findings since nobody previously considered this full set of variables in this way. Riggs and colleagues (2013) for example only included age, IC and FR and FD. The results strongly suggest that drawing skills should no longer be spoken of as if they constitute a homogeneous construct. Rather, FD and FR constitute qualities of children's drawing skill which require good motor skill more than cognitive ability, while the reverse is true of VR. The FR and FD measures firstly do not involve such conceptually challenging instructions to the children, since the former in part, and the latter totally, is assessed from drawing produced entirely from memory. Being asked to draw a mug or a house from memory (when no specific exemplar is in view in the context at the time) is more straightforward than being asked to draw exemplars in view because the child is directed to use the only information source which he has available. In the VR case, where the instructor asks the child to draw the object "exactly as you see it", memory / mental representation is inevitably also present so there are always two potentially competing information sources rather than just one. The child has to understand the instruction more precisely and pay greater attention during drawing. Motor control skill will not help with that.

Secondly FR and FD target children's ability to draw something showing distinctive features and details of which the child must not only possess a mental representation, but also have the motor skill to actually draw. Hence, motor control skills are as important as IC, if not more so, in order to obtain higher FD and FR scores. VR however is not scored with attention to picture quality in terms of figurative representation or detail, but simply for whether it in any way shows intellectual or visual realism. Hence it is more a measure of the child's cognitive representation of what they are drawing (what they see or what they recall) than of their motor skill in executing the drawing. Thus there are multiple reasons why IC might have a direct effect on VR but only have an effect mediated through FMC on FR and FD.

Furthermore, research into attentional processes in children's drawing has shown that 7-year-olds barely look more than once at the objects to be drawn, whilst 14-year-olds look more often, suggesting that attention increases with age (Mitchelmore, 1978). If this applied at the younger age group of the current study, and given that attention is associated with IC rather than FMC, this also could explain why IC has a direct effect on realism but not on FR and FD, which were scored partly or totally from drawings where no objects were presented to be drawn, but rather memory alone was relied upon. In another study, however, increasing attention in 5- to 8-year-old children did not seem to have a significant effect on drawing performance (Cox, 1991), although possibly this was due to the precise instructions being different from those in the present study. In that study, when children were presented with a partially occluded ball task, they were interrupted after they had drawn the first ball so that their attention could be drawn towards the appearance of the second ball. This had no effect on drawing performance however (Cox, 1991). Since the increased attention was unspontaneous, it is possible that children did not know the reason behind it and thus did not benefit from it. It is also possible that drawing the child's attention to the occluded object increased the child's belief that they need to draw the complete contour of the second ball. In the current study, however, there were no further instructions after the initial ones. Clearly more research is required to investigate the role of attentional processes in children's drawing.

Thus, although my finding for VR might appear initially unexpected, in not involving FMC, it can be explained as follows. Visual realism of drawing is a construct which could be seen as fundamentally cognitive rather than motor in nature, and it is measured by consideration of what the child was trying to draw rather than how skilfully they drew it. Hence it is perhaps not unexpected that FMC does not play a key role in predicting scores for VR. IC on the other hand by its nature would be expected to affect both cognitive and motor functions. I would therefore propose a crucial modification to the Motor Development account of drawing skill development, so as to explicitly limit its scope. It should not be taken to apply to measured aspects of drawing skill such as VR which depend primarily on the child’s conceptualisation of what they are drawing and where there is no measurement of how finely they control their actions when executing the drawing.

We now return to the issue of the IC – VR relationship being negative. As I have indicated, my results show that there was indeed a direct link between IC and VR, with FMC, age and gender taken into account. This finding therefore superficially offers support for the Behavioural Inhibition account. However, that account would be standardly taken to predict that, in order to score higher for visual realism (what they see), children have to suppress earlier habits of drawing with intellectual realism (what they know). This implies that as IC increases so should VR. In fact, although the direct relationship between IC and realism in the present data is highly significant and not diminished by including FMC as a mediator, it is negative rather than positive. Thus the Behavioural Inhibition account seems not to be in fact supported, and neither is any plausible prediction based on the other two accounts.

There is, however, a line of reasoning which allows us to regard the Behavioural Inhibition account as in fact fully supported. We have only to show that the progression which we assumed to exist from intellectual to visual realism is incorrect, and the progression is in fact from visual to intellectual. With that assumption, the finding is entirely consistent with the scenario of the earlier habit (drawing with visual realism) being inhibited so that the later one (drawing with intellectual realism) can emerge. Hence, we now consider whether such an assumption has any plausibility.

The assumption that stronger IC and older age would lead children to draw more visually realistically had been made in Study 1 because it is very widely agreed that visual realism is the adult target mode of drawing, and not intellectual realism (Crook, 1985; Freeman, 1980; Ebersbach et al., 2011; Riggs et al., 2013). According to Luquet’s (1927/2001) theory of drawing development (and as observed in subsequent research, e.g. Chen and Holman 1989, Cox 1991), however, the shift from intellectual realism to visual realism occurs only around eight years of age, much later than the age of the children in the present study. Thus, it is possible that younger children, such as those in the current study, may use their inhibition in a different way, to promote intellectual realism rather than to suppress it, or perhaps to suppress an earlier visual realism. This leads to the intriguing possibility that realism progresses, not in a linear pattern with age and IC, but in a U-shape.

It is possible to speculate that, maybe at age three to four years, children are suppressing the tendency to draw with visual realism, which they did when they first emerged from scribbling, at a time when they did not yet possess fixed schemata/categories which represent all of what they see (e.g., a mug is not yet 'made a mug' by its handle). Rather, they first have to learn to see the world as categories of things, which also have names, and exist, as mental constructs, so as to draw intellectually, and then they have to learn that the convention is to draw what one sees, even where exemplars of categories are obscured. Thus they revert to visual realism again, evidencing an apparent U-shaped development. In terms of IC then they would pass through three stages: first they have to inhibit a pre-potent response to scribble in order to draw representationally what they see; then they inhibit the pre-potent response of drawing what they see to draw using their newly formed mental categories, intellectually; then finally they inhibit the pre-potent response of drawing what is in their mind to draw what they see, visually, in tasks where that is required.

In other words, possibly children start with visual realism, then move to intellectual realism, around 3 and 4 years of age, and then finally move to visual realism again (Simpson et al., 2018). Thus in the present study, due to the age band chosen, I have perhaps captured children who are still largely in the first part of the U- progression, so appearing to move towards more intellectual realism as age and IC increase. This hypothesis needs to be tested with a wider age band of children, and that is the focus of Study 3.

2.4.4 Background variables

There was overwhelming confirmation of previous research with respect to the role of age, which everywhere was significantly and positively related to IC, FMC and the measures of drawing skill. Multiple regression analysis for example clearly showed that IC develops with age, consistent with previous studies (e.g., Welsh, Pennington & Groisser, 1991; Willoughby, Blair, Wirth & colleagues, 2012). Gender, by contrast, produced some unexpected findings in that it was often significantly related to figurative representation and detail, though not to visual realism, in analyses where the effects of other variables were controlled for. The prevailing pattern was of girls outperforming boys. There was no significant correlation of gender with IC or FMC, however, so the reasons for this intriguing relationship must await further research in the future.

2.4.5 Conclusion

In conclusion, Study 1 has produced some suggestive and original findings, especially in two respects: firstly, the mediation of the effect of IC on FD and FR through FMC, rather than the effect of IC being direct, and secondly the fact that the effect of IC on VR is not only direct rather than mediated through FMC, but also negative, evidencing increasing intellectual realism. In order to pursue these two results further, I therefore designed two follow-up studies, which comprise the rest of this thesis. The first (Study 2) considered in more detail the effect of IC on FMC, the mediator for two of the three dependent variables, without being concerned with drawing: in particular, it addresses the interrelationships between IC, FMC and gross motor control (GMC). The second (Study 3) is concerned with testing the hypothesis of a U-shaped relationship between age and realism of drawing, which was mentioned above, without being concerned further with IC, GMC or FMC.

Chapter 3. How are IC, fine motor control, gross motor control, and IQ associated in preschool development?

3.1 Introduction

As discussed earlier in chapter 1 (Section 1.6), inhibitory control (IC) and fine motor control (FMC), and indeed gross motor control (GMC), have often been studied separately in young children, but there is an increasing awareness and understanding of the close relationship between these abilities in development (Diamond, 2000). Recently, researchers have especially shifted their focus to the influence of IC on FMC and to an extent on GMC (e.g. Livesey, Keen, Rouse, & White, 2006; St. John et al., 2016). Evidence suggesting that IC is linked to the improvement of both types of MC is, however, limited in early childhood studies of typical children.

A few recent studies did find such a relationship in typical 18-month-old infants (Gottwald et al., 2016; St. John, Estes, Dager et al., 2016). Gottwald and colleagues (2016), for example, found an association between IC and a measure of motor planning (but not more general measures of motor control). A relationship has also been found between IC and FMC in 12-month-olds and with both FMC and GMC in 24-month-olds (St. John et al., 2016). Furthermore, there is evidence for an association between IC and FMC in 5- to 6-year-olds (based on one of two inhibitory measures used – Livesey et al., 2006). The relationship between IC and MC has not however previously been studied in typical 3- and 4-year-olds, aside from Study 1, reported in the previous chapter, which was however limited in its scope to FMC, rather than also considering GMC. This is despite the fact that IC is investigated most frequently in this age band.

The purpose of the current study therefore was to fill a research gap by investigating this three way IC-FMC-GMC relationship in early childhood (range 3- to 5- year olds).

As explained in chapter 2 the aim of Study 1 was to investigate the relationship between IC, FMC and Drawing Skills in young children. Among its findings, that study provides to my knowledge the first evidence for an association between IC and FMC in 3 and 4 years olds (typical developing children). Given the fact that the relationship between IC and GMC is also under-researched in this age group of typically developing children (chapter1, Section 1.6), I therefore proposed in my second study to follow up the relationship between IC and MC in this age group in more detail (without consideration specifically of drawing skills).

3.1.1 IQ and its relationship with MC and IC

In the current study, the possible influence of IQ is also taken into account, since there exists some evidence of relationships in children between IQ and both EF (including IC) and MC. Arffa (2007) for instance found evidence of relationship between IQ and EF, including within the latter an IC measure (the colour word Stroop test), in 6- to 15-year-olds. To explain such findings, a number of studies have suggested that IQ affects EFs, including IC, because individuals with higher IQ have the capability to activate more widely distributed regions of the brain which are specialized in relation to task performance, and so are able to process information more efficiently (Neubauer & Fink, 2009; Shaw, 2007; Van den Heuvel, Stam, Kahn & Hulshoff Pol, 2009). Indeed, some recent event-related fMRI studies have identified a distinctive pattern of processing in participants with high IQ who, in a cognitive set-shifting task, were able to involve brain regions which were more distributed, but important for successful performance (Graham et al., 2010). Recent literature reviews (Kelly & Garavan, 2005; Neubauer & Fink, 2009) also suggest that involvement of a wider set of regions of the brain in a given task, by more intelligent individuals, may be due to their greater efficiency in inhibition of other brain regions.

With respect to the relationship between IQ and MC, Smits-Engelsman and Hill (2012) reported some relationship between these in both typical and atypical children, albeit only 19% of the variance in MC was explained by IQ. Kenny, Hill and Hamilton (2016) also reported a significant positive correlation between (nonverbal) IQ and MC in 4- to 12- year old children. Furthermore, Roebers, Röthlisberger, and colleagues (2014), found significant correlations among FMC, IQ and EF (in which IC was included) in typical 5- and 6-year-olds.

It is notable, however, that such studies once again usually target children older than the preschoolers tested here. Furthermore, the MC-EF-IQ relationships are often considered within a fuller model, where they function as predictors of some other dependent variable, such as school achievement or imitation skill. In addition, IC is not usually considered separately from other EF components. Hence I deemed it valuable to include IQ in the present study, where typical children younger than 5 years of age are considered, and the inter-relationships between MC (both FMC and GMC), IC, and IQ can be revealed regardless of any other variables which they may predict.

3.1.2 Overview of Study 2

Study 2 had two main aims. First, I wished to examine what specific relationships could be found between different subsets of motor skills (i.e. GMC and FMC) and IC in typical developing children aged 3 to 5 years old. Second, I wished to confirm that the association between IC and MC could not be explained by general intelligence (IQ). The current study therefore answers the following research questions. Does the relationship between IC and FMC found in Study 1 extend to GMC? If so, how? Can the association between IC and FMC be explained by general intelligence (IQ)?

In this correlational study, age was ascertained from teacher reports and gender by researcher observation. GMC was quantified through nine tasks selected from the Gross Motor Quotient of the Peabody Developmental Motor Scale (PDMS-2, Wang, Liao & Hsieh, 2006).

Three tasks were taken from each of the subscales: the Stationary (sustaining stationary control of the whole body), Locomotion (moving the whole body), and Object Manipulation (catching and throwing) subscales (See Table 3.1).

FMC was measured through six tasks taken from The Fine Motor Quotient of the PDMS-2. Three were taken from each of two subscales: the Grasping sub-scale, and the Visual-motor Integration sub-scale. Some new tasks, however, were substituted when pilot testing revealed that only three of the tasks from the PDMS-2 produced substantial variance (grasping a marker, dropping pellets, building steps) in this age range, and so were included in the battery (See Table 3.2). The remaining three FMC tasks for the main study of Study 2 were taken from Study 1 (lacing a string, unbuttoning a strip, finger touching).

Table 3.1. Tasks used to measure GMC in Study 2.

Gross Motor Quotient		
The stationary sub-scale	**Locomotion sub-scale**	**Object Manipulation sub-scale**
Standing on one foot (task 23)	Jumping up (task 73)	Catching a ball (task 17)
Standing on tiptoes (task 22)	Jumping forward on one foot (task 72)	Hitting a target- overhand (task 18)
Imitating movements (task 26)	Walking a line backwards (task 78)	Bouncing a ball (task 21)

Table 3.2. Tasks used to measure FMC in Study 2.

Fine Motor Quotient	
The grasping sub-scale	**Visual-motor integration sub-scale**
Grasping a marker (task 22)	Lacing a string (task 58)
Finger touching (task 26)	Dropping pellets (task 74)
Unbuttoning a strip (task 24)	Building steps (task 75)

In order to measure IC, two age-appropriate response inhibition tasks were used, the day/night task and the grass/snow task (Petersen et al., 2016), together with the tapping task (Diamond & Taylor, 1996). In the day/night task children were asked to say *sun* when they see the moon card and to say *moon* when they see the sun card, so an oral verbal response was required. In the grass/snow task they were asked to point to the sun card when the researcher said *moon* and point to the moon card when the researcher said *sun*, so a gestural response was elicited. Although the grass/snow task involves a slight motor response, as children need to point towards the cued picture, this was deemed to be minimal, as pointing is an easy task for 3-year-olds. Hence it was not felt that the nature of this task biased the instrument in favour of detecting any influence of FMC. The same argument is made for the tapping task in which the child has to respond by tapping once when the researcher taps twice and twice when the researcher taps once.

Finally, IQ was quantified with the British Picture Vocabulary Scale – Second Edition (BPVS-2) (Dunn & Dunn, 2009). This is a multiple-choice test of receptive vocabulary knowledge, where, for each word tested, four pictures are supplied to choose from. The child's response is gestural, pointing to whichever of the pictures they think represents the meaning of the word they heard. Performance on the BPVS is regarded by experts as strongly linked with IQ (Dunn & Dunn, 2009; Glenn & Cunningham, 2005) and, as argued above for the grass/snow IC task, not to involve any motor challenge to children of the targeted age.

3.2 Method

3.2.1 Participants

One hundred children (55 girls and 45 boys) participated in this study, with age range from 3 to 4 years and 11 months (mean age of 3 years and 11 months). All were recruited from preschools and nurseries in Colchester, UK. All spoke English as their first language, and none were reported as having any behavioural or learning difficulties (based on teachers' reports). The sample was of mixed social background and was predominantly white. Just as described in 2.2.1, a larger number of children was initially approached in order to obtain the 100 actual participants deemed suitable for regression and mediation analyses.

3.2.2 Design

In the current study, a within-subjects correlational design was used. The variables measured were IC, FMC, and GMC, along with IQ, age and gender.

3.2.3 Materials

The following materials were used for the tasks involved in the study. For the IC grass/snow task, two pictures were used: one of the moon in a night sky, and the other of the sun in a day sky (height 12cm, width 12cm) (See Figure 3.1:2). For the IC day/night task, a flip-book was used, which contained 16 pictures, half of the sun in a day sky and half of the moon in a night sky (See Figure 3.1:2). For the IC tapping task two wooden dowels were used (See Figure 3.1:4).

For the GMC tasks, I employed materials from the Gross Motor Quotient of the PDMS-2 (Wang et al., 2006) (See Figure 3.1:3). For the FMC tasks, materials were used from the Fine Motor Quotient of the PDMS-2 (Wang et al., 2006) (See Figure 3.1:3).

Finally, for IQ, the test-book and the performance record from the BPVS-2 (see Figure 3.1:1) were used. The BPVS has four training plates for four practice words, followed by 14 sets of 12 test words, forming a total of 168 words which are arranged in order of increasing difficulty.

3.2.4 Procedure and scoring

Informed consent had previously been obtained from the parents of participants and the school authorities. The measurement sessions involved two people, the researcher (E1) and a PhD student with experience of these tasks (E2). E1 administered the tasks while E2 recorded the children's responses. All the children were tested individually, in the morning, either in a separate room from their classroom, or in a quiet corner of their classroom. E2 sat next to the child to record the responses while E1 sat across the table. The children were asked for their help, and told that they were going to play some fun games. In all, nineteen tasks were administered to each child in two separate sessions on different days, each session lasting about 20-30 minutes. Tasks followed a fixed order, as shown in Table 3.3. The first session consisted of an IC task (the day/night task) and eight PDMS-2 tasks interspersed. The second session consisted of two IC tasks (the grass/snow task and tapping task) and seven PDMS-2 tasks interspersed, concluding with the BPVS-2. All responses (correct/incorrect) were recorded on paper by E2 for later detailed analysis.

3.2.4.1 MC tasks. This included fifteen tasks from PDMS-2 (See Tables 3.1 and 3.2 and Figure 3.1:3), which were presented in a fixed order (See Table 3.3). Eight of these tasks were presented in the first session and seven of these tasks were presented in session 2. The tasks were administered as follows.

In Session 1, first came Standing on one foot (numbered 23 in PDMS-2): E1 demonstrated standing on one foot with the free leg bent back at the knee with her hands on her hips for five seconds. The child was instructed to “put your hands on your hips and stand on one foot like I did”. E1 counted the seconds out loud to further encourage the child to balance longer. Next came Standing on tiptoes (numbered 22 in PDMS-2): E1 would stand on her tiptoes with her hands held overhead for 3 seconds and then instructed the child to “hold your hands over your head and stand on your tiptoes like I did”. Third came Imitating movements (numbered 26 in PDMS-2): E1 stood three feet away from the child facing them and would say “I am going to move my arms and I want you to copy my movements”. A practice movement was done first, but using a movement, which would not be used on the test, just to be sure the child understood what was asked of him/her. No verbal cues were used while six positions were presented one at a time at one second intervals.

Fourth came Jumping up (numbered 73 in PDMS-2): E1 instructed the child to stand with his/her side to the wall and their heels flat on the floor. Then the child was asked to raise their hands overhead and the E1 marked the spot on the wall where the child's fingertips touched. A line 3 inches above the first mark was marked. While pointing to the marked line, the child was told to jump up and touch the wall as high as they could. E1 observed the point where the child touched the wall. Fifth was Jumping forward on one foot (numbered 72 in PDMS-2): E1 demonstrated jumping forward on one foot, from a line, without allowing the other foot to touch the floor. The child was instructed to "jump forward like I did". The distance from the line to where the back of the heel touched was measured. Sixth came Walking on a line backward (numbered 78 in PDMS-2): E1 demonstrated walking backwards on the line with her hands on her hips with the toes touching the heels, without stepping off the line. The child was instructed to stand at the end of the line and told to "put your hands on your hips and walk backwards touching your heels with your toes like I did". E2 would observe how the child placed their feet and the number of steps they could take before moving off the line. Seventh was Catching a ball (numbered 17 in PDMS-2): E1 stood five feet in front of the child and asked the child to "catch the ball". The E1 tossed the ball to the child so that it arrived at chest height. Eighth and last in session 1 was Hitting a target overhand (numbered 18 in PDMS-2): E1 demonstrated an overhand toss of a tennis ball towards a target from a distance of twelve feet. The child is then told to "throw the ball and hit the target like I did". This was done three times.

In Session 2, first was Bouncing a ball (numbered 21 in PDMS-2): E1 stood five feet away from the wall, facing it. She used one hand to bounce a tennis ball so that it bounced once and then hit the wall. The child was given the tennis ball to "bounce the ball like I did". Next came Grasping a marker (numbered 22 in PDMS-2): a marker and paper were placed in front of the child on the table. E1 asked the child to make a mark. E2 observed how the child held the marker. Third was Unbuttoning buttons (numbered 23 in PDMS-2): the button strip was placed in front of the child by E1 and the child was instructed to unbutton the strip as fast as they could. Fourth came Touching a finger (numbered 26 in PDMS-2): E1 demonstrated touching her thumb with each finger successively at a rate of one touch per second. Children were then instructed to do the same thing.

Fifth was Lacing (numbered 39-40 in PDMS-2): E1 placed a string on the table and showed the child a strip containing 6 holes. E1 asked the child to "watch me lace", then E1 held the string and strip clearly so that the child could see exactly what she was doing. E1 began to lace by placing the string top down through the first hole, and up through the second hole, and down through the third hole. E1 showed the child the final result, and then removed the string from the strip, and placed these two items on the table in front of the child. Children were instructed to "Do it like I did". Children were allowed to take as much time as they needed to complete the task. Sixth came Dropping pellets (numbered 41-42 in PDMS-2): E1 placed a bottle without a cap and 10 pellets on the table in front of the child. E1 would instruct the child by saying “put the food in the bottle as fast as you can”. The child was also told to place one pellet in the bottle at a time. Next was Building steps (numbered 51-52 in PDMS-2): E1 placed 6 cubes on the table in front of the child and made sure her hands were clearly visible to the child so that they could see exactly what was going on. E1 demonstrated building steps with three cubes on the bottom row, two cubes on the next row and finally one cube on top. E1 left the steps for a short while in front of the child for them to examine. The steps were then disassembled and the cubes were placed in front of the child. The child was then instructed to build the steps like E1 did.

With respect to scoring, the PDMS-2 scoring criteria were used to assess the motor tasks for each child. A score ranging from 0 to 2 was given for each task (maximum of 30 for all tasks). The scores for the nine GMC tasks (Table 3.1) were then totalled for each child to form their GMC score (out of 18) and their scores for the six FMC tasks (Table 3.2) were then added together to form the total FMC score for each child (out of 12). The total scores for MC tasks were all calculated by E1.

3.2.4.2 IC tasks. In Session 1 the day/night task was administered with an identical procedure to that used in Study 1. E1 explained the rules to the children using the pictures of the sun and moon. Four practice trials were then administered with feedback given, followed by 16 test trials, all of which were presented using a flip-book that contained 20 pictures. The oral responses were recorded by E2.

In Session 2 the grass/snow task was also administered with an identical procedure to that used in Study 1. The child was told that they were going to play a ‘silly game’. They would have to point to pictures. The researcher showed the children pictures of the moon and sun and asked the children to name them. They were then instructed to point to the sun picture when the researcher said, *moon* and point to the moon picture when the researcher said *sun*. They were clearly told not to point to the named pictures. The researcher explained the rules by saying the two names herself and pointing to the appropriate picture. Children were allowed four practice trials in the order of sun, moon, sun, and moon with feedback as to whether they answered correctly or not. For example, if the researcher said, *moon* and the child pointed to the sun, the researcher would confirm that the child answered correctly. However, if they pointed to the moon, the researcher would explain that this was the incorrect response and explain the correct response. Once the practice trials were over, children responded in 16 test trials in the same pseudorandom order (ABBABAABBABAABAB) with no comment or feedback. The second researcher (E2) coded the children’s responses.

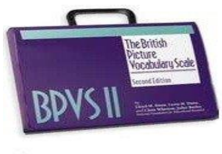
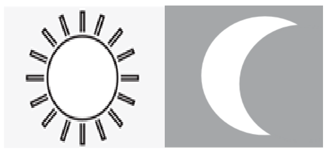
In the tapping task, children and researcher each had a wooden dowel (see Figure 3.1:4). The researcher explained the rule of the game in which the child taps twice with a wooden dowel when the researcher taps once and the child taps once when the researcher taps twice. The instruction was as follows: “When I tap one time like this (the researcher taps once), I want you to tap two times like this (the researcher taps twice). So let’s try that. When I tap one time (researcher taps once), you tap…” If the child responded correctly, the child would be praised and would then continue on to the second rule. On the other hand, if the child responded incorrectly, the researcher would explain and once again demonstrate the first rule before proceeding onto the next. Once again, the second rule would be explained and demonstrated in the same way as the first rule. The child was praised if he/she responded correctly or corrected if they responded wrongly. The researcher began with two pre-test trials and if the child responded incorrectly the rules of the task would be explained once again. The child had to be correct on each of the rules at least once during the two practice trials, in order to continue to the testing trials. The researcher needed to be sure that the child understood what was asked of him/her. However, children who answered correctly in the practice trials had those trials counted as part of the testing. This was done to prevent the children becoming bored when given too much practice, since they usually easily understood what was required of them.

A total of 16 tapping trials were conducted in pseudorandom order with each trial being composed of the researcher's taps and the child's response. Two wooden dowels were used, one for the researcher and one for the child. The series of taps by the researcher was as follows: 1,2,2,1,2,2,1,1,1,2,1,2,1,1,2. During the trials, no feedback was given.

With respect to overall scoring of IC, given that some other studies (e.g. Livesey et al., 2006) did not find an unambiguous correlation between scores for different tasks used to measure IC, I first ascertained the agreement between the three measures. Even though the mean score for the tapping task (5.68/16) was noticeably lower than that for the day/night (9.53) and grass/snow tasks (9.92), a Cronbach's alpha of .783 was obtained across the three measures of IC, which is satisfactory. Pairwise correlations between the task scores were also significant, even with age partialed out, for the correlation between the day/night and grass/snow tasks, $r(98) = .640$, $p < .001$, and for the correlation between the day/night and tapping tasks, $r(98) = .223$, $p = .027$; only the correlation between the grass/snow and tapping tasks failed to reach significance, $r(98) = .105$, $p = .300$.

Although the agreement was not perfect, a Cronbach alpha of .783 is widely considered to be satisfactory, and perfect agreement is not found in the literature either. Given this evidence of substantial agreement between the tasks, I therefore felt justified in using the total of the three task scores as a valid measure of IC for each participant. A total score out of 48 was therefore given to each child depending on their correct responses given in the three IC tasks, which of course reflects their tapping task score somewhat less than the other two scores.

Figure 3.1. Materials used in Study 2.

1. BPVS-2 Test materials[3]	**2. The day/night task pictures**[4]
	
3. PDMS-2 test materials[5]	**4. The tapping task**[6]
	

3.2.4.3 BPVS-2 tasks. The BPVS-2 was the last task in Session 2. For each item, the child was shown a page with four simple line drawings and they were instructed to point to the representation which matched the meaning of the stimulus word spoken by E1 the best.

[3] Image from publisher's website
[4] Images from Simpson and Riggs (2010)
[5] Image from publisher's website
[6] Image from advertisement

The test-book (see Figure 3.1:1) was placed in front of the child who was asked, "Where is X?" avoiding using the word *the* so as not to cue the part of speech of the word, i.e. whether the item was a noun or not (Dunn and Dunn, 2009). The results were recorded in the Performance Record.

The standard procedure for children under the age of eight years was followed, beginning with the researcher telling the child: "I want you to look at some pictures with me. See all the pictures on this page". The researcher pointed to each of the four pictures in Training Plate A and then said: "I will say something, and then I want you to put your finger on the picture of what I have said. Let's try one. Put your finger on 'ball'." When the child responded correctly, without any help, the researcher says *Good* and then continued to Training Plate B. On the other hand, if the child points to the incorrect picture, the researcher showed them the correct response and says "that was a good try, but let's try again." The researcher could help as much as required until the child responded correctly, allowing continuation to the next Training Plate. If the child responded correctly to the second training word in Training Plate A, without any help, the researcher continued onto Training Plate B. However, if the child's response was incorrect, the researcher once again points to the correct response and give as much help as needed for the child to reach the correct response. On the other hand, if the child kept giving incorrect responses and it was clear that they could not perform the task, the testing was discontinued and a note of this was written on the Performance Record.

The children who participated in the study were of a young age; hence I began the test with the first set of words, of the easiest level offered in the test. The test continued until the child answered 8 or more out of one of the sets of 12 items incorrectly, at which point the test was stopped.

With respect to scoring, the total number of correct answers constituted the 'Raw Score' which was used in the statistical calculations. Using the norm tables provided by the BPVS-2 (Dunn and Dunn, 2009), a standardised score was calculated together with the age equivalent.

Table 3.3. Overall task order in Study 2 (showing optimum age suitability in months for PDMS-2 tasks).

Session 1	Session 2
1. Standing on one foot (45-46)	1. Unbuttoning (41-42)
2. Jumping up (45-46)	2. Dropping pellets (41-42)
3. Catching a ball (44-45)	3. Grass/snow task
4. Grasping a marker (41-42)	4. Imitating (59-60)
5. Day/night task	5. Walking a line backward (51-52)
6. Lacing (39-40)	6. Bouncing a ball (51-52)
7. Standing on tiptoe (43-44)	7. Tapping task
8. Jumping forward on one foot (43-44)	8. Touching a finger (53-54)
9. Hitting a target overhand (43-44)	9. Building steps (51-52)
	10. BPVS task

3.2.5 Choice of Statistics

For similar reasons to those given in relation to the previous study, I elected first to explore the relationships between all the included variables through simple bivariate correlation. Since, however, interrelationships between more than two variables at a time needed to be taken into account, partial correlation was also used, and then multiple regression, which allowed me to assess the relationship between each of five predictors and any potential dependent (IC, FMC, or GMC), with inter-correlations between predictors controlled for. Once again, indirect relationships were also of interest, so a set of mediation analyses was also conducted using a macro within SPSS as described for Study 1. These were used to explore which of the three types of control of interest (IC, FMC, GMC) might best be seen as predictor, mediator or dependent with respect to the others.

3.3 Results

As described earlier, the aim of Study 2 was to assess the links between age, fine motor control (FMC) and gross motor control (GMC) and the development of inhibitory control (IC) in early childhood, taking account also of age, gender and IQ. Table 3.4 provides descriptive statistics for five of the variables. I performed a variety of analyses in order to illuminate the relationships among the six variables, including simple bivariate correlation, multiple regression, and mediation analysis.

Table 3.4. Descriptive statistics for Study 2.

	N	**Minimum**	**Maximum**	**Mean**	***SD***
Age in months	100	36	59	48.39	7.809
IQ	98	0	56	26.87	15.065
GMC	100	0	17	7.04	3.736
FMC	100	0	13	6.78	3.252
IC	100	0	53	25.17	16.391
Valid *N* (listwise)	98				

3.3.1 Correlation Analysis

Bivariate correlations were computed on the total sample of 100 children to investigate the relations between the six variables (age, gender, general intelligence (IQ), IC, FMC and GMC) in early childhood. Table 3.5 provides the correlations between these variables. From the correlation table, it can be seen that all the variables had significant and positive relationships with each other, with the exception of gender.

Table 3.5. Correlations among the variables of Study 2.

		1	**2**	**3**	**4**	**5**	**6**
1	Age	-					
2	Gender	-.078	-				
3	IQ	.590**	-.017	-			
4	Gross motor control	.675***	-.059	.600***	-		
5	Fine motor control	.659***	-.063	.647***	.750***	-	
6	Inhibitory control	.700***	-.112	.563***	.631***	.749***	-

(* *p*<.05, ***p*<.01, *** *p*<.001)

***3.3.1.1 IC and other variables*.** The data revealed that IC had a strong positive correlation with both FMC, $r(98) = .75$, $p < .001$, and GMC, $r(98) = .63$, $p < .001$. Indeed, I had expected the relationships between performance on IC, FMC and GMC to be positive, where children with higher IC performed better on FMC and GMC tasks. In fact the IC-FMC correlation was even stronger than that found in Study 1 ($r(98) = .635$: Table 2.3).

Furthermore, analysis showed that there was a strong positive correlation between IC and general intelligence (IQ) and this correlation was also significant, $r(98) = .56$, $p < .001$). In this case, a strong positive correlation between preschool children's response inhibition IC and general intelligence is also expected from the literature (See 3.1.1).

Finally, a strong positive and significant correlation between IC and age was also found, which again is as expected, $r(98) = .70$, $p < .001$. The gender coefficients are all very low and non-significant, consistent with some other studies, which found no gender difference at this age (see 2.3.1).

***3.3.1.2 FMC and other variables*.** The results of the correlation analysis again indicated that all four variables (age, IQ, IC and GMC) had a strong positive and significant correlation with FMC (Table 3.5): IQ, $r(98) = .65$, $p < .001$; GMC, $r(98) = .75$, $p < .001$; and age, $r(98) = .66$, $p < .001$. These correlations suggest that higher values on the FMC variable were associated with higher value on all four variables, as would be expected from the literature. The lack of correlation with gender is again not surprising.

***3.3.1.3 GMC and other variables*.** The results again indicated that there were strong positive and significant correlations between GMC and IQ, $r(96) = .60$, $p < .001$, and age, $r(98) = .68$, $p < .001$. In this case, once again better performance on the GMC task was linked with higher scores on the IQ task; also higher values on the GMC variable were associated with higher values on the age variable (older children). Once again there was no significant difference in GMC between girls and boys.

At this point Study 2 replicates the findings of Study 1, in the areas where the same relationships were measured in both studies. However, it adds to those findings that GMC and IQ, not included in Study 1, are also correlated with all the other variables except gender. However, these simple bivariate correlations are misleading, as they do not take account of inter-correlations among all the variables included. Hence I proceeded to measure relationships in ways that do take account of such inter-correlations.

3.3.2 Partial Correlation Analysis

The simple bivariate correlations above give us an initial idea of the relationships between the six variables in the current study, but have the weakness that each pair of variables is considered without attention to the other four. Hence the correlation coefficients do not control for wider inter-relationships among the whole set. One simple way to take care of this is by calculating partial correlations, which are used to remove the effect of possible confounding variables. Partial correlation is an extension of bivariate correlation, which provides a more accurate picture of the relationship between pairs of variables by controlling for the effects of others.

Partial correlation coefficients were therefore calculated in order to control for the possible effects of potentially confounding variables (age, gender and IQ) on the relationships which were of most interest, that is those between IC and FMC, and between IC and GMC. Table 3.6 demonstrates that, when the variables of age, gender and IQ have been partialed out, there still exist significant correlations between IC, FMC and GMC. Strong positive and significant correlations were found between IC and FMC, $r(91) = .47$, $p < .001$, and between GMC and FMC, $r(91) = .49$, $p < .001$. However, there was only a weak positive and significant correlation between IC and GMC, $r(91) = .244$, $p = .017$, when the effects of age, gender and IQ were partialed out.

At this point it seemed apparent that IC and GMC were not very strongly related, thus only weakly supporting the hypothesis of Study 2. Therefore, multiple regression analyses were used to explore these relationships further, controlling for all inter-relationships among the variables when considering the relationship of each of them with one chosen as a dependent variable.

Table 3.6. Partial correlations in Study 2.

Control Variables		Variables	1	2
Age & Gender & IQ	1	Gross motor control	-	-
	2	Fine motor control	.492***	-
	3	Inhibitory control	.244*	.474***

(* *p*<.05, ***p*<.01, *** *p*<.001)

3.3.3 Multiple Regression Analyses

Multiple regression was conducted taking each of the three focal variables (IC, FMC, and GMC) in turn as dependent variables and examining the relationships with the dependent of the other variables, regarded as multiple predictors, in each case (Table 3.7).

In the first analysis, multiple regression analysis using the standard ‘enter’ method was conducted, where, IQ, gender, IC, age and FMC were entered as predictor variables and GMC as dependent to see whether IQ, gender, IC, age and FMC impact on GMC collectively and individually, once the inter-relations among all these predictors are controlled for. The overall model explained 63% of variance, which was revealed to be statistically significant, F (5, 92) = 31.947, p < .001, R = .797, R^2 *Adjusted* = .615. The analysis showed that FMC, *Beta* = .492, t(97) = 4.709, p < .001, and age, *Beta* = .278, t(97) = 2.499, p = .004, both significantly predict GMC. However, neither IC, *Beta* = .014, t(97) = .137, nor gender, *Beta* = -.013, t(97) = -.200, nor IQ, *Beta* = .110, t(97) = 1.270, significantly predict GMC. This suggests that strong FMC would be associated with strong GMC, and that GMC develops with age, as expected, but notably fails to find a significant relationship between IC and GMC, contrary to my hypothesis. The lack of effect of gender is not surprising given that gender showed no significant bivariate correlations with any variables. The lack of impact of IQ could be seen as due to any effect of IQ (seen in the simple correlations) being only due to its correlation with FMC, whose effect is stronger.

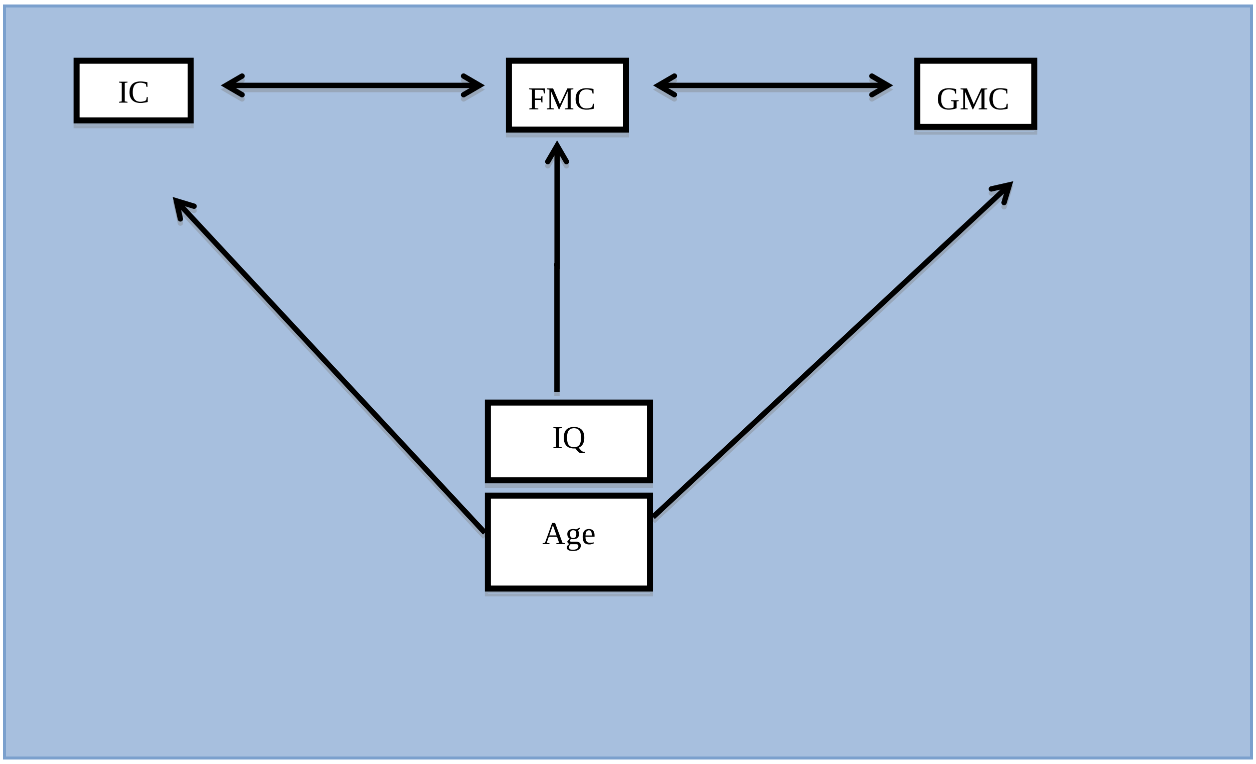
In the second analysis, multiple regression using the standard method was conducted to examine whether IQ, gender, IC, age and GMC impact on FMC considered as dependent. The overall model explained 70% of variance, which was revealed to be statistically significant, F (5, 92) = 44.301, $p < .001$, $R = .841$, R^2 *Adjusted* = .691. The result showed that IC, *Beta* = .373, $t(97) = 4.429$, $p < .001$, and GMC, *Beta* =. 395, $t(97) = 4.709$, $p < .001$, and IQ, *Beta* = .193, $t(97) = 2.547$, $p = .013$, all significantly predict FMC. However, neither age, *Beta* = .013, $t(97) = .151$, nor gender, *Beta* = .018, $t(97) = .320$, significantly predict FMC.

In the third analysis, IC was taken as the dependent. The overall model explained 63% of variance, which was revealed to be statistically significant, F (5, 92) = 31.187, $p < .001$, $R = .793$, R^2 *Adjusted* = .609. The result showed that both FMC, *Beta* = .471, $t(97) = 4.429$, $p < .001$, and age, *Beta* = .351, $t(97) = 3.797$, $p < .001$, significantly predict IC. However, neither GMC, *Beta* = .014, $t(97) = .137$, nor gender, *Beta* = -.044, $t(97) = -.698$, nor IQ, *Beta* = .042, $t(97) = .472$, significantly predict IC. The picture that emerges could be summarized in the diagram displayed in Figure 3.2.

Table 3.7. Multiple regressions of Study 2.

	Dependent variable								
	Inhibitory control			Fine motor control			Gross motor control		
Predictor	***Beta***	***t***	***p***	***Beta***	***t***	***p***	***Beta***	***t***	***p***
Age	.351	3.80	<.001	.013	0.15	.880	.278	2.95	.004
Gender	-.044	-.698	.487	.018	0.32	.750	-.013	-0.20	.842
IQ	.042	.472	.638	.193	2.55	.013	.110	1.27	.207
IC	-	-	-	.373	4.43	<.001	.014	.137	.891
FMC	.471	4.43	<.001	-	-	-	.492	4.71	<.001
GMC	.014	.137	.891	.395	4.71	<.001	-	-	-
Model statistics									
F (df)	31.2 (5, 92)			44.3 (5, 92)			31.9 (5, 92)		
R^2	.629			.707			.635		
p	<.001			<.001			<.001		

Figure 3.2. Significant inter-relations among variables revealed through multiple regression analyses in Study 2.



3.3.4 Mediation Analyses

The main finding of interest that emerged from the multiple regression analyses was that, counter to my hypothesis for Study 2, no significant relationship was found between IC and GMC when effects of all other variables were controlled for. This was the case both when GMC was treated as a predictor with IC as dependent, and when GMC was treated as dependent and IC as predictor.

Now, from the literature on these variables (1.6), it has often been assumed that IC is prior to GMC and FMC in terms of having any effects on each other and on any other variables, as indeed was assumed for IC and FMC in Study 1. This, together with the picture seen in Figure 3.2, suggested that, in order to complete the investigation of the IC relationship with GMC, it would be instructive to conduct a mediation analysis to ascertain whether FMC can be interpreted as a mediator variable between IC and GMC. However, it could also be argued that, despite the appearances of Figure 3.2, it could make more sense to see GMC as a potential mediator between IC as independent and FMC as dependent. Hence I also conducted a mediation analysis to explore this scenario. Furthermore, as was reviewed in 1.6, there exists also in psychology an increasing body of theory and evidence suggesting that the causal relationship between cognitive and motor development could be from the latter to the former (e.g. Piek, Dawson, Smith & Gasson, 2008) or that both could stem from a third agency (Gottwald et al., 2016).

To examine these possibilities, as in Study 1, I followed the recommendations of Shrout and Bolger (2002), who suggest a mediation analysis, which includes a bootstrapping procedure to compute a confidence interval around the indirect effect (i.e., path ab from the independent variable to the dependent through the mediator). If zero falls outside of this interval, significant mediation is said to be present. The SPSS macro designed by Preacher and Hayes (2008) was again used to perform all the required analyses, both those using customary multiple regression and those using bootstrapping.

Considering GMC as the dependent variable, as seen in Table 3.8, multiple regression analyses showed that IC was positively associated with GMC when the effects of other, possibly mediating, variables were not taken into account, $B = .057$, $t(97) = 2.429$, $p = .017$. That effect is commonly termed path c. With all predictors taken into account it was also found that IC was positively related to FMC, $B = .093$, $t(97) = 5.192$, $p < .001$, on what is called path a. Lastly, results indicated that the potential mediator, FMC, was positively associated with GMC, $B = .576$, $t(97) = 4.709$, $p < .001$, on path b. Since all three paths a, b, and c showed significant relationships, further analyses were used to test if FMC was truly mediating between IC and GMC.

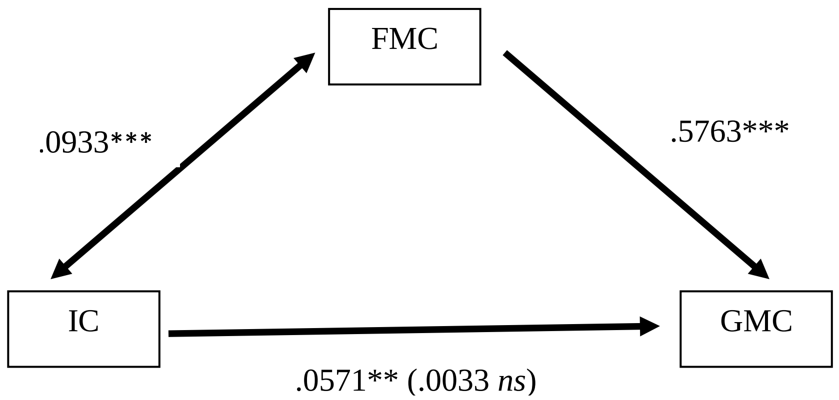
First, further multiple regression results indicated that the direct effect of IC on GMC became non-significant, B = .003, $t(97) = .137$, $p = .891$, when controlling for FMC (path c'), thus suggesting full mediation of the effect of IC through FMC on GMC. The indirect path ab was also tested using the bootstrapping method with bias-corrected confidence estimates (MacKinnon, Lockwood, & Williams, 2004; Preacher & Hayes, 2004). In the present study, the 95% confidence interval of the indirect effects was obtained with 1000 bootstrap resamples (Preacher & Hayes, 2008). Results of the mediation analysis confirmed the fully mediating role of FMC in the relation between IC and GMC, $B = .054$; *CI* = .0307 to .0886. Figure 3.3 displays the results.

Table 3.8. Mediation analysis with GMC as dependent.

Effect and Path	Variables	*B* Coefficient	*SE*	*t*	*p*
IV to MV (Path a)	IC → FMC	.093	.018	5.192	<.001
Direct Effect of MV on DV (Path b)	FMC → GMC	.576	.122	4.709	<.001
Total Effect of IV on DV (Path c)	IC → GMC (not considering FMC)	.057	.024	2.429	.017
Direct Effect of IV on DV (Path c')	IC → GMC	.003	.024	.1372	.891
Partial Effect of Control Variables on DV	Age → GMC	.134	.046	2.949	.004
	Gender → GMC	-.095	.475	-.200	.842
	IQ→ GMC	.028	.022	1.270	.207
				Bias corrected 95% confidence interval*	
Indirect Effect of IV on DV through MV (Path ab)	IC→ FMC→ GMC	.0538, .0540*	.0142 *	.0307 to .0886	

*Bootstrapped estimates (1000 resamples)

Figure 3.3. Mediation model of IC and GMC through FMC (*B* coefficients are shown with probabilities: *ns* not significant, * *p*<.05, ** *p*<.01, * *p*<.001).**



I next considered the scenario where GMC is the potential mediator and FMC the dependent. Considering FMC as the dependent variable, as may be seen in Table 3.9, multiple regression analyses showed that IC was positively associated with FMC when the effects of other, possibly mediating, variables were not taken into account, path c: B = .093, $t(97)$ = 5.192, p < .001. With all predictors taken into account (path a) it was also found that IC was also positively related to GMC, *B* = .057, *t*(97) = 2.429, *p* = .017. Lastly, results indicated that the potential mediator, GMC, was positively associated with FMC, *B* = .337, *t*(97) = 4.709, *p* < .001) on path b. Since all three paths a, b, and c were significant, further analyses were used to test if GMC was truly mediating between IC and FMC.

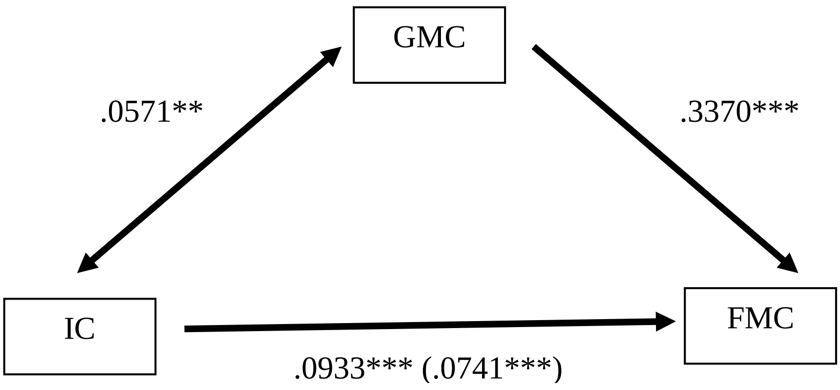
First, further multiple regression results indicated that the direct effect of IC on FMC was also significant, B = .0741, *t*(97) = 4.429, *p* < .001, even when controlling for GMC (path c'), thus not supporting full mediation of the effect of IC through GMC on FMC. The indirect path ab was also tested using the bootstrapping method with bias-corrected confidence estimates (MacKinnon, Lockwood, & Williams, 2004; Preacher & Hayes, 2004). In the present study, the 95% confidence interval of the indirect effects was again obtained with 1000 bootstrap resamples (Preacher & Hayes, 2008). Results of the mediation analysis confirmed the mediating role of GMC in the relation between IC and FMC, *B* = .0192; *CI* = .0012 to .0399, although it is noticeable that the lower limit of the confidence interval is very close to zero. Figure 3.4 displays the results. Overall, the evidence here is for partial mediation, since paths ab and c' both yield significant effects: IC has a significant impact on FMC both directly and via GMC.

Table 3.9. Mediation analysis with FMC as dependent.

Effect and Path	Variables	*B* Coefficient	*SE*	*t*	*p*
IV to MV (Path a)	IC → GMC	.057	.024	2.429	.017
Direct Effect of MV on DV (Path b)	GMC → FMC	.337	.072	4.709	<.001
Total Effect of IV on DV (Path c)	IC→FMC (not considering GMC)	.093	.018	5.192	<.001
Direct Effect of IV on DV (Path c')	IC → FMC	.074	.017	4.429	<.001
Partial Effect of Control Variables on DV	Age → FMC	.006	.036	.152	.880
	Gender→FMC	.116	.363	.320	.750
	IQ→ FMC	.041	.016	2.547	.013
				Bias corrected 95% confidence interval*	
Indirect Effect of IV on DV through MV (Path ab)	IC→ GMC →FMC	.0192, .0194*	.0097*	.0012 to .0399	

*Bootstrapped estimates (1000 samples)

Figure 3.4. Mediation model of IC and FMC through GMC (*B* coefficients are shown with probabilities: *ns* not significant, * *p*<.05, ** *p*<.01, * *p*<.001).**



Thirdly, in order to take account of approaches which view cognitive functions as developmental consequences of motor abilities, I conducted a mediation analysis with IC as dependent and GMC as independent, and FMC as potential mediator.

As shown in Table 3.10, multiple regression analyses showed that IC was positively associated with GMC when the effects of other, possibly mediating, variables were not taken into account, path c: $B = 1.045$, $t(97) = 2.429$, $p = .017$. With all predictors taken into account (path a) it was also found that FMC was positively related to GMC, $B = .4144$, $t(97) = 5.451$, $p < .001$. Finally, results indicated that the potential mediator, FMC, was positively associated with IC, $B = 2.373$, $t(97) = 4.429$, $p < .001$, on path b. Since all three paths a, b, and c were significant, further analyses were used to test if FMC was truly mediating between GMC and IC.

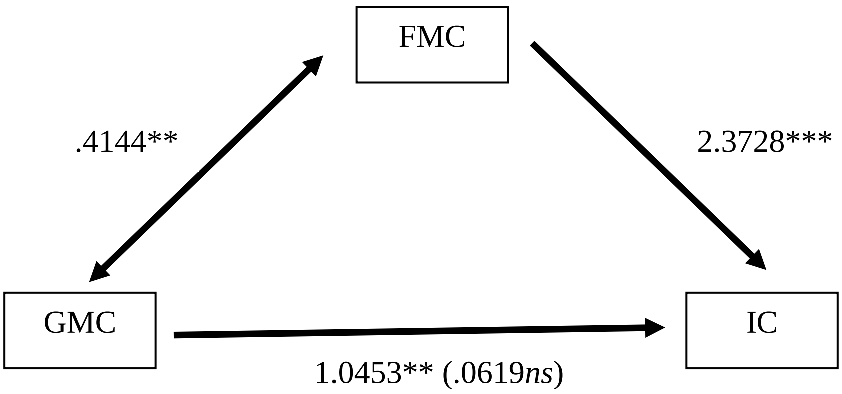
First, further multiple regression results indicated that the direct effect of GMC on IC was not significant, B = .0619, $t(97) =.1372$, $p = .891$, in the presence of the other variables (path c'), thus supporting a possible mediation of the effect of GMC through FMC on IC. The indirect path ab was also tested using the bootstrapping method with bias-corrected confidence estimates (MacKinnon, Lockwood, & Williams, 2004; Preacher & Hayes, 2004). In the present study, the 95% confidence interval of the indirect effects was again obtained with 1000 bootstrap resamples (Preacher & Hayes, 2008). Results of the mediation analysis confirmed the mediating role of FMC in the relation between GMC and IC, $B = .9833$; $CI = .4922$ to 1.650. Figure 3.5 displays the results. Overall, the evidence here is for full mediation, since path ab but not c' yields a significant effect: GMC has a significant impact on IC only via FMC.

Table 3.10. Mediation analysis with IC as dependent.

Effect and Path	Variables	*B* Coefficient	*SE*	*t*	*p*
IV to MV (Path a)	GMC → FMC	.414	.076	5.451	<.001
Direct Effect of MV on DV (Path b)	FMC → IC	2.373	.536	4.429	<.001
Total Effect of IV on DV (Path c)	GMC→IC (not considering FMC)	1.045	.430	2.429	.017
Direct Effect of IV on DV (Path c')	GMC → IC	.062	.451	.137	.891
Partial Effect of Control Variables on DV	Age → IC	.727	.191	3.796	<.001
	Gender → IC	-1.430	2.050	-.698	.487
	IQ→ IC	.045	.094	.472	.638
				Bias corrected 95% confidence interval*	
Indirect Effect of IV on DV through MV (Path ab)	GMC→ FMC → IC	.9833, .9947*	.2847*	.4922 to 1.4698	

*Bootstrapped estimates (1000 resamples)

Figure 3.5. Mediation model of GMC and IC through FMC (*B* coefficients are shown with probabilities: *ns* not significant, * *p*<.05, ** *p*<.01, * *p*<.001).**



Finally, it is necessary to consider which of the three mediation analyses above is to be preferred, since each represents a different model of the possible sequences of effects among the variables. If one refers to the model summary statistics for each analysis it is found that all three models account for the variance of the DV with high significance ($p < .001$). The model with

GMC as dependent however yields *F*= 31.95, R^2 = .6345, adjusted R^2 = .6417, while the model for FMC as dependent yields *F* = 44.30, R^2 = .7065, adjusted R^2 = .6906, and the model with IC as dependent gives *F* = 31.19, R^2 = .6289, adjusted R^2 = .6088. Statistically, therefore, the best fitting model, with an adjusted R^2 of .69, is that with IC as main predictor, FMC as dependent and GMC as mediator, which as has been seen exhibited both direct and mediated significant effects of IC on FMC. I believe that this also represents a plausible cause-effect scenario in real life, i.e. that IC impacts on GMC skill and that improvement in GMC skills leads to, rather than is a consequence of, development of FMC skills associated with FMC. As Salkind (2005) indicates, fine motor control development depends on gross motor control development because the former presupposes the ability to control gross movements and body posture.

Interestingly, the preferred model also exhibits a significant effect of IQ, but not of age. In other words, the impact of IC on FMC, both independently and via GMC, occurs within the 3- to 5-year-old age group of my study without any significant developmental component: IC rather than age is what determines differential FMC in these children. IQ, however, does have some independent effect (*B*=. 041). This indeed is greater than the mediated effect of IC on FMC via GMC (*B* = .019) though less than the independent direct effect of IC on FMC (*B* = .074).

3.4 Discussion

Study 1 indicated that IC and FMC are associated in early childhood. Hence, the purpose of the current study was primarily to examine this relationship further and to determine whether this association extends to GMC (taken up in 3.4.1 and 3.4.2), and secondarily to determine the nature of any role played by IQ (3.4.3).

3.4.1 The direction of the relationship between IC and FMC

The preferred model in the earlier analyses (3.3.4) appears to support a scenario where IC affects FMC. However, on the vexed issue of causality it is necessary to remain cautious. It must be remembered that Study 2 is purely based on correlational research, and that prediction in the analyses presented above does not equate necessarily with causality. Hence I now consider possible ways in which the key relationship which I have found might be explained. I explore first the proposal that good IC might lead to more effective FMC, and second the suggestion that in fact FMC leads to IC. Finally I elaborate on how embodied cognition might explain why FMC and IC simply develop together.

One approach to explaining why IC might improve FMC would be to attempt to apply the three accounts which I tested in Study 1. That is to say, although these accounts concern possible mechanisms which explain how IC might affect drawing skill development, one could reinterpret them as potential accounts of why IC might affect FMC development, given that Study 1 showed that FMC mediated the effect of IC on two of the three measured drawing skills.

One of the accounts, however, seems hard to apply to FMC. The Symbolic Competence account (Riggs et al., 2013) suggests that IC assists the development of symbolic understanding (e.g., Sabbagh, *et al.*, 2006), which in turn means that IC impacts indirectly on any abilities which require symbolic understanding. However, actions requiring FMC, such as undoing a button, need no symbolic understanding since real objects are directly involved, rather than any symbolic representations of them. Hence this does not seem to be a convincing suggestion for how IC might impact upon FMC.

Second, the Behavioural Inhibition account by contrast proposes that development in drawing skill occurs through the inhibition of previously established drawing behaviour (Ebersbach, et al., 2011; Riggs et al., 2013). Most actions which require FMC, however, do not appear to depend on the inhibition of previously established behaviours. If a child cannot undo a button, it is not so much that they possess an unsuitable behaviour which needs to be inhibited as that they do not possess a coherent, controlled, behaviour at all.

A different approach to explaining the relation between IC and MC in this account is to consider how preschooler's IC develops. One scenario compatible with the Behavioural Inhibition account is that inhibition *strength* increases, which prevents *inappropriate* responses (Simpson & Riggs, 2007). Another scenario would be that IC improves through the *slowing* of behaviour, so that more care can be taken to produce the *appropriate* response (Diamond, Kirkham & Amso, 2002). There is in fact evidence that preschoolers complete IC tasks better when their response is slowed (e.g., Simpson et al., 2012; although see Barker & Munakata, 2015 and the response of Ling, Wong & Diamond, 2016).

The link between IC and some kinds of MC could be explained, then, by the proposal that effective IC is the consequence of slowed responding. For example, toddlers who respond more slowly show better performance on an MC task requiring some precision (e.g. building a tower from blocks); such toddlers do not differ from others in performance on an imprecise MC task, however (e.g. placing blocks into a container in no particular pattern, Chen, Keen, Rosander & von Hofsten, 2010). In just this way, I found that IC was associated with FMC (e.g. undoing a button), an activity which might benefit from unhurried response, but not with GMC (e.g. catching a ball), which might not. With respect to drawing, it has similarly been argued (Lange-Küttner, 2000) that the development of drawing techniques (e.g., linking distinct elements of the subject represented) depends on the modification of *fast* procedural routines. Consistent with this proposal, she found evidence that young children do in fact slow down their speed of drawing when they produce open rather than closed shapes (Lange-Küttner, 1998). All these findings, then, are consistent with the proposal that effective IC improves MC (and some drawing skills) by slowing down the response process.

Moving now to the third account of how drawing skill develops, the Motor Development account, it is at once clear that the findings of Study 2 are consistent with it, as were those of Study 1 (for two of the drawing skills measured). Recall that the Motor Development account proposed that IC and FMC are associated directly in early childhood and indeed that IC affects drawing skill only via FMC. In the present study, after controlling for age, gender and IQ, mediation analysis using regression with bootstrapping indicated that a relationship existed between IC and FMC both directly and, less strongly, mediated through GMC.

Explanations of the association of IC with FMC which see IC as leading to FMC are, however, not the only possible interpretations. With respect to the suggestion that FMC might improve IC, however, it must be noted that the tasks used to measure IC in the present study were selected precisely because they make minimal demands on motor skills. The day/night task only required a verbal response and while the grass/snow and tapping tasks did require manual responses, they were undemanding (e.g., pointing at any area of a picture) and not performed under time pressure. Hence it appears most unlikely that effective FMC improved performance on the IC tasks due to their motor demands. It remains possible however that while particular MC tasks are performed better where children have greater IC (second/preferred model in 3.3.4), rather than the reverse, it could also be true that, in terms of developmental change, the experience of MC task performance is instrumental in the improvement of IC (compare third model in 3.3.4).

By contrast with the above, the theory of embodied cognition suggests an alternative explanation for how the development of MC and EFs are connected, where they each help each other and neither has priority. This approach proposes that cognition in humans develops through the physical interaction of their bodies with the world (see Marshall, 2016, and Shapiro, 2011, for reviews). This idea follows on from earlier work by Piaget (1952), as mentioned in 3.4.1, in which the first stage of cognitive development was the sensorimotor stage. Current thinking is that later cognitive development occurs in situations where a child is able to act upon the world through control of their body (Wilson, 2002). An example is the A not B task where an infant has to find something hidden in a new place, after previously retrieving it from somewhere else.

In such a task, the child has to use IC and working memory work together with MC to find the new location (e.g., Thelen, Schöner, Scheier & Smith, 2001). Such bi-directional interactions between EFs and MC are highlighted in Dynamic Systems Theory (e.g., Smith & Thelen, 2003), and reflected in the interactions between the regions of the brain which are associated with them (e.g., Diamond, 2000; Koziol et al., 2012).

It remains unclear, however, whether certain aspects of MC are linked more closely with EFs than others, and how such linkages change during development. Study 2 suggests that it is FMC, but not GMC, which is associated with IC in early childhood. There is however some previous research with younger children which showed that GMC is related to IC at 24 months, but not at 12 months (St. John et al., 2016). Adopting a dynamic systems approach, it could be argued that this shows that different aspects of MC interact with EFs at different ages. For instance, the move from crawling to walking (in the second year) may lead to the integration of EFs such as IC with GMC. Later, however, FMC comes to the fore as preschoolers focus on activities such as dressing and drawing, which require finer motor skills. In order to better understand this sequence, a longitudinal approach needs to be adopted in future research. In that way a fuller account could be obtained of the development over time of the association found between FMC and IC in preschool children.

3.4.2 The role of IQ.

Turning to the second aim of Study 2, an effect was found of IQ on FMC, but not on GMC, in the presence of IC. This agrees, for example, with Frick and Möhring (2016), who in a study of 6-year-olds also found no relationship between GMC and verbal IQ. FMC however was not tested in that study, and they measured IC with a fruit colour Stroop task which requires control of visual attention rather than of behaviour, so is not close to the type of IC which I focus on, which is behavioural.

Roebers and colleagues (2014), by contrast, like the present study, found a significant relationship between IQ and FMC in preschool children, and indeed a relationship between EF (including IC) and both IQ and FMC. Interestingly, their analysis suggests that FMC could be seen as predicting IQ, rather than the reverse. Since, however, in the present study IQ was included only in the role of a control variable, this issue will not be pursued further.

3.4.3 The relationship between IC, GMC and FMC

With respect to the first aim, the result of Study 2 has provided strong evidence again for the relationship between IC and FMC in early childhood, after controlling for age, gender and IQ as well as for GMC. The main finding was that IC is indeed directly associated with FMC, but only indirectly with GMC, in typical 3- to 5- year olds.

Previous research has provided strong support for the existence of a relationship between MC and EFs in older children and adolescents with DCD (see review in Leonard & Hill, 2015). The current result may also be seen as consistent with some studies on the FMC of children with learning disabilities (Hartman, Houwen, Scherder & Visscher, 2010). These report evidence of EF, including IC, difficulty in children who suffer from motor difficulties, so by implication suggest that IC might be related to MC. This however falls short of demonstrating, as I do, an actual correlation between degree of MC difficulty and degree of IC limitation.

There also exists some evidence for a relationship between IC and MC in typically developing infants (Gottwald et al., 2016; St. John et al., 2016), 5- and 6-year-olds (Livesey et al., 2006; Roebers et al., 2014), and adolescents (Rigoli et al., 2012). Livesey and colleagues (2006), however, found some association between one measure of IC (a day/night task), but not another (a stop/go task), and FMC. This therefore only partially agrees with my finding. Wassenberg and colleagues (2005) also found little evidence of "a global relation between cognitive and motor performance" (p. 1099) in 5- and 6- year olds, although they did find a significant relationship with MC of a specific IC task (word order). Here again my finding presents more definite evidence in favour of an association between IC and MC.

Most notably, the current study, together with Study 1, for the first time shows evidence for an association between IC and FMC in 3- and 4-year-old children, at the stage of development when IC in known to develop most rapidly (e.g., Wiebe et al., 2012; Willoughby et al., 2011). Furthermore, none of those aforementioned studies examined, as the present one did, IC relationships with GMC separately from FMC, nor considered any possible mediating role of GMC in relation to IC (or EF more generally) and FMC.

My finding may further be located more broadly in relation to a fundamental difference of view found in psychology concerning the connection between global cognitive and global motor performance capabilities of humans. Descartes (1984-1991) for example long ago proposed that cognitive processes are to be seen as totally distinct from motor processes (Hatfield, 2003). Piaget however more recently took the view that cognitive and motor processes must be seen as connected because development of the former relies on development of the latter (Piaget & Inhelder, 1966). Nevertheless, an important objection to Piaget's theory of cognitive development is that insufficient consideration was given by it to the young child's motor capabilities (Berger, 1988). Moreover, there appears to be little experimental evidence concerning what is often nowadays assumed to be a global relationship between cognitive and motor abilities of children (Wassenberg et al., 2005). Churchland (1986, 2002) in fact suggested that presenting this whole issue as a dichotomy is in any case a mistake. She rather hypothesized that there exists a continuum, which runs from lower (sensorimotor) functions (e.g. grasping and visual perception) at one end, to higher cognitive functions (e.g. planning and regulating of behaviour) at the other (Churchland, 1986).

My study then provides evidence for an intimate connection between fairly general, if not global, cognitive and motor abilities, supporting a more Piagetian view. I not only demonstrate that IC, a key component of the executive function, which is to be regarded as a global cognitive component of the human mind, is associated with the global MC category of FMC (but not directly with GMC), but that there is also possibly a more detailed interrelationship between these three variables in terms of mediation.

3.4.4 Conclusion

Through a series of increasingly sophisticated analyses of the relationships among the six variables included in this study I have revealed that IC impacts on FMC predominantly directly, though also with a smaller but significant effect mediated through GMC. IQ is also associated with FMC, though to a lesser extent than IC.

Having in Study 2 followed up and illuminated more fully the IC-FMC relationship found in Study 1, I next turn in Study 3 to pursuing the precise nature of the age - drawing skill relationship suggested in Study 1.

Chapter 4. Is the development of visual realism in children's drawing linear or U-shaped?

4.1 Introduction

This chapter follows up on the findings of the Study 1 in a different direction from that pursued in the previous chapter. In Study 3 I leave IC and MC and focus attention instead on age and visual realism as a drawing skill. In particular I aimed to investigate a possible explanation for the finding in Chapter 2 that, in contrast with the result for figurative representation and detail as dependents, age (and IC) correlated significantly negatively with visual realism, despite a positive development generally found in the literature (e.g., Jolley and Rose, 2008). As already discussed (Chapter 2), this initially puzzling finding could be accounted for if the developmental pattern of visual realism in children's drawing is in fact U-shaped. The first part of this Chapter is concerned with the relevant background, in particular Luquet's (1927) traditional theory of children's drawing, which was adopted as a theoretical framework for Study 3. The second part of this Chapter describes Study 3.

4.1.1 Luquet's four stages

There are several frameworks that have been used to explain the processes of drawing and its development, such as Perceptual theories (Willats, 1977, 1997), Gestalt theories (Kellogg, 1970, Arnheim, 1974), and Cognitive development theories (Luquet, 1927; Piaget, 1930, 1956; Karmiloff-Smith 1990). For the purpose of this study, I focus primarily on Luquet's (1927) theory for a number of reasons. First, Luquet's ideas have deeply influenced many later researchers (e.g., Costall, 1995, 1997; Cox, 1992; Freeman, 1972, 1980; Golomb, 2002, 2004; Light & Barnes, 1995; Milbrath, 1998; Thomas & Silk, 1990; Willats, 1997, 2005). Second, although published 90 years ago, Luquet's seminal paper was not available in full in English until relatively recently (Luquet, 2001). This has enabled Luquet's ideas to become more widely known in an accurate form, rather than in the second-hand summaries, which were available before. Third, it provides the clearest account of the development of what is referred to as realism of children's drawing, focused on the distinction between visual and intellectual realism.

Luquet is credited with proposing that children's drawing develops through four stages, which are considered in turn below. Luquet's ideas were later incorporated by Piaget into his stage theory (Piaget & Inhelder, 1956). Although, studies have shown that development is not stages-like in the strict sense that children manifest the characteristics of one stage and lose the characteristics of that stage when adopting the characteristics of the next stage (Flavell, 1963). Rather, findings show that children's drawing performance changes gradually and does not develop in discrete steps (for reviews, see Cox, 1991, 1992; Freeman & Cox, 1985; Light & Barnes, 1995; Thomas & Silk, 1990). Provided that Luquet's stages are thought of as phases in a continuum rather than discrete steps, however, I suggest that what Luquet has to say remains valuable.

According to Luquet (1927; 2001) 'trace making or scribbling' is the child's first experience of drawing. He suggested that children, even though young, know that pictures can represent life but they do not believe that they can draw such representations and so suffice with scribbles. As children grow older they begin to notice that some of their trace making resembles something from the real world, which allows them to believe that they can represent life, so their drawing begins to develop, although at this point, children's drawings are far from reality and do not yet resemble the original object from the researcher's standpoint.

Luquet (1927) argues that children's drawing develops through stages of realism. There is no realism in their initial scribbles, as there is nothing in them which can be compared to something in the real world, even if the child may have wished to represent something. The scribbles appear random and unplanned. However, as children grow older, there comes a time where they interpret their scribble as something other than simply lines. For example, they may see lines that look a little like a car within a larger scribble. This is the beginning of what Luquet calls 'Fortuitous realism' (The First Stage), which is the first stage when the child begins noticing similarities between their scribbles and an object from environment. For example, in an observational study, Luquet refers to a 2-year-old girl who apparently noticed a similarity between her scribbles and a bird and so added two vertical lines for legs (Luquet, 1927). Luquet interprets this as the child having not set out to make a realistic drawing, but later (post-hoc) making a realistic interpretation of it.

Luquet proposes that children will happily go on scribbling in later drawings without intending to represent anything. However, they will increasingly notice chance similarities with real objects as time goes by. In this way, little by little, the child becomes an intentional 'realist', meaning that they begin to draw with the intention from the start of representing something. An adult observer, however, may still at this stage experience difficulty in perceiving any likeness between the drawing and reality. It may be argued that there are some issues with Luquet's approach at these early stages of drawing ability, in that it is not clear how the researcher can reliably ascertain what intention was in the child's mind when drawing. However, this is not so problematic at the later stages, which are of concern in the current study.

Once the child becomes more consistent in drawing with a representational intention, the drawings initially have the characteristic which Luquet terms 'Failed realism' (The Second Stage). At this stage, the child's drawings are recognizable to a researcher, and there can be no doubt about the child's intention to draw something, but they still lack realistic features due to motor and cognitive immaturity, which the child is struggling to overcome. This leads the child to try to include some details in their representations, but quite clearly demonstrates 'technical graphic problems of poor position, orientation and proportion' (p 12). For example, the child often draws the human figure in 'tadpole' form, where the torso is missing and the arms and legs are drawn inappropriately from the head. Luquet (1927) uses the term 'synthetic incapacity' to describe the lack of proper relations between the individual elements in the drawing. Piaget and Inhelder (1956), following Luquet, similarly described a progression characterized at age 3 to 4 by synthetic incapacity in which children draw bounded objects (e.g., a closed circle) but ignore size and shape, and often are incapable of capturing the spatial relationships in any objects.

It is through a gradual process that the child increases the number of details in what is drawn, as synthetic incapacity decreases, allowing the drawing to become more characteristic of the third stage of realism, 'intellectual realism', which is the first stage which is of central concern in my study. 'Intellectual realism' is evidenced when the drawings are based on many of the essential characteristics of a real object and represent it in its characteristic individual shape. The child is also more skilled at synthesizing the parts. Human figures may, for example, begin to be drawn clothed and with arms and legs from the body. The ability to draw the details in their usual and generic shape is described by Luquet (1927) as 'exemplarity'.

An important characteristic of children's drawing at this stage, however, is as follows. In reality, the shape and visibility of an object's constituent parts changes as an observer moves around it, to view it from different angles, sometimes causing certain parts to appear partially or completely occluded. However, children at this stage do not use the techniques required to draw the objectively 'real' or visible picture. Instead, children portray the features that they believe to be important aspects of the object, regardless of what can actually be seen (See Figure 4.3). The techniques used include separation of the details of the object, transparency, drawing some features from an air-view plan, and folding out certain parts of the topic (such as rooms in a house). Using these methods, the child may produce an "impossible" drawing, where the object or scene is drawn from several different perspectives. According to Luquet, children are not basing their drawing on an external visual model (i.e. how an object or scene appears from a particular standpoint), but rather an internal model (what features of the object or scene the child regards as important or definitive).

Some researchers have criticized Luquet due to the fact that his approach was based on his direct observations of children's drawings without any instructions, rather than experimental manipulation. However, examples of intellectual realism are not only found in children's spontaneous drawings. Jolley (1991), for example, asked children to draw a man riding on a horse and a man in a boat from three-dimensional scenes presented to them with some features of the man occluded (Jolley, 1991; see also Cox, 1992, 2005). The findings were interesting, since, for example, the drawing of a 7-year-old girl showed the man and the horse with no occlusion of one by the other. In other words, she used 'transparency' so that both of the man's legs were seen. Likewise, a profile view of a horse was drawn, while the man was drawn in frontal view. Hence, both drawings seem to be based on the child's knowledge or internal model of the main features of the objects which were to be drawn, and the perspective from which they are usually drawn separately (e.g., horse in profile and person frontal), regardless of how they appeared in the scene that they were asked to represent. Hence their representations of the scenes were not accurate depictions of them as seen.

The dominance of children's internal model changes over time, however, leading to the inclusion of more appropriate features in drawings of scenes such as those above (Jolley, 2010). Luquet argues that children's realisation grows that their representations do not always capture how the objects and scenes appear in reality on a particular occasion. That is, they do not look visually realistic. This begins to bother children, which leads them to attempt to draw in a style with more 'visual realism' (Stage 4). There is a decreased use of separation and transparency. The drawings may include fewer folding-out techniques and there is an increased use of occlusion, suppression of details, and of perspective, which are graphic techniques associated with the last stage.

At this final stage, children begin to draw only what is visible, instead of relying on internal models or mental categories of each of the objects in a scene. For example, human figure representations begin to take the form of an individual that they are asked to draw, rather than a generic drawing used for all humans. According to Luquet (1927), even though children reach this final stage eventually, the laws of perspective still need to be learned and few children actually succeed in fully acquiring the conventions of visual realism. Hence, although children ultimately enter the stage of visual realism, Luquet argues that this stage is more a stage of intention rather than achievement. As Luquet points out, even many adults fail to draw in a fully visually realistic style. Luquet notes that many children stop drawing between 10 and 12 years of age (and this is still evident today), and that it is easy to find adult drawings similar to those produced by 12-year-olds and even those that use the intellectual realism system.

Critics of Luquet’s model, especially with respect to the last two stages, which are of current concern, have pointed out that details of the research conditions in which drawings are elicited from children may have a considerable effect on their inclination to intellectual or visual realism. This therefore suggests that both styles may co-exist in the child, rather than that the child progresses from one to the other. For example, Lewis, Russell and Berridge (1993) found that the way in which the object to be drawn was named by the researcher had an effect on how it was drawn. In a study where the object to be drawn was a transparent glass mug, previously inspected by the children, but presented to be drawn with the handle turned away, labelling the object to be drawn as a 'glass' increased 5-year-olds use of visually realistic to 73%, compared to 52% when calling it 'this', and even less (31%) when naming it 'mug'. The result can be interpreted as showing that the children’s use of intellectual realism, referring to canonical features of the object, was prompted by the word used by the researcher, since a glass does not typically have a handle, while a mug does.

Furthermore, when two cups were placed in front of the child, one with the handle hidden from view and the other visible, 77% of 5- and 6-year-olds drew visually realistically compared to 59% when a single cup was placed in front of them with the handle out of sight (Davis, 1983). Furthermore, Davis and Bentley (1984) asked children to draw a cup with its handle visible before drawing a cup with an occluded handle. This again increased production of a visually realistic drawing of the second cup. Again, when the paired cup task was presented first followed by the single cup task, more children produced visually realistic drawings as opposed to the reverse order of presentation (Davis, 1983). Based on such findings, Davis (1983) and Davis and Bentley (1984) concluded that both providing a contrast within a task or between tasks, and the order of tasks, had an effect on children's awareness of the precise task demands, and hence how they drew.

Other studies have also shown how the removal of a defining feature in the exemplar of an object used in a study can have an effect. Freeman and Janikoun (1972) established that children understand a handle as a defining feature of a cup by asking children to draw an imagined cup. They always included the handle, showing that the handle is for them the defining feature of a cup. Taylor and Bacharach (1982) then presented a cup with a broken handle, thus lacking this defining feature of a cup. Five- and 8-year-olds produced visually realistic drawings even when the broken handle was occluded which suggests that removal of defining features leads to an increase in visual realism. Finally, increasing the explicitness of instructions, such as by stressing to the child that they should draw from their point of view, increased the production of visual realism in children between the ages of 4 and 8 years (Barrett & Bridson, 1983). Light and Humphreys (1981) believe that standard instruction to "make the best drawing that you can" is seen as ambiguous and may actually encourage intellectual realism, suggesting that such instructions do not provide enough information to ensure the correct interpretation of the task demands.

In my study, these issues were dealt with predominantly by making standard choices of task conditions. Thus, I used only normal exemplars of the object (balls and mugs), without defining features like handles being missing or unusual materials used (e.g. a glass mug). I only used the usual names for the objects (*mug* and *balls*). The instructions also took the current standard form, asking participants to draw exactly what they could see from where they were sitting, thus prompting visual realism rather than encouraging intellectual realism.

4.1.2 Age of transition from intellectual to visual realism

I turn now to the age at which the transition may occur from drawing predominantly with intellectual realism to drawing mainly with visual realism, bearing in mind that this must be a considered to be a flexible age, dependent upon the precise task conditions under which the measurement is made (4.1.1).

According to Luquet (1913), between the ages of 5 and 8 years, children produce intellectually realistic drawings. However, children begin to draw visually realistically *after* the age of 8 by suppressing this knowledge and only drawing from their viewpoint of the model placed before them. Cox (1991) however reports children as able to overcome this early strategy *between* the ages of 5 and 8 years.

In fact, even discounting the effects of task conditions described in 4.1.1, it further emerges that the age of transition is influenced by the precise objects that are required to be drawn. Thus, a ball drawing task has been found to be more difficult than a cup drawing task (and both these objects were used in my study). Whilst almost all (94%) of 7-year-olds could omit the handle of a cup, only 54% were able to use hidden-line elimination for a partially occluded ball (Chen & Holman, 1989). It is possible however that the contrast effect used in this study led to that significant difference (Davis, 1983). On the other hand, it is possible that the instructions were less clear on the ball task, leading to poorer performance. Freeman (1980) however supported the above finding by demonstrating that visually realistic ball drawings are produced until the age of 9.

More recently, Ford and Rees (2008) used a range of tasks involving and cups and mugs, but not balls, with (amongst others) typical children aged 3 years to 7-years-5-months. Relevant to my concerns, this age group exhibited only 22% visual realism on the task with a single mug with handle not visible. They found no significant age differences. This is therefore consistent with the view that the transition from intellectual to visual realism has not progressed far in this age range.

Given the above estimates of the age of transition, it was felt appropriate in the current study to employ the technique of partial occlusion, with a mug task and a two balls task, to investigate the shift between intellectual and visual realism in the drawings of children aged from 2-years-6-months to 9 years. A partial occlusion model is where an object is only partly visible or partly hidden behind another object. Intellectual realism is evidenced if, when the model is presented to young children, the partly occluded object tends to be drawn as if it were fully shown. Hence Study 3 spanned this age range.

4.1.3 The developmental trajectory of visual realism

Luquet and much other research in this area tends to assume without question that the child's drawing ability progresses in a linear, or at least monotonic, way through various stages, or along a continuum. This implies a progression only *from* intellectual realism *to* visual realism, not the reverse. There have however recently arisen some signs that this may not be the case.

First, it must be noted that U-shaped patterns are not uncommon in child development in general (Morse, Belpaeme, Cangelosi & Floccia, 2010). The most commonly cited examples are linguistic, such as the phenomenon of young children producing irregular forms like *mice* and *bought* at an early age, then going through a stage of saying *mouses* and *buyed*, before returning to the adult irregular forms (although this progression is nowadays seen as in detail more complex: Lust, 2006). As Morse and colleagues (2010) say, however, the "U-shaped curve phenomena appear to be independent from any particular task or modality" (op. cit., p. 3034). A general characterization of the mechanism underlying U-shaped child development is offered by Morse and colleagues (2010), who see it as essentially falling into three phases. At the start, the child's ability operates "in an isolated way relying on local information only" (e.g. rote learning the plural form *mice*) and the child is successful on a relevant task. Later, accumulation of additional information leads to refinement or reorganisation of ability (e.g. learning and generalising the rule that, to make a plural, you add /s,z/ to the singular form), during which time performance is disrupted, and the child scores lower on the task (sometimes saying *mouses*). Third "eventually this reorganization will conclude and the system will stabilize with new competences and high performance once again" (p. 3036), so the child once again scores high on the relevant task (e.g. having learned that the rule for plurals has some exceptions, such as *mice*). Thus, the two high points of the U, although both indicating success on some task, in this model do not at all indicate that the same underlying ability or cognitive organisation is being depended upon to produce that performance at the two high points.

This could be applied to realism in drawing skills if the very young child is thought of as first drawing based on local information in the form of the specific exemplars of objects such as mugs as they see them (visual realism). Possibly this external information is prepotent for the simple reason that at the age of 2 to 3 years they are still developing their mental categories for common objects. Hence their focus is still on the real world input from which they build such mental representations rather than on the mental representations themselves. Later, as they see more examples of mugs, they develop established general concepts or cognitive categories for things like mugs incorporating certain typical attributes, independent of the specific instances seen. This internal 'intellectual' information then interferes (following the Morse model) with their performance in tasks where they are actually asked to draw what they see. Temporarily their newly developed internal model of the world becomes pre-potent, and they prefer it to the world as it actually appears. Finally, their category development matures and they learn to operate both with the general mental categories and with the specific exemplars of those categories as perceived in daily life, without interference between one and the other, and use those two types of information appropriately when one of them is called for and not the other. That is to say that visual realism again becomes pre-potent and intellectual realism is inhibited (Ford & Rees, 2008; Luquet, 1927/2001), albeit in a different cognitive landscape from that which existed at the 'early visual' stage, in accordance with the Morse model.

Next there are some studies which have in fact found U-shapes in the domain of drawing research. Davis (1997) for example studied the expressive drawing produced across an age range running from 5 years to adult. Pictures were elicited representing emotions such as anger, happiness and sadness. On almost all measures of quality used, the 5-year-olds and the adult artists scored higher compared with other ages in between, including teenagers and adult non-artists. This study, then, yielded a U-shaped pattern with, in age terms, a very long low middle component. Although this does not relate directly to the scale of realism with which the present study is concerned, and involves a vastly different age range, it does show that drawing skill can evidence U-shaped progression.

Davis (1997) explains this pattern as due to the young children and the adult artists producing more truly expressive drawings while the ages in between were hampered by conventionalization of their representations (e.g. use of conventions such as visual metaphor and metonymy). This does not mean, then, that the 5-year-olds and the adult artists are seen as identical. As implied by the Morse explanation above, the child is seen as producing good expressive drawings in a local way through "understanding ….emotion …in terms of him or herself" (Davis, 1997, p. 155), in other words, spontaneously and not affected by artistic conventions, which they have not yet begun to learn. The adult artist, by contrast, has been through a process of refinement and reorganization, involving learning the roles of metaphor and the like in drawing pictures, which the intervening age groups are in process of learning but have not yet learnt how to handle appropriately. The adult artist, however, has emerged "consciously employing the same lines and form that the boundariless young child exhibits": "the artist breaks down the boundaries between symbol and referent and reclaims the lack of differentiation which is the gift …. of the youngest child".

In Study 1 (Chapter 2), recall that I found, somewhat unexpectedly, a negative relationship of all predictors, including age, with visual realism as the dependent. This called for explanation, since the usual assumption by researchers, including Luquet, has been that older age would lead children to draw more visually realistically, with improvement progressing in a more or less linear fashion, i.e. approximating ever more closely to the adult mode of drawing. Interpreted in terms of more recent discussion, it would be said that greater IC enables children to inhibit their early tendency to intellectual realism and adopt a visually realistic way of drawing (Ebersbach et al., 2011; Riggs et al., 2013). The findings of Study 1, however, appeared to be the opposite of this.

I suggested, however (Chapter 2 Section 2.3.4) that a U-shaped development of realism could account for this. As seen in 4.1.2, the shift from intellectual realism to visual realism occurs only around eight years of age, yet the participants in Study 1 were in fact all considerably below that age (3-4 years old). Hence if that shift around age 8 represents the 'right-hand side' of what is in fact a U-shaped pattern of development, it would not be unexpected to find children in the age range of Study 1 evidencing the falling pattern of the left-hand side of the U, rather than the rising pattern of the right-hand side of it. In that scenario the turning point of the U-might be expected to occur after the age range of Study 1, around age 5 or 6, after which visual realism would rise towards mastery at age 8. It was precisely the purpose of

Study 3 to see if such is indeed the case by measuring realism in children's drawing across a range from age 2 years 6 months to age 8 years six months.

Furthermore, the hypothesis that a U-shaped pattern applies to realism development does admit of a possible interpretation. It is not just a suggestion, which might account for a pattern of scores, but lacks any plausible explanation. As described above, it can be interpreted as a particular instance of a mechanism of the type which Morse and colleagues (2010) suggest generally underlies U-shaped development. The relationship with IC is also explicable. IC may be seen as developing predominantly in a linear fashion, with age. However, as the child develops, a succession of changes occurs in the child's cognitive make-up which leads to a series of pre-potent responses being adopted which the child's IC has to inhibit in turn in order for the child to develop normally. In the domain of drawing, the child initially is inclined to scribble and this is the first response that IC has to act upon to enable representational drawing to emerge. At that point the pre-potent drawing response of the child becomes to draw visually what they see, rather than to rely on whatever cognitive categories they possess at that stage for objects. They are still (in the Morse et al. view) at a stage where the child performs tasks in a more isolated and local way, in a cognitive world with fewer developed abilities. The child, however, is at this point establishing more developed cognitive categories for objects in the world, independent of their local exemplars in daily life, and for a time (the bottom of the U), the child's pre-potent response becomes to draw these (intellectual realism). IC then has to operate again to suppress this and allow visual realism to emerge a second time.

Having made the above case for a possible U-shaped development of drawing realism, it must be said, however, that the evidence for it in existing studies is lacking, even in studies which potentially might have revealed it. Take, as an example, Ford and Rees (2008), which included measuring intellectual realism of pictures produced by typical children across an age range of 3 years 7 months to 7 years 5 months. This then might have been expected to show some signs of a U-shape in development, if one exists, yet none was reported. There are many possible reasons for this. One is that, of course, the aims of that study were not to investigate such a possibility: the focus was on differences between groups of typical and autistic children. Hence correlations with age are not explored, so the researchers may not have noticed any such pattern, even if it was there. Again, the sample size of typical children was small (n = 27), which could well have led to no significant quadratic trend being identifiable, even if it had been tested for. It is also possible that, in studies which covered the requisite age range and measured realism, a U-shaped development may have been evidenced, and even noticed by the researchers, but that, given the prevalence of the assumption that such development is linear (e.g. Jolley & Rose, 2008), it was deemed inconvenient rather than a crucial observation, so not reported.

4.1.4 Tasks used to measure drawing skill

In Study 1, like many other researchers, I measured children's drawing ability, including realism, by asking children to draw. It was observed, however that a considerable amount of the children's responses had to be classified as scribbling (59% of house drawings and 12% of person drawings). While this contributed usefully to my measure of figurative representation, it was not helpful for my measure of realism, since scribbles did not tell us whether what was drawn was either visual or intellectual. Scribbles had to be regarded as neutral, or similar to non-responses, with respect to this measure. Since in Study 3 I included children of a lower age even than those in Study 1, as well as much older children, it therefore seemed prudent to search the literature for other means of measurement of realism which could be used with very young children and avoid such a loss of usable data. A way forward presented itself, in the form of the use of receptive picture comprehension tasks. DeLoache, Strauss and Maynard (1979), for example, long ago found that even babies, who clearly could not produce recognisable drawings, could nevertheless successfully perceive the similarity between an object and its picture.

Other studies have demonstrated that children of an age range 3 to 9 years, who were able to produce a picture with some degree of figurative representation, when offered a choice of pictures, did tend to choose the picture which matched the features of the picture they would produce (Moore, 1986; Brooks et al., 1988; Littleton, 1991). Other studies, however, have demonstrated some tendency for a lag, in the sense that children in selection tasks prefer pictures which are a little ahead of what they are able to produce themselves in terms of typical drawing development (Kosslyn, Heldmeyer, & Locklear, 1977; Fayol, Barrouillet, & Chevrot, 1995). Although some of these early studies have design flaws (Jolley & Rose, 2008), better recent studies generally confirm that drawing production and receptive selection follow the same trajectory, but with some lag (Jolley, Knox and Wainwright, 2001).

Given the above findings, and the prior use of picture selection tasks specifically for measuring realism (e.g. Jolley & Rose, 2008), I therefore adopted a task of this sort in Study 3. Children less than 4 years old are unlikely to be able to draw, although if the U hypothesis is correct, they would *like* to draw visually realistic pictures, but lack the motor control to do so. Thus, by the time they are able to draw, they often have already reached the stage of drawing intellectually realistic pictures. This means that it is very difficult to measure visual realism in very young children. Nevertheless, using a selection task can help us to see this U-shaped pattern, if it exists.

Although all such tasks involve the child pointing to a picture rather than drawing one, there remains an issue of precisely what form of selection task is to be preferred. Ones found in the literature vary in the number of pictures chosen to select from and the precise instructions. In Taguchi and Hirai (2003), for example, there were five pictures and the instructions were to choose the one “which looks closest to what you want to draw” (p. 911). Brooks and colleagues (1988), on the other hand, offered 8 pictures and instructed children to choose the best drawing. Those studies were concerned with wider aspects of drawing ability than just realism, however.

In the current study, since only realism was in focus, only two pictures were relevant, relative to a particular scene on display: one showing a visually realistic representation of what was displayed, such as a mug with the handle turned away, and the other the intellectually realistic version, with the handle included.

4.1.5 Overview of Study 3

In this study, the focus was on the intellectual and visual realism stages of child drawing development, and the precise pattern of development of these when plotted against age. Thus it was designed to replicate and expand upon the finding of a negative relationship between age and Visual Realism in Study 1. Children between the ages of 2 years six months and 8 years six months were tested since previous studies suggest that any transitions between these two realism styles occur within this age range. Hence, such a range was needed so as to achieve the aim of establishing whether the development of Visual Realism in fact follows a U-shaped pattern in child development. Such a pattern would indicate that children may start with visual realism, and then move to intellectual realism and then back to visual realism in their drawings. In detail, I hypothesised that children’s age related progression with respect to realism of drawing would follow a pattern broadly in three stages. Initially, corresponding to the left hand side of a U, younger children (up to around 4 years old) would make greater use of visual than intellectual realism (provided they did not just scribble or in other ways produce a drawing which gave no evidence of either). Next, corresponding to the low point of a U (perhaps 4 to 6 years old), children would evidence greater reliance on intellectual realism. Finally, corresponding to the right hand side of a U (approaching 8 years old), children would revert to dominance of visual realism.

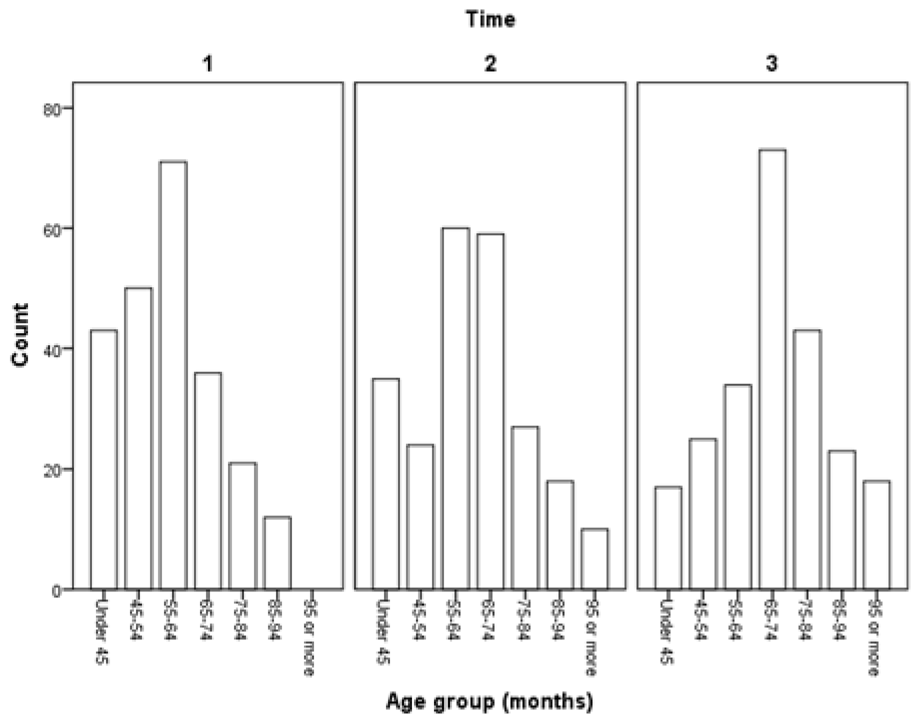
4.2 Method

4.2.1 Participants

As in the previous studies, and for similar reasons, the target was 100 participants, but I was aware that in a longitudinal study considerable attrition of participants had to be anticipated. Therefore I initially targeted a much larger sample. Two-hundred and thirty-three children were assessed at the start of the Study but, due to attrition, by the third occasion when data was gathered, the total sample was 164. At the start of the study approximately half the children were between the ages of 2½ and 4¾ years of age (n = 115), and half between the ages of 4¾ and 7½ (n = 118). Children were recruited from preschools or nurseries in the Riyadh region of Saudi Arabia. Although all were Saudi, some of the children normally spoke English whilst others spoke Arabic. None of the children were reported as having any behavioural or learning difficulties. Although the sample of children was predominantly white-Arabian, their backgrounds varied in terms of socio-economic status. As in Study 1, children were not eliminated if they failed to produce a recognisable drawing, although some were inevitably eliminated who produced no representational drawings at all out of the four trials (see further 4.2.5).

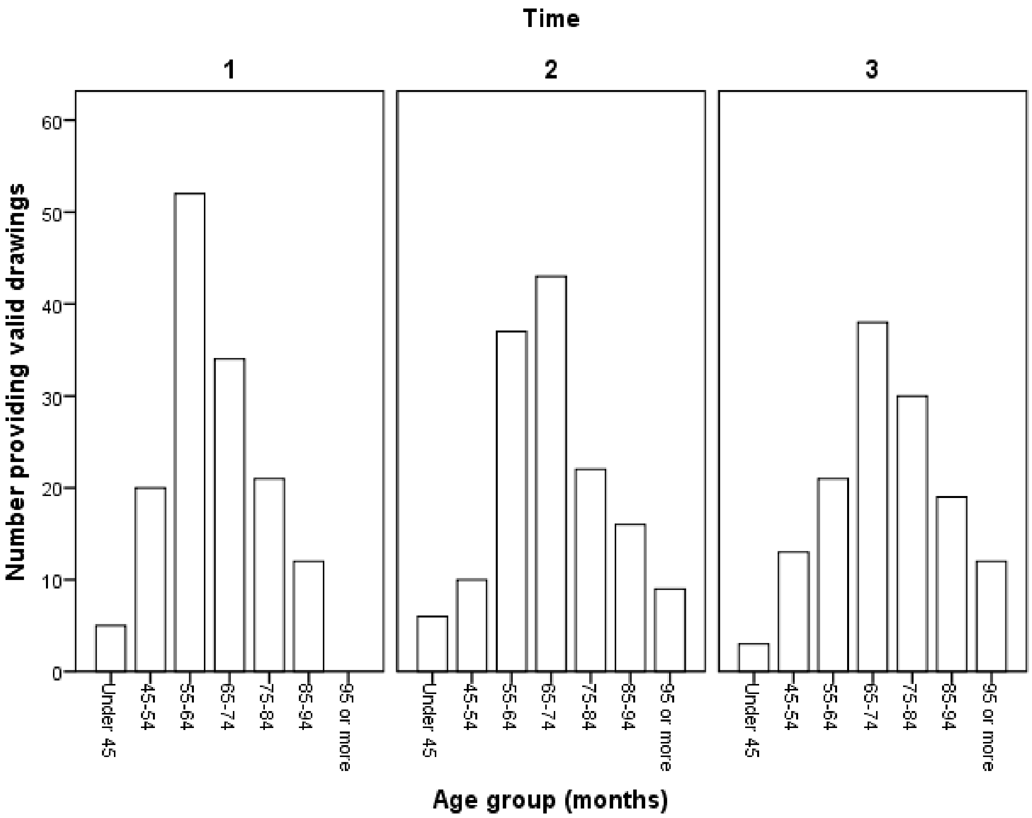
For the purposes of graphic presentation, I divided the participants into age bands, although for statistical tests age was treated as a continuous variable of individual participant ages. Figure 4.1 shows the distribution of participants across age bands.

Figure 4.1. Numbers of children in different age bands in Study 3 at each time-point.



Besides attrition, the analysable data was reduced by children not responding, or responding with scribbles (which I could not analyse with respect to visual or intellectual realism see 4.2.5). Hence the usable responses were smaller numbers (e.g. Figure 4.2). In fact only 83 children provided valid drawings on all three occasions. On the less demanding selection task, however, 148 provided responses on all three occasions. It is particularly noticeable that in the youngest age band, which is crucial for establishing the left-hand side of any U-shaped distribution, the rate of valid drawing response was quite low despite the quite large numbers of children recruited. This should be borne in mind when interpreting the findings.

Figure 4.2. Numbers of children giving valid responses on the drawing task at each time-point.



4.2.2 Design

This study follows a sequential design, where the variable of time is represented both by a covariate (age of child on each of three occasions when data was gathered), and by a longitudinal component (time: three data gathering occasions over one year). Data collection involved a total of three occasions of measurement, with two equal intervals of 6 months. This study also included gender of child. The dependent variable of intellectual versus visual realism of drawing was measured in two ways: by the children producing drawings of objects presented and by the children selecting drawings for objects presented.

4.2.3 Materials

The study involved two tasks, the drawing and the selection task. The following materials were used. *Drawing tasks:* plain A4 paper, pencil, a mug, two balls, a block and a toy man. *Selection tasks:* the same objects as for Drawing (apart from A4 paper and pencil). In addition, there was a book consisting of four pages, with each page showing two versions of the objects placed in front of the children. One picture consisted of a visual realism representation, such as a mug with an occluded handle, and the other demonstrated intellectual realism, such as the mug with the handle. These pictures had been drawn in pencil on white paper by an artist expressly for the study, and represented the precise objects used in the tasks.

4.2.4 Procedure and scoring

Age at the start of the study was ascertained from teacher reports, and gender by researcher observation. Realism was measured through 8 tasks: four drawing tasks and four picture selection tasks. Informed consent had previously been obtained from the parents of participants and the school authorities. The measurement sessions involved two people, the researcher (E1) and a PhD student with experience of these tasks (E2). E1 administered the tasks while E2 recorded the children's responses. All the children were tested individually, in the morning, either in a separate room from their classroom, or in a quiet corner of their classroom. E2 sat next to the child to record the responses while E1 sat across the table. The children were asked for their help, and told that they were going to play some fun games. The eight tasks were administered to each child in two separate sessions on same day, each session lasting about 10-20 minutes (longer for drawing than for selection). There was no time limit for the participant to select a picture or to draw the objects. Tasks followed a fixed order, from simpler to more demanding, as shown in Table 4.1.

The first session consisted of four drawing tasks. The second session consisted of the four selection tasks. Drawing was elicited first because the same objects were used in both the drawing and selection tasks, and if the selection task had been presented first, this would have offered them models to recall and copy in a later drawing task.

The standard instructions were used for both drawing and selecting tasks. The researcher asked the child to draw or select a picture of the model "exactly as you can see it from where you are sitting". Responses for the drawing tasks were collected for later analysis. All responses on the selection tasks (visual realism choice versus intellectual realism choice) were recorded on paper by E2.

4.2.4.1 Drawing tasks. All the drawing tasks were presented in the first session. Children were given an A4 paper and a pencil for each task. In each task, if the children asked any questions about the drawing they were simply told to do their best in drawing. With respect to scoring, on each task a score of 1 was given if the children managed to draw the true representation of what they saw in front of them, with respect to what was hidden. Representation of irrelevant features such as the smiley face or shape of the mug was not considered. A score of 0 was given if the children drew what they knew instead of what they saw in front of them, with respect to what was hidden (see further 4.2.5). Examples of responses produced are shown in Figure 4.3.

The tasks were administered and scored individually as follows. For the occluded-handle task, a mug with a smiley face design on the outside was placed on the table in front of the child in such a way that the smiley face was visible to the child and the handle not visible. Children were then instructed to draw the picture of the mug. A score of one was given if the handle was correctly omitted. A score of zero was given if the handle was not omitted. The occluded-ball task involved two balls. One ball had a smiley face design outside and the other ball not. These two balls were placed in front of the child on the table, with one ball with the smiley face half-occluded by the other. Children were asked to draw what they see. A score of 1 was given if one ball was drawn behind the other. A score of 0 was given if two balls were drawn in full together.

For the occluded ball behind block task children were asked to draw a picture of a ball that was placed behind a block situated on the table in front of them. This ball included a smiley face design outside and only the top of the ball could be seen behind the block. A score of 1 was given if the ball was drawn behind the block. A score of 0 was given if the ball was drawn separately from the block. For the occluded man task: a model of a man was placed behind a block in such a way that only his head could be seen. Once again, children were asked to draw the picture of the man and the block. A score of 1 was given if the man was drawn behind the block. A score of 0 was given if the man was drawn separately from the block.

4.2.4.2 Selection tasks. There were a total of four selection tasks, which were presented in a fixed order, the same as for the corresponding drawing tasks (See Table 4.1). Children were presented in turn with four pages of a booklet, each page showing two pictures of the objects placed in front of them on the table in the same way as for the drawing tasks. Two versions of the objects were shown in the pictures on each page. One version showed a visual realism representation, whilst the other demonstrated an intellectual realism version. For two of the tasks the visual representation appeared in the left-hand picture on the page, and for two in the right-hand picture. For each task, the researcher first drew the child's attention to the objects that she had just set up and then asked the child to point to the picture that looked like what they saw.

Again, a score of 1 was given on each of the selection tasks if the children pointed to the picture that looked like what they saw in front of them (visual realism). A score of 0 was given if the children selected the picture which showed complete objects separately (intellectual realism). The tasks were administered in detail as follows. For the occluded-handle task, children were presented with a page which contained two pictures of the objects. One version omitted the handle and showed a smiley face visible outside the mug. The other picture showed a visible handle with a smiley face design outside. Children were then instructed to select the picture that looked like what they saw. In the occluded-ball task one of the pictures included one ball half-occluded by the other, and the other picture had two separate balls. Then children were asked to select the picture that looked like what they saw from where they were seated.

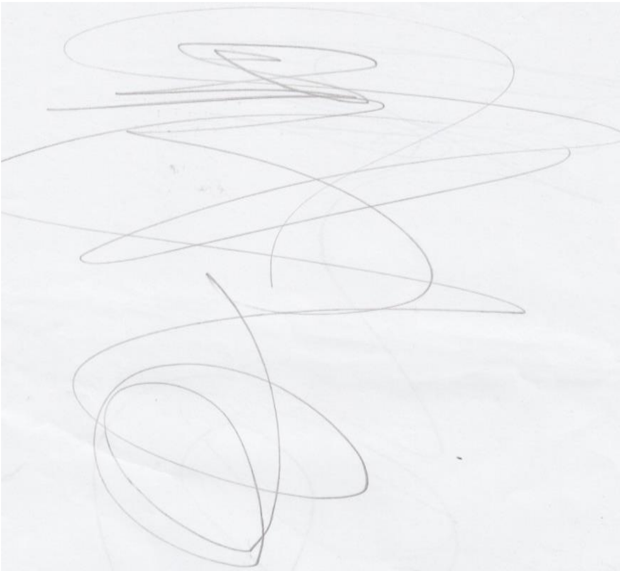
In the occluded ball behind block task children were asked to select either a picture of a ball that was placed behind a block situated on the table in front of them, where only the top of the ball could be seen behind the block, or a picture of a block and a ball one below the other but separated. The ball again had a smiley face on it. Finally, in the occluded man task children were presented with two pictures, one of which showed only the head of the man behind the block, while the other picture showed a whole man separately above the block. Once again, children were asked to select the picture that looked like what they were seeing in front of them.

Table 4.1. Task order in Study 3

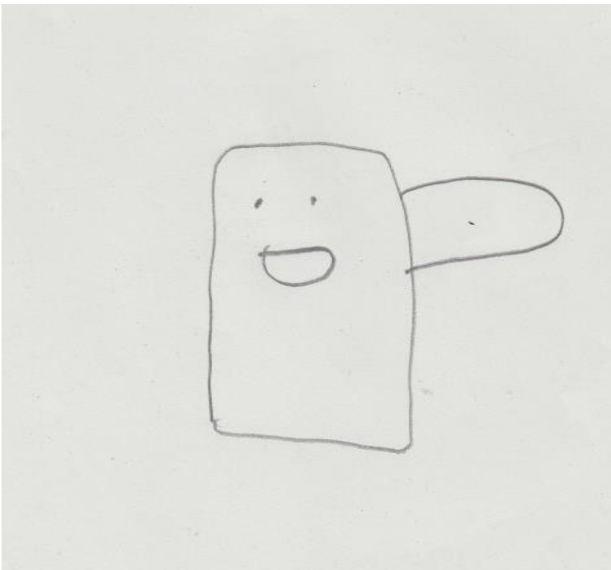
Drawing tasks – Session 1	**Selection tasks – Session 2**
A mug (occluded-handle task)	A mug (occluded-handle task)
Two balls (occluded-ball task)	Two balls (occluded-ball task)
Ball & block (occluded-ball behind block task)	Ball & block (occluded-ball behind block task)
Man & block (occluded-man behind block task)	Man & block (occluded-man behind block task)

Figure 4.3. Seven examples from the study data, illustrating the three types of children's drawing relevant to the VR scale.

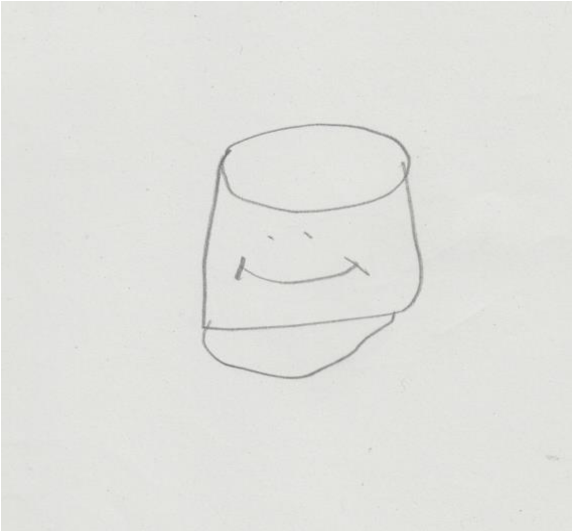
1. **A scribble.**



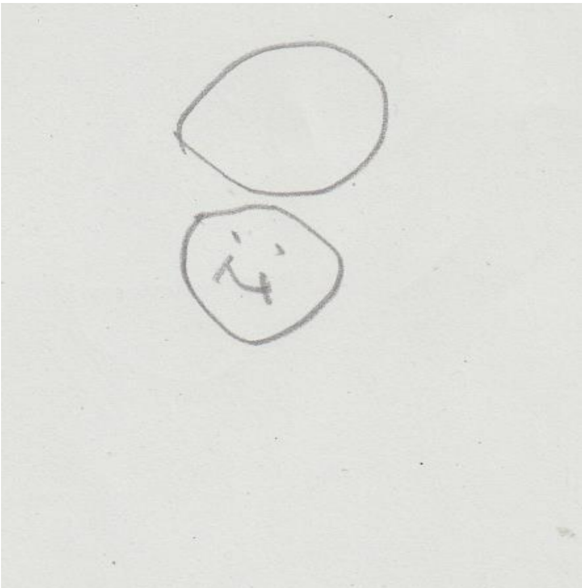
2. **Mug with hidden handle drawn overtly (intellectual realism).**



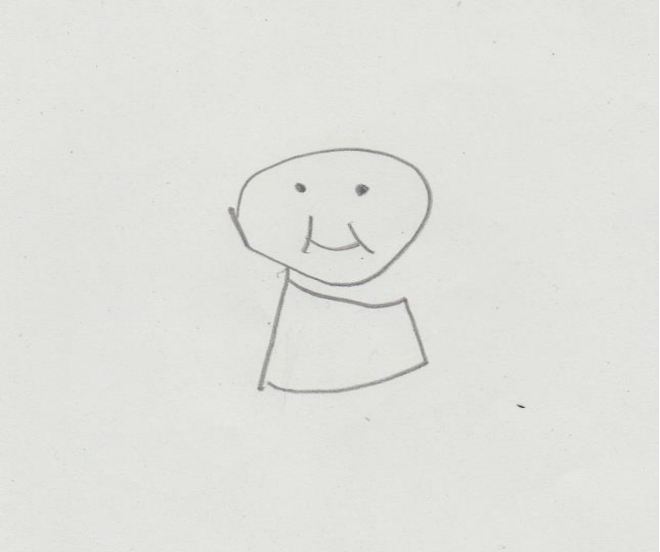
3. Mug drawn as seen, with hidden handle omitted (visual realism).



4. Overlapping balls drawn separately (intellectual realism).

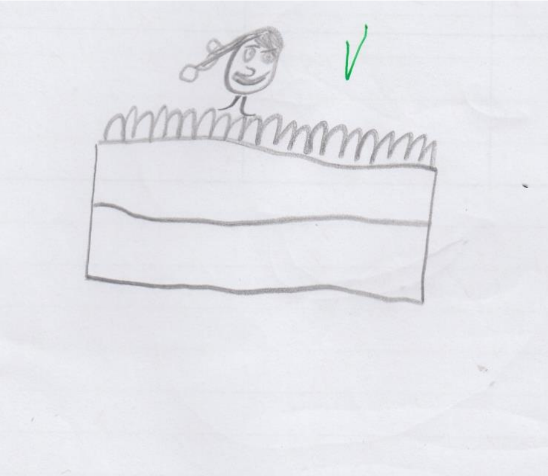


5. Ball behind block drawn separately (intellectual realism).



6. Man behind a block drawn in full (intellectual realism).

7. Man behind a block drawn as seen partly hidden (visual realism).



4.2.5 Overall score calculation

In this study, it was required to assess the extent to which each child exhibited visual versus intellectual realism. There were however many instances in the drawing tasks of children missing out task items or drawing only one of the two objects in view, or, especially, producing scribbles which gave no evidence of either kind of realism. These were totalled for each child on each task at each data gathering time point and used in some analyses. In the selection tasks, however there were almost no missing responses, so they were treated as negligible. The focal issue then was, how best in the drawing production tasks to quantify children's degree of visual realism for the purposes of the statistical analyses, in the light of the missing/scribble instances. There is more than one way of doing this, of which I describe here three.

The first method, which I initially considered, since I had used it in Study 1, was to award each child on each task 1 for each visual realism response, -1 for each intellectual realism response, and zero for a missing or scribble response. The 4 responses for a given task would then be totalled, giving a child a score between -4 and +4, with higher scores indicating more visually realistic response. This, however, in effect treated a missing or scribble response as actually closer to a visually realistic response than an intellectually realistic response was, and hence, on reflection, was considered not to validly capture what I intended to measure. For instance, a child who produced three visually realistic responses and one intellectually realistic one would gain a score of 3+(-1)=2 but a child who produced three visually realistic responses and one scribble would gain a score of 3+0=3, which would unwarrantedly suggest that the child favoured visual realism to a greater extent. In reality, a missing or scribble response should be treated simply as uninformative as to which type of realism is indicated. What was needed, then, was a scoring system that treated scribbles/missing instances in a fairer way, as not really indicating anything definite about either sort of realism.

A second method which was suggested simply took the view that each child had four opportunities to evidence visual realism, so their visual realism score was simply how many of those four opportunities evidence visual realism, as compared with anything else (whether a scribble, missing response, or intellectual realism response), giving a scale 0 to 4. (Correspondingly a child could also obtain a raw number out of 4 for scribble/missing responses, and another for intellectually realistic responses.) This approach to quantifying visually realistic responses therefore does not appear to distinguish between a scribble/missing response and a drawing with intellectual realism: they all just count as non-visually realistic responses. By this method, however, a child who produced one scribble, two visually realistic drawings and one intellectually realistic drawing scored 2 for visual realism and a child who produced no scribbles/missing responses, two visually realistic drawings and two intellectually realistic drawings also scored 2 for visual realism. Once again this did not capture what I wanted, since a scribble was in this case in effect being counted as the same as an intellectually realistic drawing, which it clearly is not.

The third method, which I adopted, therefore took the view that missing or scribble responses (or instances where only one of two objects presented was drawn) give no information as to what kind of realism the child was drawing with. Hence, scores for visual realism were calculated for each child on the drawing production tasks excluding all such missing/scribble responses as invalid. For each valid drawing produced, a visually realistic response then scored 1, and an intellectually realistic one zero, and the overall 'total' score was calculated as the mean score out of the total number of valid responses. This mean score represents the proportion of valid (representational) drawings or selections, out of the four available, which exhibited visual rather than intellectual realism, with scribbles treated in the same way as omitted responses. Thus, the scale ran from 0 to 1. For instance, a child who produced one scribble, two visually realistic drawings and one intellectually realistic drawing scored 2/3 = .67 for visual realism. A child who produced no scribbles/missing responses, two visually realistic drawings and two intellectually realistic drawings scored 2/4 = .50 for visual realism.

Consistency between the individual drawing task items was demonstrated separately at each of the three times with item-total correlations, i.e. the correlations between children's scores for a single item (one drawing or selection) with their total scores for all four items (the four drawings or four selections). The drawing task reliabilities on this measure are in Table 4.2. The correlations are all acceptable, and those for items 2, 3, and 4 are impressively high. The lower correlations for item 1 could be due just to the fact that the first item was the first item, and so served as, in effect, a practice item. Alternatively, it could be due to the fact that the first item was always the item featuring the mug with the hidden handle, and possibly something about this specific task led to greater inconsistency in response. The same analysis for the selection task yielded the mostly slightly lower but still acceptable correlations seen in Table 4.3.

Table 4.2. Item - total correlations in the drawing task (with *n*).

	Time 1	**Time 2**	**Time 3**
r Item 1 with total	.541 (119)	.493 (124)	.568 (121)
r Item 2 with total	.752 (112)	.773 (118)	.788 (105)
r Item 3 with total	.765 (106)	.731 (114)	.830 (111)
r Item 4 with total	.780 (96)	.735 (109)	.855 (106)

Table 4.3. Item - total correlations in the selection task (with *n*).

	Time 1	Time 2	Time 3
r Item 1 with total	.473 (231)	.574 (193)	.634 (160)
r Item 2 with total	.652 (231)	.648 (193)	.595 (161)
r Item 3 with total	.700 (231)	.702 (193)	.749 (161)
r Item 4 with total	.589 (231)	.677 (192)	.625 (161)

The generally lower item-total correlations on the selection task compared with the drawing task could be due to a number of factors. One is that this task was performed immediately after the drawing task, and children might have been tired by this point. Secondly, the selection task involved pictures of the same objects that children had just drawn, and it was noted that some children did not appreciate the need for the task and asked, “Why do we have to do this, as we have already drawn pictures?” Thirdly, since the selection task, on each item, took the form of a choice between two pictures, it lent itself to random choice of one of the two alternatives if children were tired or otherwise not motivated to pay attention. Although not impressively high, the correlations for the selection task were deemed to be adequate, bearing in mind that some of the participants were very young children and that degree of measured internal reliability is due not just to the nature of the test/task items but also to the capacity of the participant to attend and respond consistently across multiple items within a test.

Mean scores for each participant on each task on each occasion when data was gathered were then calculated. These were all on a scale of 0 to 1 with zero indicating maximum intellectual realism and 1 indicating maximum visual realism.

4.2.6 Choice of Statistics

As in the studies reported so far, it was deemed useful initially to explore the relationships in the data through the use of simple bivariate Pearson correlations. My interest was however especially in discovering a quadratic or U shaped relationship, if one existed, between age and drawing realism, while the Pearson correlation statistic essentially assesses only linear (straight line) relationships. In order to overcome this, I included the square of age as well as age in the Pearson correlations (and indeed in the mixed model analysis below). Since the squares of numbers follow a quadratic pattern, with respect to their un-squared counterparts, anything correlating linearly with age squared would be exhibiting a U shaped relationship with age, or at least some part of such a U, while a linear correlation with age would reflect a simple linear relationship.

At the next level of sophistication it was required to assess the nature of the age – drawing realism relationship treating age both as a between subjects and a within subjects variable. When examining the rate and pattern (linear or not) of the development of any characteristic with age, it is often deemed as ideal to pursue individuals longitudinally, gathering repeated measures from within the same subjects over time. In that way, individual characteristics of participants other than the one of interest would be eliminated from consideration. That is beneficial since such other characteristics might otherwise vary between children of different ages and some might have an impact on the trait of interest, and so become confounded with it. In a longitudinal design, however, arguably the subjects are their own controls since they are the same with respect to individual differences at all ages. In the present research, however, the age range that we wished to study in Study 3 was of the order of 6 years (from age 2 years six months to 8 years six months). Hence it was not feasible within the scope a PhD study to undertake a fully longitudinal study of the development of drawing realism in the same individuals, and predominantly different children had to be measured at different ages. Nevertheless I wished to retain something of the benefit of longitudinal study so I additionally measured all the children three times over one year. The effect of this particular mixture of the within and between subjects designs was that I had a set of children of a wide range of ages, each measured three times within one year. This meant that age was a covariate in the design, but in such a way that it took different values on the occasion of each repeated measure. For instance, a child of age 60 months when first measured would be 72 months when measured for the third time. This departs from the standard situation which implementations of ANOVA deal with in statistical packages, where covariates are assumed to take constant values for each case across all repeated measures or occasions. In order to deal with this situation of a covariate which varied with repeated measures, within SPSS therefore it was found necessary to use the Mixed Linear Models option rather than the General Linear Model option (see further 4.3.2).

4.3 Results

In the current study, I needed primarily to ascertain the effects of age of the child, and of the time when the child was tested (out of three successive occasions), on their realism score in both the drawing and the selection tests. In order to test the hypothesis that the age related progression of visual realism followed a U-shape, it was necessary to include age in the analysis both as a linear and quadratic covariate (i.e. both age and age squared). Interaction effects of age and age squared with time were also of interest. Following the procedure used when analysing Study 1 and 2, I first performed correlation analysis, then, in this case, mixed linear model analysis.

4.3.1 Correlation Analyses

Bivariate correlation analyses were first conducted including all the independent variables gender, time, age and age squared - together with the dependent variables: visual realism of drawing production and drawing selection scores. Scribbling production (raw numbers, out of 4) was also examined, simply as a means of demonstrating the validity of the drawing task instrument. A decrease in scribbling with age and time would naturally be expected, and, if observed, would support the view that the drawing tasks were performing as they should. In these analyses the maximum potential number of data points is 233 (the initial number of children sampled) for each time when considered separately, and 699 when all times are considered together. In many analyses *n* is smaller than these figures due to missing data.

4.3.1.1 Scribbling and other variables. As Table 4.4 shows, with the data for all three times considered together, scribbling correlated negatively and highly significantly with time, $r(591) = -.204$, $p < .001$, and age, $r(591) = -.697$, $p < .001$, and age squared, $r(591) = -.673$, $p < .001$. This is as would be expected, and is consistent with the findings of Study 1: older children are better able to inhibit scribbling. Interestingly gender also exhibited a highly significant negative correlation with scribbling, $r(591) = -.223$, $p < .001$, showing that girls scribbled less than boys. This could at least in part be due to the fact that gender also showed a small but significant positive correlation with age, $r(697) = .196$, $p < .001$. That is to say that girls in the sample tended to be on average slightly older than boys: for that reason, possibly they appeared also to scribble less. Notably there was no significant relationship, however, between scribbling and incidence, among non-scribble responses, of visual realism, $r(421) = -.086$, $p = .079$.

4.3.1.2 Visual realism and other variables. Turning now to visual realism, there were no significant correlations with gender or time. Crucially, however, the relationships with both age and age squared were highly significant and positive. The relationship with age squared was however slightly stronger, $r(421) = .228$, $p < .001$, than that with age, $r(421) = .216$, $p < .001$, indicating some support for a U-shaped relationship between the two.

Table 4.4. Correlations between the variables of Study 3: Drawing production task (visual realism scores).

		1	2	3	4	5
1	Scribble	-				
2	Visual realism	-.086	-			
3	Gender	-.223***	.009	-		
4	Time	-.204***	.062	.000	-	
5	Age	-.697***	.216***	.196***	.304***	-
6	Age squared	-.673***	.228***	.206***	.298***	.988***

(* *p*<.05, ***p*<.01, *** *p*<.001)

The correlation analysis of the selection task data (Table 4.5) shows similar non-significant correlations with visual realism scores to those for drawing with respect to time, *r(584)* = .002, *p* = .968, and gender, *r(584)* = .039, *p* = .340. A notable difference however is that, while the correlations between visual realism and both age and age squared are again positive and highly significant, the correlation coefficients are almost identical for the selection task: with age, *r(584)* = .335, *p* < .001; with age squared *r(584)* = .336, *p* < .001. This suggests that the distribution of the selection task visual realism scores against age is such that a U-shape and a linear pattern fit the data equally well.

Table 4.5. Correlations between the variables of Study 3: Selection task (visual realism scores).

		1	2	3	4
1	Visual realism	-			
2	Gender	.039	-		
3	Time	.002	.000	-	
4	Age	.335***	.196***	.304***	-
5	Age squared	.336***	.206***	.298***	.988***

(* *p*<.05, ***p*<.01, *** *p*<.001)

The general picture emerging from the overall correlations is that age squared always has stronger positive correlations than age with the dependent drawing variable, although both are highly significant. The difference between the correlations is however very small in the case of the selection task. The correlations of gender and time with drawing are weak. Since I was additionally interested in the interactive effects of age with time, I also calculated the correlations for each time separately (Table 4.6).

Table 4.6. Correlations between the variables of Study 3, by time (visual realism scores).

Time		Mean Visual Realism (4 drawings)	Mean Visual Realism (4 selections)
1	Gender	.099	.124
	Age	.224**	.227**
	Age squared	.249**	.238***
2	Gender	-.077	.044
	Age	.184*	.471***
	Age squared	.191*	.462***
3	Gender	.011	-.065
	Age	.213*	.360***
	Age squared	.220*	.352***

(* p<.05, **p<.01, *** p<.001)

Correlations with gender are again never significant, as would be expected. For the drawing production, positive correlations with age squared are greater than those with simple age at time one: with age *r(142)* = .224, *p* = .007; with age squared *r(142)* = .249, *p* = .003. The same is true at time two: (*r(141)* with age = .184, *p* = .027; *r(141)* with age squared = .191, *p* = .022. And again at time three: *r(134)* with age = .213, *p* = .013; *r(134)* with age squared = .220, *p* = .010. All however are significant. It is noticeable, however, that the correlations with age and with age squared, and the differences between those correlations, are stronger at time one than at times two or three. This suggests a possible interactive effect of time and age and of time and age squared, such that the U-shaped relationship is stronger at time one than at the other times for the drawing production task.

The selection task data yields a different picture. All correlations of drawing selection with age or age squared are highly significant. However, it is only at time one that the correlation with age squared exceeds that with age: *r(229)* with age = .227, *p* = .001; *r(229)* with age squared

= .238, p < .001. The reverse is true at time two: *r(191)* with age = .471, p < .001; *r(191)* with age squared = .462, p < .001. And again at time three: *r(160)* with age = .360, p < .001; *r(160)* with age squared = .352, p < .001. The differences are small, however. Hence a U-shape is supported only at time one from the selection task correlation data.

4.3.2 Mixed Linear Model Analyses

Although correlation analysis produced some suggestively significant results in favour of my hypothesis concerning the U-shaped development of visual realism, at least with respect to the drawing task scores, they suffer from some major objections. One is that, in the overall analyses including all three times, they both treat the three times on which each child was measured as three independent groups of cases; in other words they treat data points at different times as independent of each other in the same way that each child is independent of each other child. In fact, however, the three times are not independent as they are repeated measures, which come from the same children. Hence it would be expected that responses at different times would be correlated within each child and not independent. The consequence of this is that correlation analyses may produce deceptively strong significance values, due to the fact that they effectively treat the data as if it consisted of 699 rather than 233 children. A small relationship detected in a sample of 699 is more likely to be judged as unlikely to be due to sampling error (i.e. significant) than the same relationship detected in a sample of 233.

A second problem is that correlation analysis (and indeed regression analysis) cannot conveniently test interaction effects, and some such interactions are of interest in this study (those between age and time, and between age squared and time).

In order to overcome these obstacles, I first considered using the repeated measures option within the general linear model (ANOVA), since that allows within-subjects variables (like time in our case) to be analysed along with between subjects factors like gender and (usually) covariates such as age. Since, however, the covariate of age did not take the same value for a given child on all three of the repeated occasions (times) when the child was measured, the analysis could not be performed using the standard ANOVA or General Linear Model repeated measures options in SPSS. Instead it was necessary to employ Mixed Models analysis, since that allows for the inclusion of a covariate which takes different values for a participant at different levels of a repeated measures variable. Although the use of Mixed Models is usually associated with the inclusion in the model of multiple random factors, beyond the cases/participants themselves, in fact there was no need for this feature to be involved in the present case since I did not regard times or ages (or genders) as constituting random choices.

A further advantage of the Mixed Model mode of analysis is that it uses the data in the 'long' form (with repeated measures data listed in the same column, one column per variable, several rows per participant) rather than the 'wide' form (where repeated measures data is listed in columns side by side, one for each repeated-measures variable value, and with one row per participant). This in turn has the advantage that missing data is handled in a more refined way. In my data, there were a number of instances where a child produced only scribbles or missing drawings on one testing occasion (so was treated as missing on that occasion), but produced at least one valid drawing on other occasions (so was not missing on those occasions). Using data in the wide form (e.g. as occurs when using Repeated Measures ANOVA in SPSS), such a child would have their data excluded for that child as a whole, across all occasions. Using data in the long form, however, data gets excluded only for the occasion where the data was missing. Hence there is a reduced loss of data due to such circumstances.

The mixed model analysis of the visual realism data of the drawing task (Table 4.7) shows that only one of the effects included in the model was significant. That is age squared: $F(1, 262) = 4.85$, $p = .028$. Age as a linear component, by contrast, is not quite significant: $F(1, 255) = 3.56$, $p = .060$. Thus, when the within-subjects variable of time is properly dealt with in the analysis, and interaction effects of age with time are taken into account, the analysis yields significances which are much more clearly separated than those of the correlation analysis given above (Table 4.4). Time and gender continue to register no significant impact on drawing realism.

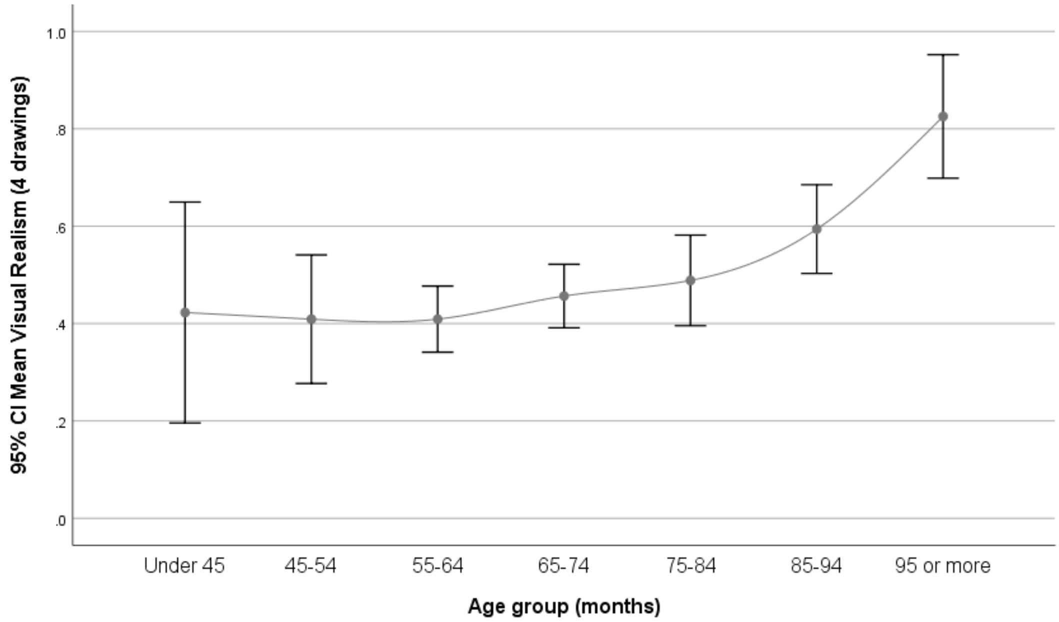
Overall, since the relationship with age squared is significant while that with age is not, a U-shaped relationship fits the data better than a linear one, as may be observed visually also in Figure 4.4. The effect size is not large, however, since R^2 for the linear trend is .046, while that for the quadratic trend is .058.

Table 4.7. Mixed model analysis for Study 3, with visual realism in the drawing task as dependent.

Source	**Numerator *df***	**Denominator *df***	***F***	***p***
Intercept	1	248.102	3.934	.048
Gender	1	413.874	.613	.434
Time	1	291.087	1.006	.317
Age	1	254.818	3.557	.060
Age squared	1	262.000	4.853	.028
Time * Age	1	293.056	1.435	.232
Time * Age squared	1	296.200	1.849	.175

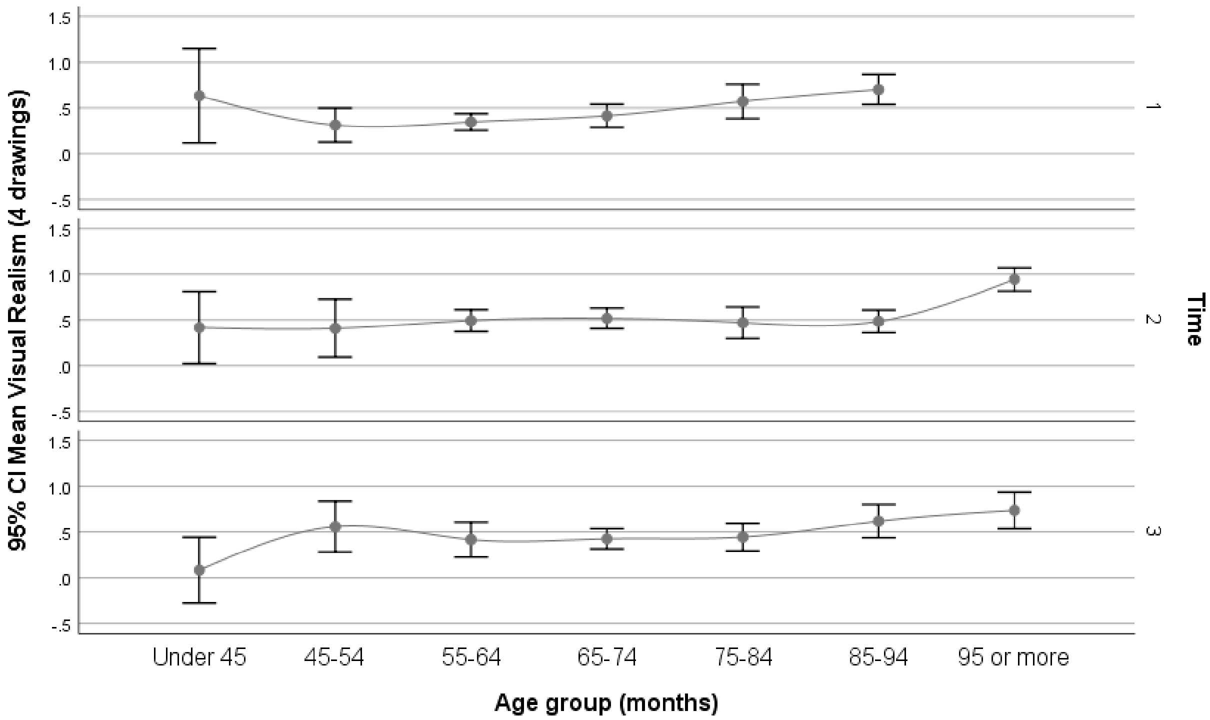
In Figure 4.4, it may be seen that a quadratic or U-shape is quite clearly apparent, albeit the ‘fall’ on the left-hand side is not strongly present. Arguably the best fit curve is more of a J than a U. This is however consistent with my hypothesis concerning the possible existence of an early visual realism stage. Such an early stage is, however, evidenced only in a quite weak way, in that even the highest visual realism scores on the left-hand side of the graph are below .7, and most participants record less than 50% of valid responses exhibiting visual realism. The majority even at that stage still exhibit intellectual realism. Furthermore, it is apparent that even at the lowest point of the U, around age 4½ years of age, where there is maximum evidence of intellectual realism, that maximum is not absolute since there always remains a minority of responses (around 40%), which exhibit visual realism. Furthermore, it is not until after around 7 years of age that children's responses tend to exhibit a definite majority of visual realism.

Figure 4.4. Mean realism scores on the drawing task (scale 0-1).



Although the mixed model analysis did not show time, or any interactive effect of age with time, to be significant, the patterns for each time separately are descriptively informative. As Figure 4.5 shows, a U-shape is very visible at time 1, where the youngest age band is best represented, and even evidences a majority for the mean of visually realistic responses in the very lowest age group. At time 2 the left side of the graph starts level, resembling the bottom of a U, while at time three it more clearly resembles the steep start of the right-hand side of a U only. This is consistent with the lowest scores at each time exhibiting progression from left to right through a U-shape. It also suggests that any early visual realism stage rapidly passes as children move on from the very youngest age band in our sample.

Figure 4.5. Time differences in age related progression in visual realism on the drawing task (scale 0-1).

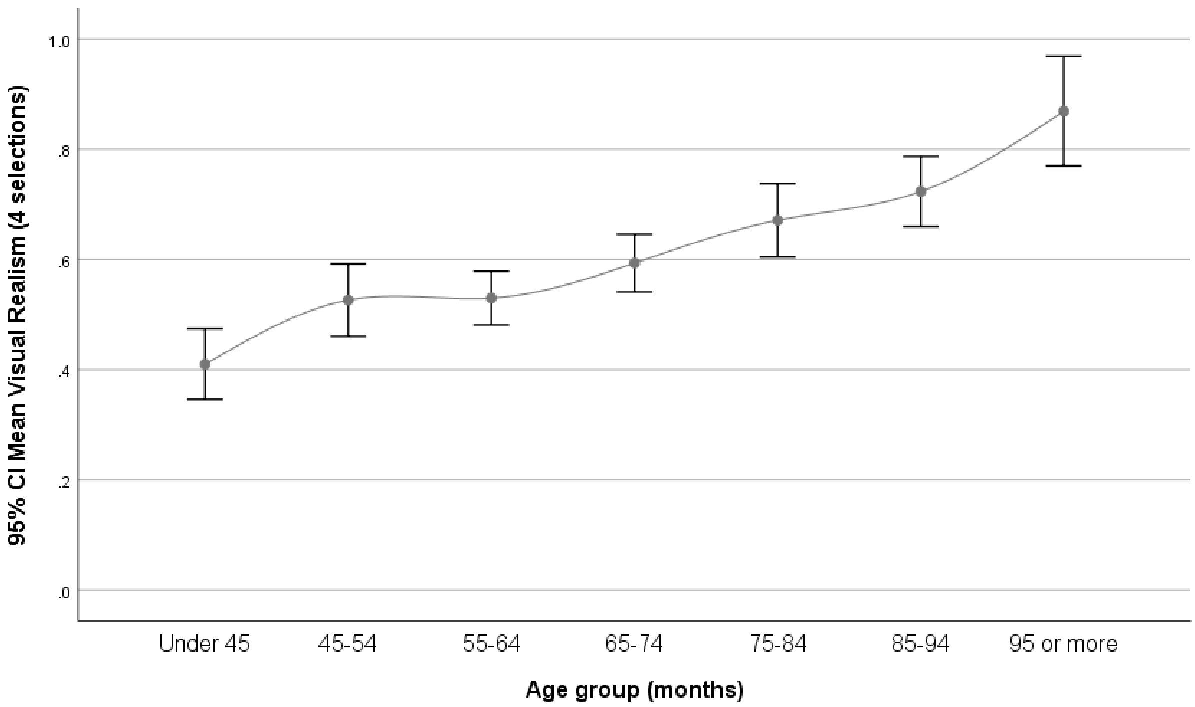


Turning now to the selection task, as seen in Table 4.8, a number of effects are significant. The statistics firstly show that, once time is treated, as it should be, as a within subjects variable, and has its interactions with age taken into account, again the effect of age squared is significant, *F(1, 392)* = 4.39, *p* =.037, and that of age alone is not, *F(1, 382)* = 2.77, *p* = .097. The R^2 values are, however, barely different: linear .112, quadratic .113. Furthermore, the evidence of Figure 4.6 shows a rising monotonic pattern, which visually is somewhat ambiguous between a linear or quadratic trend. Certainly, if it really has a U-shape, it is very much the right-hand side of the U with no crucial high values of visual realism to the left of any low point, so not even approximating a J.

Table 4.8. Mixed model analysis for Study 3, with visual realism in the selection task as dependent.

Source	Numerator *df*	Denominator *df*	*F*	*p*
Intercept	1	375.404	8.276	.004
Gender	1	576.479	.902	.343
Time	1	420.698	5.384	.021
Age	1	381.774	2.767	.097
Age squared	1	392.041	4.386	.037
Time * Age	1	418.146	4.460	.035
Time * Age squared	1	418.993	4.106	.043

Figure 4.6. Mean realism scores on the selection task.



With respect to the visual realism results for the selection task, it must further be considered that the effect of time also emerges as significant, *F(1, 421)* = 5.38, *p* = .021, indeed more markedly so than that of age squared. Furthermore, the interaction effects of age with time, *F(1, 418)* = 4.46, *p* = .035, and of age squared with time, *F(1, 419)* = 4.11, *p* = .043, are also significant. Examined further (Figure 4.7), the simple time related effect is somewhat puzzling as it exhibits lower rates of visual realism at times 1 and 3 than at time 2, rather than a successive rise across times as would be expected. Figure 4.8 further illustrates the interaction effects. It shows that the change across ages does not follow the same pattern at different times. Instead of continuously rising patterns (monotonic) there are dips in certain age groups, but inexplicably these dips are in different age bands at different times. At the moment, I have no suggestion as to why such patterns would occur. Possibly the selection task results are non-informative due to the lower degree of concentration perceived by the researcher to be given by the children to this task (as noted in 4.2.6).

Figure 4.7. Time differences in visual realism on the selection task.

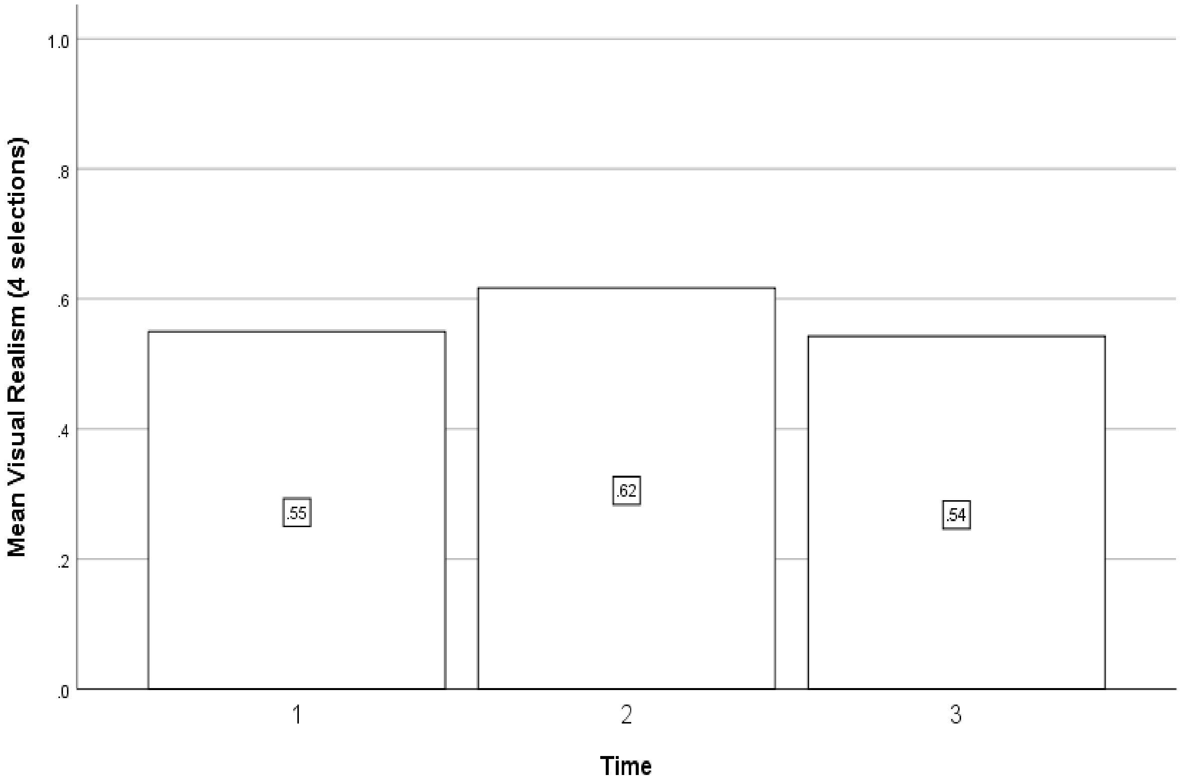
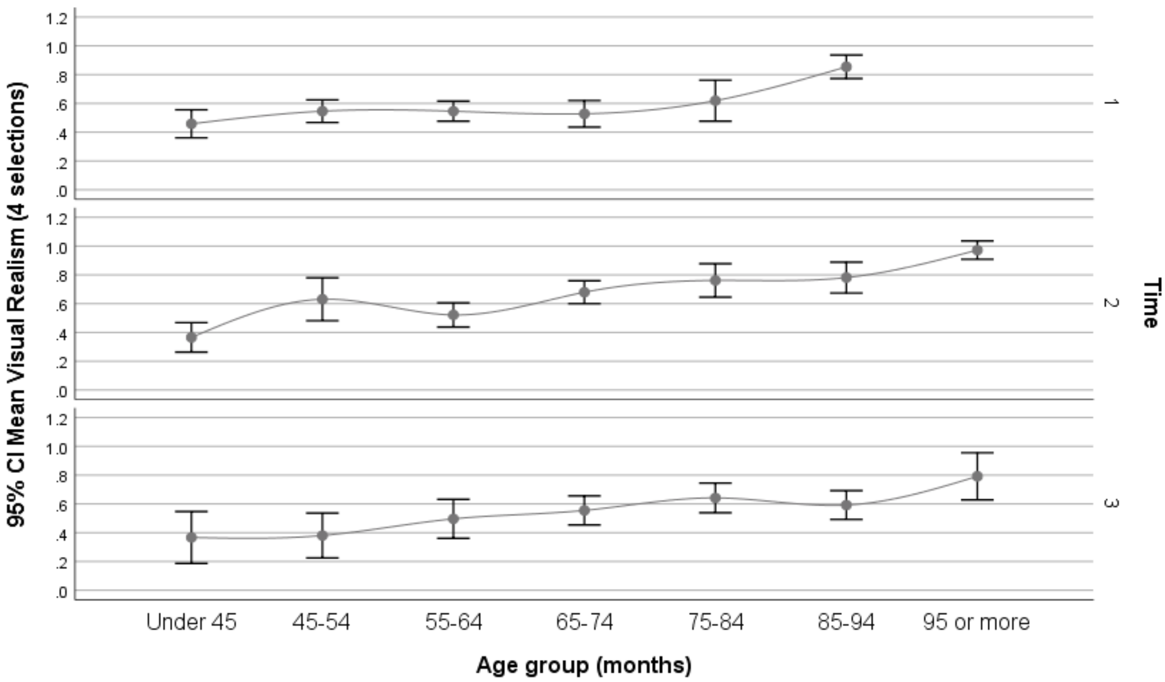


Figure 4.8. Time differences in age related progression in visual realism on the selection task.



4.4 Discussion

From Study 3, I found that correlational and mixed model analyses combine to give a reasonably consistent picture of the findings, at least for the drawing production results. The fact that different statistical methods produced similar findings suggests that the findings are reliable. I next discuss these findings, with an eye to the research hypotheses concerning a possible U-shape to the development of visual realism of drawing (4.1.5).

First, it is clear that the results agree in one basic respect when the drawing production task is considered in comparison with the drawing selection task. Both are consistent with the general finding that visual realism changes with age, as has been found in a number of studies such as Luquet (1927), Jolley and colleagues (2001). My findings do not however accord with Ford and Rees (2008), who failed to find any change in intellectual realism of pictures produced by typical children across an age range of 3 years 7 months to 7 years 5 months (discussed in 4.1.3).

Secondly, the mixed model analysis findings from both tasks agreed in that they both showed a significant overall effect on visual realism of age squared, but not of age. Thus both supported the existence of a quadratic pattern of development for visual realism which has not previously been established in typical children.

Notwithstanding, the two tasks differed in that the drawing task showed some evidence of the left-hand side of a U-shape, while the selection task did not. This difference between the findings from the two tasks is however explicable on the basis of the difference in nature between the tasks, which we may suppose generates a lag, in the following way. Clearly, in the drawing production task, no prompt was offered to guide how the picture was drawn, apart from the objects themselves, which were displayed to the child, and the task was to produce a drawing. By contrast, in the drawing selection task, just two possible pictures were offered, with no further distractors, and the task was to receptively select and not productively draw. This made the selection task considerably easier, and, as reviewed in 4.1.4, it is a common finding that children evidence mature drawing behaviour receptively ahead of the age at which they produce it. It was found both by early studies such as Kosslyn and colleagues (1977) and Fayol and colleagues (1995) and by better designed studies (Jolley et al., 2001) that the age-related sequence which drawing production follows in children matched the sequence which their receptive selection preference followed, but with some lag. It is possible therefore to interpret the results for the bottom age band in Figure 4.6 as essentially corresponding, with lag, to a band after the base of the U-shape in Figure 4.4, such as the 55-64 months age band, and progressing from there. Hence the selection task scores are all after the low point of the U, and so, if anything, exhibit only the right-hand side of a U pattern.

Next, I had anticipated (4.1.5) that, corresponding to the left hand side of a U, younger children up to around 4 years old would make greater use of visual than intellectual realism. From the U-shape found in the drawing production data, the evidence is that the point of least evidence of visual realism, and greatest of intellectual realism, does lie at around the age of 4½ years. It is therefore possible to say that there is some evidence in support of this part of my hypothesis, in that, before this age, there was slightly more use of visual realism than at this age, at least for drawing production. Indeed, this result accords with the findings of Study 1, where a negative correlation was found between age and realism of drawing in the 3-4-years age range.

Crucially, however, I was only able to demonstrate an actual *majority* use of visual realism over intellectual realism in this early age range at time 1 (Figure 4.5), not in the graph representing the data as a whole (Figure 4.4). This is connected with the fact that although the result in favour of a quadratic trend is significant, the effect is quite small. As may be seen from Figure 4.4, the pattern for drawing is far from presenting a complete U. Instead, the left-hand side of the U is quite low, so visually the pattern is more of a J than a U. Furthermore, in terms of the measure used (mean proportion of visual drawings, out of all valid drawings), the mean sample value for the lowest age group overall is only .42. In other words, before the bottom of the U, when all times are considered together, there was still a majority (58%) of drawings being produced with intellectual realism and only a minority with visual realism. This minority then fell very slightly to produce the low point of the U/J before increasing steadily after that. Notably, it was only for the first time-point that a majority of responses in the lowest age band displayed visual realism (Figure 4.5). This section of the data of course included the lowest aged children in the entire study, and suggests that at the very lowest ages a majority of response (60%) is in fact visually realistic.

Confronted with a picture like this, one might of course be encouraged to extrapolate the U pattern backwards into age groups earlier than those which I sampled. Then I might claim that, if I had sampled children below the age of 29 months, I might have obtained a result where visual realism of drawings was in a great majority over intellectual realism. This, however, we cannot do. The logical conclusion of such extrapolation would be that children in the womb have a dominant ability to draw with visual realism. In reality, of course, even at the lowest age group which I sampled, I struggled to obtain a reasonable number of instances of valid drawings. Undoubtedly at earlier ages instances of omitted or scribbled drawings would rise to 100%, so that no data would be available to judge any type of realism. Indeed, the point at which children start to be able to produce a drawing with any sort of even partial representational or figurative realism is probably around age 2, the age of ‘fortuitous realism’ (Luquet, 1927). Hence, I must be content to have shown at least some evidence of the low age group side of a U pattern, as I have. Indeed, the implication is that it may be impossible to demonstrate a U-shape much more convincingly than I have done, even with a much larger sample of participants under the age of 3½ years, due to the greatly increased rate of invalid drawings which children of such an age inevitably produce.

Nevertheless, it constitutes an original and novel contribution to this area of research to have shown even slight, but significant, evidence of a U-shaped rather than a linear progression in visual realism of drawing development. This constitutes a modification of the picture revealed by the many studies which evidenced a progression where intellectual realism simply lost ground with age in favour of visual realism (Crook, 1985; Freeman, 1980; Riggs et al., 2013). Such studies often did not sample at the very low age bands, which I did, or, if they did, did not find, or did not notice, any evidence of greater use of visual realism at the lowest levels.

There are several possible interpretations of my findings. One follows the argument used in the discussion of Study 1, and suggests that, prior to the age of 4 or 5, it is visual realism that is pre-potent and which has to be inhibited to increase the rate of use of intellectual realism in drawing tasks; then later intellectual realism becomes pre-potent and has to be inhibited so that visual realism re-emerges. This explanation however leaves unexplained why prepotency, and hence what it is that inhibitory control acts upon, should shift from visual to intellectual realism.

An alternative explanation, inspired by Morse and colleagues (2010), is a modification of the scenario suggested in 4.1.3. When a child first starts to inhibit her inclination to scribble, or starts identifying something representational in her scribbles, at age 2 onwards, she may perhaps be at a mixed stage of cognitive development with respect to cognitive categories for common objects such as are often included in tests of drawing development (mugs and balls etc.). For some of these she may already have developed idealised stereotypical mental categories, where a mug, for example, always has a handle, and these are prepotent when it comes to drawing such an object (intellectual realism). For others, she may not yet have developed any such category, and so of necessity relies on local information in the form of specific exemplars of the objects exactly as they appear in the environment at the time of attempting to draw them (visual realism). At age 3½ she has perhaps reached over 50% category formation for such objects and this increases to nearly 60% at age 4½, as reflected in the rate of drawing with intellectual realism.

Thereafter, however, with development of IC (Study 1), the default choice of what to draw, in ‘draw what you see’ tasks, shifts from the general category that is in the mind to what is specifically in the environment. The pre-potency of the stored concept/image starts to be inhibited and visual realism starts regaining ground in children’s drawing, regardless of whether the child possesses or does not possess a mental category for the object to be drawn (and by this time children would surely possess such categories for all the items commonly used in drawing tests). The internal ‘intellectual’ information however continues to interfere (following the Morse model: Morse et al., 2010) with their performance in tasks where they are actually asked to draw what they see. Finally, their category development matures but they learn to operate both with the general mental categories and with the specific exemplars of those categories as perceived in daily life, without interference between one and the other, and use those two types of information appropriately when one of them is called for and not the other in a task (e.g. ‘draw a mug from memory’ versus ‘draw the mug as you see it presented to you now’). That is to say that pre-potent intellectual realism is finally widely inhibited in tasks where the request is to draw what is seen (For & Rose, 2008; Luquet, 1927/2001).

In this view, the choice of visual realism at the early stage would be due to absence of a mental category to be relied upon, while at the later stage it arises through inhibition of an existing mental category, when the task requires it. This is consistent with the general observation of Morse and colleagues (2010) that the two high points of a U typically arise from quite different cognitive backgrounds that exist at the relevant ages. In other words, this explanation introduces the idea that intellectual realism is pre-potent from the start, and does not (around age 4-5) replace pre-potency of visual realism: the apparent greater preference for visual realism at an early age, under this account, is simply due to deficit, in the form of lack of the mental category which is a prerequisite for intellectual realism to operate. Clearly future research, which replicated Study 3 but included also measures of IC and of category formation, might address further this issue.

Turning to my second expectation, that corresponding to the low point of a U, around 4 to 6 years old, children would evidence greater reliance on intellectual realism in their drawing, I would have to say that the relevant age band characterised by drawing with intellectual realism appears somewhat wider in my data than 4-6 years. If we regard the age band dominated by drawing with intellectual realism as being that where the mean proportion of visual realism is less than .5 (50%), then this period runs from my lowest age group up to around 6½ or so. Only around that time does the proportion of visual realistic drawings tend to exceed 50% of valid drawings produced.

Finally, with respect to the prediction that, corresponding to the right hand side of a U, approaching 8 years old, children would revert to dominance of visual realism, my results suggest that the switch to a majority of visually realistic drawings occurs around age 7 rather than 8. However, as I have shown in my discussion above, this cannot be unequivocally be referred to as ‘switching back’ to a dominant use of visual realism which obtained at an earlier age, since my data does not comprehensively succeed in demonstrating an early stage where visual realism actually predominates over intellectual realism. It remains best treated as the age of onset of visual realism, if we mean by that a majority use of visual realism in tasks which call for it. My finding is therefore broadly consistent with Cox (1991), who reported children as able to overcome the early intellectual realism strategy between the ages of 5 and 8 years. It also accords with Luquet (1913) who stated that between the ages of 5 and 8 years, children produce intellectually realistic drawings: in my data even at age 8 they are still producing up to 10% of intellectually realistic drawings. However, in my data they also produce such drawings before age 5. Davis (1983) more precisely reported that 59% of 5-6 year old children drew visually realistically when a single cup was placed in front of them with the handle out of sight. My data on this item and age band separately yields the value of 55%, which is remarkably close.

If we consider finally the evidence of the selection task with respect to age of onset of visual realism (calculated in the same way as above), then the picture is strikingly different. We can see from Figure 4.6 that the age when choice of visually realistic drawings starts to exceed the choice of intellectually realistic drawings is around age 4 years. This is at least two and a half years before this happens in my data for drawings that are produced rather than selected (Figure 4.4). This however is to be expected, since as discussed above, a lag is typically found between receptive and productive drawing test scores. In my data, this lag appears to be of the order of 2½ years.

Chapter 5. Summary and Conclusion

5.1 Introduction

In this chapter I first summarize and discuss the findings of the three studies conducted for this thesis. I then present the limitations of the study and conclude by making some suggestions for further research.

5.2 Overview of the three studies

In the present study, three separate but connected studies were conducted with young children, together illuminating the inter-connections between Inhibitory Control (of the response inhibition type), Motor Control (both Fine and Gross), and several drawing skills (Figurative Representation and Detail, and Visual vs Intellectual Realism), together with Gender, verbal IQ and Age. It therefore contributes to extending our understanding of the relative roles of the Executive Function, represented by Inhibitory Control, and the physical aspects of drawing ability, represented by Motor Control, in determining the qualities of a young child’s drawing, and the pattern of development of these over time. An association between Inhibitory Control and at least some drawing skills in preschool children had already been established from previous findings (Panesi & Morra, 2016; Riggs et al, 2013). My studies built on this foundation to clarify the additional involvement of Motor Control. Indeed they show that all types of drawing skills are not related in the same way with Inhibitory Control and Motor Control and furthermore do not follow the same developmental trajectory.

Overall, my findings give us a better understanding of the role of Inhibitory Control during early childhood development. An important finding (Studys 1 and 2) is the direct and strong relationship between Inhibitory Control and *Fine* Motor Control, but perhaps surprisingly, not Gross Motor Control. Even though Fine Motor Control and Gross Motor Control are directly associated, there is only an indirect association between Gross Motor Control and Inhibitory Control. Furthermore, an association was established between Inhibitory Control and drawing skills. This relationship was positive for those measured by the figurative representation and figurative detail scales (which quantify respectively how far a drawing represents a real object recognizable to an adult, and with what degree of detail). However, the pattern of results differed for the Visual realism measure of drawing (which measures how far the child draws objects exactly as they see them, rather than with properties which they know they possess but cannot see). That was not associated with Fine Motor Control, but rather with Inhibitory Control. Furthermore (Study 3), its developmental progress was shown to follow a partial U-shaped pattern moving in some measure from visual realism to intellectual then back to visual, rather than a monotonic one.

5.2.1 Study 1: The relationship between Inhibitory Control, Fine Motor Control, and Drawing skills

Study 1 primarily was concerned with evaluating three alternative accounts of the role of Inhibitory Control in drawing skill. These were termed respectively the Symbolic Competence account, the Behavioural Inhibition account and the Motor Development account. The first two had been introduced, in essence though not by name, by Riggs and colleagues (2013), while the third was proposed here.

Riggs and colleagues (2013) state that the Symbolic Competence account suggests that effective inhibition is associated with the domain-general development of symbolic understanding which in turn is essential to improvement in drawing skill. The Behavioural Inhibition account, on the other hand, proposes that inhibition is directly required to suppress immature drawing behaviour and so lead to drawing skill improvement (Golomb, 1992; Ebersbach et al., 2011; Morra, 2008; Panesi & Morra, 2016; Riggs et al., 2013). The third and final account is the Motor Development account which suggests that inhibition improves drawing skill due to its direct relationship with Fine Motor Control, without which the finer hand movements required for good drawing cannot be made. This led me to three areas of prediction.

One hypothesis was that all three of the accounts predicted a relationship between Inhibitory Control and the Figurative Representation and Figurative Detail aspects of drawing skill. The Behavioural Inhibition account, however, predicted this relationship to be direct, while the other two regarded it as indirect. The Motor Development account proposed it to be mediated through Fine Motor Control, while the Symbolic Competence account saw it as mediated through Symbolic Understanding, although since Study 1 did not measure Symbolic Understanding, in my study the link would appear to be direct (and with a particularly strong association expected between Inhibitory Control and Figurative Representation).

The findings here did not support the Behavioural Inhibition account since there was only an indirect association of Inhibitory Control with Figurative Representation and Detail, mediated via Fine Motor Control. The Symbolic Competence account was also not supported, due to the notable indirect rather than direct association of Inhibitory Control with Figurative Representation (and Figurative Detail), mediated via Fine Motor Control. The Motor Development account, however, was supported since it alone predicted a strong positive association of Inhibitory Control with FMC, which would mediate its relationship with children's performance on the Figurative Representation and Detail.

The second area of hypothesizing was that only the Behavioural Inhibition account predicted a relationship between Inhibitory Control and degree of Visual Realism of drawing (in contrast with intellectual realism). That is, it suggested that children needed to inhibit a tendency to draw what they know is there in order to correctly draw just what they can actually see. It further predicted that this link would be direct, not mediated, and, following the literature, that Visual Realism would move from intellectual to visual as Inhibitory Control strengthened, thus showing positive correlations. The other two accounts did not appear to predict anything definite, since the visual-intellectual dimension of drawing skill might be deemed not to differ in demands made upon Symbolic Understanding or Motor Control ability. The findings supported the Behavioural Inhibition account, in that a direct link was indeed found between Inhibitory Control and Visual Realism of the children's drawing, not mediated through Fine Motor Control. The relationship was, however, unexpectedly negative (see further below).

Third, on the basis of much previous research, age was in all the three accounts expected to be positively associated with performance on all types of drawing ability, as well as increased Inhibitory Control and Fine Motor Control. Indeed, the transition in middle childhood from intellectual realism to visual realism (Clark, 1897; Freeman and Janikoun, 1972) is one of the oldest findings in cognitive development. Furthermore, use of visual realism is usually seen as increasing monotonically during childhood (Cox, 2005; Golomb, 2002; Jolley, 2010). Gender was, on the basis of previous research, not expected to be associated with drawing skills. These expectations were supported for all the variables except Visual Realism, whose relationship with age (and Inhibitory Control) was significantly negative rather than positive (i.e. intellectual realism increased rather than decreased with age).

Overall, the findings support the view that theories which try to explain the relationship between inhibition and drawing skill might well be expected to include Fine Motor Control in some way, at least with respect to those drawing measures which focus on the degree to which a drawing has more representational quality and detail, rather than being a simpler representation or indeed just a scribble. This dimension of drawing ability is, after all, a skill clearly requiring careful hand motor control. Two of the accounts of drawing development, however, do not refer explicitly to Fine Motor Control as a relevant variable in the model. The Symbolic Competence account proposes that inhibition helps the development of symbolic understanding, and only in that way impacts on drawing skill, yet Fine Motor Control, which does not require symbolic understanding, is not mentioned. On the other hand, the Behavioural Inhibition account suggests that the development of drawing skill occurs only through directly inhibiting previously established drawing behaviour. This again does not refer explicitly to any involvement of Fine Motor Control. My Study 1 therefore established that Fine Motor Control, as well as Inhibitory Control, must both be present in any convincing model of drawing skill development (though it does not rule out that other variables, such as Symbolic Understanding, which I did not measure, may also prove to play a key role). What this next prompted me to consider was the issue of whether Gross Motor Control, which is known to be associated with Fine Motor Control, is also intimately related to Inhibitory Control, and this became the issue which formed the core of Study 2 (next section).

In contrast with the findings for Figurative Representation and Detail, when it comes to measures of drawing skill which focus on the degree of intellectual versus visual realism, my findings were quite different. Fine Motor Control no longer played a key mediational role and it was the direct effect of inhibition which emerged as paramount, thus supporting the Behavioural Inhibition account rather than the Motor Development account. While this makes sense, since similar levels of motor control are surely needed to produce both visually and intellectually realistic drawings (where non-realistic drawings are, as they were, treated as missing data), it does bring to the fore the idea, not hitherto much emphasized, that drawing skills do not constitute a homogeneous set of constructs. Hence, different accounts or models are needed to explain different dimensions of drawing skill.

While the finding that inhibition was directly linked to performance on the Visual Realism scale came as little surprise, it was initially quite unexpected that young children who had acquired better Inhibitory Control were better able to produce intellectually realistic drawings, rather than more visually realistic ones. This negative association, reflected also in the correlation between age and Visual Realism, was a paradoxical finding since the standard view in the literature is that children progress from drawing with intellectual realism to visually realistic drawing, not the reverse. Hence the role of inhibition is usually claimed to be to prevent behaviour that could lead to intellectually realistic drawings so that visually realistic drawing can be produced (Crook, 1985; Freeman, 1980; Riggs et al., 2013). In my findings, the reverse was the case: visual realism seemed to be being inhibited in order to produce intellectually realistic drawings.

However, this finding is not as contrary to the established theory as may seem at first glance. The most common age group selected to investigate the developmental shift from intellectual to visual realism is between the ages of 5 and 10 years (Bremner & Moore, 1984; Chen & Holman, 1989; Cox, 1978; Cox & Martin, 1988; Freeman, Eiser and Sayers, 1977; Freeman & Janikoun, 1972; Taylor & Bacharach, 1982), whereas the participants in my study were 3 and 4 year olds. Therefore, it is quite possible that while 5 to 10 year olds do evidence increasing preference for visual realism, younger children may exhibit a different progression of preferences. I proposed therefore that the younger subjects in my study were progressing from a very early stage where their preference was for drawing with visual realism into a stage around age 5 where preference for drawing with intellectual realism is at its greatest. Hence for them it was visual realism that needed to be inhibited in order to execute drawing with more intellectual realism.

This scenario then provides a plausible explanation for the negative correlation between Inhibitory Control and Visual realism of Drawing in preschool children. Such young children need to inhibit visual realism so as to be able to draw in an intellectually realistic manner, thus supporting the Behavioural Inhibition account. This can be further explained by arguing that young preschool children, at the point when they emerge from just scribbling, may indeed initially simply draw what they see, which corresponds to visual realism. If so, this would require effective inhibition in order to draw something beyond visual realism. Studies of young talented artists and autistic children gifted in drawing have indeed provided evidence of visual realism in early drawing development (Golomb, 1992; Selfe, 1983; Winner, 1996), although to my knowledge this has not previously been shown for typical preschool children such as those in Study 1.

This then suggested a second line of enquiry to be followed up in the current study (in Study 3): the precise development with age of visual and intellectual realism of drawing, across a comprehensive range of ages from below the age group of those in Study 1 up to age 9 years. If my suspicion was correct, it was possible that a U-shaped pattern of development might be observed.

5.2.2 Study 2: The relationships between Inhibitory Control, Fine Motor Control, Gross Motor Control and General Intelligence

Study 2 had two main aims. First, I wished to examine what specific relationships could be found between different subsets of motor skills (i.e. Gross and Fine Motor Control) and the executive function (specifically Inhibitory Control) in typical developing children aged 3 to 5 years old. In particular, did the relationship between Inhibitory Control and Fine Motor Control found in Study 1 extend to Gross Motor Control? If so, how? In fact, the relationship between Inhibitory Control and Gross Motor Control was found not to be direct, but mediated by Fine Motor Control. The relationship between Inhibitory Control and Fine Motor Control by contrast was found to be both direct and mediated by Gross Motor Control. However, the size of the direct link ($B=.074$, $p<.001$) was greater than that of the indirect association via Gross Motor Control ($B=.019$, $p<.05$). In short, Inhibitory Control is more intimately linked to Fine than to Gross Motor Control in pre-school children.

Second, I wished to confirm that the association between Inhibitory Control and Motor Control could not be explained by general intelligence (IQ). In fact, it was only in the analysis with Inhibitory Control as main predictor and Fine Motor Control as dependent that IQ did have a significant effect on Fine Motor Control mediated through Gross Motor Control, in the presence of Gender and Age (B=.041, p=.013). This was however less than both the direct effect (B=.074) and the total effect of Inhibitory Control on Fine Motor Control, not considering General Motor Control (B=.093). Hence the role of IQ must be considered minor.

Study 2 was novel in at least three ways. First it showed the relationship between Inhibitory Control and Fine Motor Control at an age level where it has not been considered before in typical children. Secondly it demonstrated the role of Gross Motor Control as an added variable in that relationship. The latter has been considered in relation to Inhibitory Control at the age level of my study before, but not in the presence of Fine Motor Control in the same study. Third it revealed the limited impact of IQ on those other inter-relationships.

There are many previous studies confirming the relationship between motor control and executive function in older children and adolescents diagnosed with DCD (Leonard and Hill, 2015). Such a relationship specifically exists between inhibition and motor control in typically developing infants, and 5- and 6-year-olds, as well as adolescents (Gottwald et al, 2016; St. John et al, 2016; Livesey et al, 2006; Rigoli et al, 2012). The first evidence for an association between Inhibitory Control and Fine Motor Control specifically in 3 and 4 year olds is however provided by the current study. This age is in fact usually the time when Inhibitory Control develops most rapidly, according to several authors (Garon et al., 2014; Johansson, et al., 2015; Petersen, et al., 2016; Simpson & Riggs, 2005; Wiebe et al., 2012). There are two possible explanations for the correlation. First, Inhibitory Control may in fact be needed so that effective Fine Motor Control can develop. Second, the notion of embodied cognition may explain why Fine Motor Control and Inhibitory Control develop alongside one another. The embodied cognition theory provides an explanation as to how executive function and motor control development are associated by means of its suggestion that human cognition is built through the physical interaction that our bodies have with the world (Marshall, 2016; Shapiro, 2011).

In Study 2, the current study not only confirmed that Fine Motor Control is indeed directly associated with Inhibitory Control in early childhood but additionally demonstrated the position of Gross Motor Control with respect to these. Hitherto it has been unclear which specific components of the motor system are linked to the executive function more than others in this age group, and how these relationships change during development, although Gross Motor Control has been separately shown to be related to Inhibitory Control at 24 months (St. John et al., 2016). My finding is that Inhibitory Control is significantly and directly related to Fine Motor Control, and indeed also, less strongly, but still significantly, via Gross Motor Control. A variety of different analyses however failed to show any instances where Gross Motor Control and Inhibitory Control were directly linked, if Fine Motor Control was included in the analysis at the same time.

A Dynamic Systems account can provide the explanation for different components of the motor system interacting with executive function at different ages in this way. At the age of one year, infants usually begin to walk, hence maximizing the relationship between Gross Motor Control and executive function. By the age of two years, infants are exploring their environment. Later on, Fine Motor Control is more prominent, allowing for the development of more delicate skills in preschoolers, such as drawing and dressing.

This finding I also deem to be consistent with the Motor Development account of how drawing skill develops, and so with the result of Study 1, at least with respect to the drawing skills of Figurative Representation and Detail. Recall that the Motor Development account proposed that Inhibitory Control and Fine Motor Control are associated directly in early childhood and indeed that Inhibitory Control affects drawing skill only via Fine Motor Control. Study 2 extended this through a mediation analysis with regression and bootstrapping showing that, after controlling for age, gender and IQ, a relationship existed between Inhibitory Control and Fine Motor Control both directly and, less strongly, mediated through Gross Motor Control.

Another explanation for the relationship between inhibition and motor control is related to how Inhibitory Control develops in pre-school children. An explanation which fits the Behavioural Inhibition account, suggested by Simpson and Riggs (2007), is that as the strength of inhibition increases, inappropriate responses are put on hold, and this was supported by the findings of Study 1 with respect to the drawing skill of Visual Realism. Alternatively, however, Diamond, Kirkham and Amso (2002) suggest that such findings arise because Inhibitory Control improves due to behaviour slowing down, and hence the child being able to take better care to produce the appropriate response. There is some evidence to support this explanation, found in preschool children who performed better on inhibitory tasks when their response was slowed down (Diamond et al., 2002; Simpson & Riggs, 2007; Simpson et al., 2012; although see Barker & Munakata, 2015; Ling, Wong & Diamond, 2016). Evidence specifically related to drawing and showing that improved Inhibitory Control is associated with slowed responding comes from a study by Lange-Küttner (2000) who found that children slowed down whilst drawing open shapes rather than closed shapes. She suggests that, in order to integrate different segments and components into an overall outline in a drawing, a child is reliant on being able to modify their procedural speed.

If effective Inhibitory Control in preschool children is indeed reliant on being more careful and responding slowly then one might suggest that such behaviour could also improve performance on the more delicate motor control tasks as well. Hence, this suggestion is compatible with the observation in Studys 1 and 2 of a link between Inhibitory Control and Fine Motor Control but not between Inhibitory Control and Gross Motor Control. Since, however, none of the studies in the current research either measured or manipulated speed of response, this must remain for now in the realm of conjecture.

5.2.3 Study 3: The pattern of development of Visual Realism in children's drawing.

Study 3 set out to confirm and extend the striking finding of Study 1 that the relationship of age (and indeed of Inhibitory Control) with the drawing skill of Visual Realism was highly significant but negative in the pre-school age range. In order to obtain information about children's receptive ability with respect to drawing realism to complement information on their drawing production ability, I measured not only their skill of picture drawing of objects in view, as in Study 1, but also their skill of selecting the picture which most closely resembled objects in view. This also allowed the researcher to obtain data relevant to the assessment of visual realism from children who were as yet unable to produce a drawing that was not a scribble, and hence gave no information about their realism in drawing production. This study furthermore included a much wider age range (from 29 to 102 months) than the previous ones, so as to have the best chance of showing a U-shaped pattern of development, if one existed. Finally, in order to obtain the benefits of a within subjects design, at least in part, it re-measured the same children three times over the period of one year, with six month intervals. Naturally, however, it was not practical within the time span of a PhD to follow up the same children over the entire age range of interest in a fully longitudinal study (which would have taken six years).

It was hypothesised that the children would progress through a U-shaped continuum of behaviour with respect to Visual Realism of drawing following a pattern which, for convenience, could be divided into three phases. Initially (the left-side of the U), younger children (up to around 4-years-olds) would make greater use of visual than of intellectual realism, provided they did not just scribble. Next (the low point of the U), there would be a period (perhaps 4- to 6-years-olds) when children would evidence greater reliance on intellectual realism. Finally (the right-hand side of the U) children approaching 8-years-old would revert to dominance of visual realism. This pattern was substantially confirmed, in that in the mixed models analyses a quadratic trend fitted the data significantly, while a linear trend did not. There are however some reservations as to the first phase, where a left-hand side of a U was only weakly supported for the drawing production and not at all for the picture selection: hence the overall pattern followed more a J than a U-shape.

This study demonstrated that indeed, when Visual Realism of drawing is plotted against age across an age range of 2½ to 8½ years, a quadratic pattern fits the data for picture drawing, and, less markedly, for picture selection. In other words, in picture drawing, both the youngest and oldest in the age range exhibited higher proportions of visual realism while those in between displayed more intellectual realism. As to picture selection, it may be argued that this, as a two-choice receptive selection task, was much easier than picture drawing, and therefore presented children as more advanced in Visual Realism than did their scores for picture drawing (Jolley et al., 2001). Even for the youngest children, therefore, the pattern of scores for picture selection had progressed to the right-hand half of the U-shape, and the overall pattern did not exhibit the two-peak J shape found for picture drawing.

My study was informed by Luquet's (1927) account of drawing realism development. Indeed, it is Luquet who popularized the terms 'intellectual realism' and 'visual realism' for the last two stages of this kind of development, after some form of representational drawing has become dominant. Luquet however recognises a number of stages prior to these two, which he discusses under labels such as 'fortuitous realism', 'failed realism' and 'intentional realism'. As far as I am aware, he does not apply the terms intellectual or visual at these earlier stages, where he is more concerned with characterizing child progress in terms of being able, or not, to produce any form of drawing that would be recognized by an adult as figurative representation, i.e. as representing something definite. Nevertheless it makes sense to ask, even at the stage of failed realism, whether what the child failed to fully represent successfully was in fact what they were looking at (visual realism) or a mental representation of an ideal exemplar of something (intellectual realism). My study in effect suggests that there may exist a (probably brief) stage between failed realism and intellectual realism, in Luquet's terms, where the child, given a sufficiently simple object to draw (e.g. a mug or a ball rather than a human figure), may produce a drawing where the realism is not failed, but it is visual rather than intellectual. Such a stage might be termed 'early visual realism'.

Neither Luquet nor anyone else to my knowledge has discussed a possible U-shape in the development of drawing realism in typical children. Instead, a linear or at least monotonic pattern of progression is always claimed or assumed (e.g. Jolley and Rose, 2008). Hence, I drew on more general accounts of U-shaped developmental phenomena such as that presented by Morse and colleagues (2010). This recognized that a variety of phenomena in child development exhibit a U-shaped progression, such as famously the ability to produce irregular verb forms. They share, however, a number of features. The early success is characterized as due to children working in some sense in a local and isolated way. Later the child refines or reorganizes their underlying knowledge, e.g. by seeing general patterns. While this is occurring, performance changes in some instances to what is often from the adult or objective point of view the wrong performance. Finally, the reorganization concludes and new abilities are established in such a way that the correct performance emerges again, while the new cognitive structures are essentially retained. This is very obvious for the irregular verbs where a child initially simply copies what he/she hears, e.g. *toy broke*. Later, however, the child notices that many verbs in the past end in a sound /d/ or /t/, e.g. *walked, loved* and begins to form a mental rule. For a time this generalization dominates their thinking and the child may then say erroneously *toy breaked.* Finally, the child gets to realize that there are exceptions to the generalization and reverts to the correct form *broke* in the case of that verb, although this is now based on knowledge radically different from that before. It is no longer an isolated fact but identified cognitively as an exception relative to a general pattern.

Analogously one can see the child as initially, as soon as they manage to inhibit scribbling and draw something recognizable, trying to draw just what they see in the local context when they are drawing (early visual stage). Later, however they increasingly notice that many objects which they see (e.g. mugs) are in some slightly abstract sense the same, even though they differ in details like colour and precise shape. E.g. they all have handles, are made of some opaque material, are taller than they are wide, and usually contain something to drink. Hence, they begin to form mental categories which incorporate these prototypical features. Temporarily they are captivated by this discovery, so that these categories become their pre-potent response, even when the task is to draw an exemplar that does not have all the features visible (intellectual realism stage). Finally, they manage to inhibit that general response where they are asked to draw what they actually see in a particular context (visual realism stage), although they will of course still draw on the mental category when asked to draw a mug or whatever from their general memory of it. Thus, the cognitive abilities underlying the correct response at the end are quite different from those underlying the correct observed performance at the start.

In conclusion, it must be noted, however, that while the evidence for a quadratic trend of visual realism development with age was undoubtedly supported by the significance tests for both tasks, the existence of a full U-shape, with a clear left-hand side, is more questionable, even for the drawing production task. In fact, the most convincing indication of a full U-shape came only from the drawing task on the first data gathering occasion, when the greatest number of the youngest participants was available (Figure 4.4). Here the mean for Visual Realism achieved a value greater than 0.5 for the youngest group (under 45 months of age), showing that a majority of the drawings were in fact visually realistic. This gave way at higher ages to a majority of intellectually realistic drawings, and a majority of visual drawing was not achieved again until after the age of 75 months.

5.3 Limitations of the study

The field of investigation which the present thesis was engaged with, concerning the development of cognitive and motor aspects of young children, relies heavily for the validity of its conclusions on the careful choice, creation and administration of various tasks suited to the age groups of the children involved, which are used to measure the key variables involved. In the current study, great care was therefore taken in particular to make sure that the key variables of Fine Motor Control, Gross Motor Control, and Inhibitory Control were quantified in ways which uncontestably quantified the intended constructs and were not contaminated by partly measuring each other at the same time. For example, the SRC tasks used to measure Inhibitory Control were chosen from the range commonly used in studies of this variable specifically because they have minimal motor demands. Whilst the day/night task requires only a verbal response, it is true that the grass/snow task and the tapping task require a manual response. Nevertheless, I argue that this is not a limitation since the motor element is undemanding and performed with no time constraints. Therefore, although some might see this a limitation of this task, I deem that it is very unlikely that children with more effective Fine Motor Control performed better on the inhibitory tasks purely as a function of their motor demands.

Related to this point is that in Study 1 I found that the IC measurement tasks, both of which required knowledge of the words *sun* and *moon*, were too difficult for a few children simply due to the fact that they did not know the words *sun* and *moon*. Hence they responded with guessing, which of course meant that on some occasions they gave the right (inhibitory) response purely by chance. I countered this issue however by excluding these children from the analyses, and in the second study remedied this by including the tapping task which measures IC without the requirement for lexical knowledge of this sort.

In Study 3, there was perhaps a limitation related to subject sampling. Despite my efforts to access sufficient children right through the age range of interest, there was in the end a rather limited number of children producing valid drawings (i.e. ones that were sufficiently representational to be able to be scored for exhibiting visual or intellectual realism) in the very lowest age bands (under 45 months). This is reflected in the wide confidence intervals for the lowest age groups represented in Figures such as 4.4. The youngest children are, however, crucial for the demonstration of a clear left-hand side to any U-shaped relationship between age and degree of Visual Realism of drawing. It is undoubted that, as one samples children at successively lower ages below the age of 4, it becomes increasingly difficult to obtain drawings with any degree of figurative representation. Hence clearly very large numbers of such children need to be recruited in order to obtain a really solid basis for claims about a left-hand side to the U pattern. A disadvantage then, however, would be that many children of that age would remain unrepresented in the study, since the majority would still be scribbling. An alternative could be to rely on the picture selection task rather than drawing production at that age. However, that too carries disadvantages since it did not seem from our findings that the pattern of results of the selection task matched that from the drawing task directly at all, but only possibly with a considerable time lag. That is to say that children appear more advanced in development on an easier receptive task such as picture selection than they do on a harder production task such as picture drawing. Hence it may be that, as in our study, relying only on selection data will mean that no U or J shape will ever emerge.

Finally, some difficulties were experienced with the picture selection task. This was administered immediately after the drawing tasks, in the same session, and the researcher noticed that some children seemed unwilling to do it. For this reason, possibly they did not all respond very assiduously, as could be reflected in the somewhat lower item-total correlations obtained for this task compared with the drawing production task. With hindsight, if doing such a study again, it would be advisable not to attempt to administer both tasks in the same session. This would not only combat fatigue, but also the fact that the same objects were represented as had been used in the drawing task (as was desirable so as to control for any object familiarity effect). Some children in fact complained that they were being asked to respond about the very same things that they had just drawn pictures of. If, on the other hand, the selection task was on a different day, the drawings they had made themselves would not be fresh in their minds. The selection task could also be made more appealing to young children if presented, for example, on a tablet with the response being to place a sticker on the preferred picture, rather than in hard copy with the response being merely to point.

Other possible limitations concern further variables which, in retrospect, might usefully have been included, which will be considered in section 5.5.

5.4 Implications

This study has implications of a number of types. First, as summarized in 5.2, there are at least two considerable implications for theory. In particular the study has contributed substantially to finding an answer to the issue of which of the three currently suggested accounts of the relationship between IC and drawing skill is correct. My work has importantly shown that there is in fact no single answer to the issue of which account is correct. It depends on what drawing skill is considered. Thus while the Motor Development account seems suitable to explain development of figurative, representational aspects of young children's drawing, it is the Behavioural Inhibition account which better explains the development of visual realism.

Secondly, the non-linear relationship between age and visual realism of drawing which I uncovered is in striking contrast to the predominant finding of recent decades, albeit with slightly older children than mine, that visual realism simply starts low and increasingly supplants intellectual realism. Although a U shaped development starting in children at pre-school age is well known in certain areas, such as the development of irregular language forms, it was somewhat of a novelty to find it in a similar age range in an area such as drawing development.

We might speculate however that there could be a similar underlying mechanism. Very young children have an under-developed cognitive apparatus, and so rely heavily on input to guide their production. If they hear *mice* they say *mice*. If they see a mug without a handle in view, they draw it without a handle. As their cognitive ability develops, however, they establish mental categories, patterns or rules. When more than one thing is spoken of, the word usually ends with /s, z, iz/. If a cup or mug is to be seen, it almost always has a handle. There is a period then when their production over-relies on the cognitive model at the expense of perceived input. Just as some words come with irregular plurals but are said as if regular by the child (*mouses* rather than *mice*), so also some mugs come with handles missing or hidden but are drawn as if prototypical (with a handle rather than without). In both cases IC seems to be involved to eventually ensure that reality triumphs over the child's cognitive representation of reality. If further work supported the parallelism of development here, that would, for example, have considerable implications for those who believe that language acquisition is in some way a different kind of process (a separate 'module') from the general development and learning processes of young children.

Second, there are implications for research practices. For instance, as just indicated, it seems that researchers in future need to speak less about 'drawing skill(s)' as if they were a uniform construct, and pay more attention to separate subskills. Furthermore, my findings combine to suggest that including drawing tasks in measures of EF or FMC needs considerable care, and might best be avoided. With respect to FMC, drawing measures would need to be used that focused on figurative representation and detail rather than realism. With respect to EF, a measure focused on visual realism would be relevant, but the complexity of the relationship between visual realism on the one hand and age and IC on the other makes it difficult to use such a drawing score as a simple linear indicator of IC. That point is relevant both for research and pedagogical or therapeutic uses of standard measures of EF or FMC which include drawing measures

Third, one may speculate about the practical applications of the research which is reported here. Although my studies were all ‘pure’ in nature, there are potential implications for the practices of teachers and therapists who are concerned with young children’s drawing. In particular it is surely of value for them to understand better what aspects of a child’s drawing can be interpreted as requiring good motor control and which not. Only then, for example, can they better judge where the common intervention of practicing drawing simple shapes and lines, which targets FMC, is really going to be relevant to assist the child’s development.

Finally, the study has implications for how research may usefully proceed in future in this area, to which I now turn.

5.5 Suggestions for future research

During my study, several specific points came to my attention as needing further work. In Study 1, for instance, I feel that although my design adequately dealt with the Motor Development account and the Behavioural Inhibition account, the Symbolic Competence account (Riggs et al., 2013) was not adequately considered. This was due to the fact that I did not include a measure of Symbolic Understanding, and it is central to the Symbolic Competence account that Inhibitory Control is primarily associated with the domain-general development of Symbolic Understanding, through whose mediation it has an effect on drawing skill development. In order, definitely to discount this theory it would be necessary to conduct a study similar to Study 1 but with a measure of Symbolic Understanding included as well, so as to ascertain what role if any that plays in relation to Inhibitory Control and Fine Motor Control, with respect to the development of either Figurative Representation or Detail of drawing, or indeed Visual Realism. While my study has, for the targeted age group, supported the Motor Development account as an explanation of the development of Figurative Representation and

Detail and the Behavioural Inhibition account as an explanation of the development of Visual realism, it has not been able to show whether Symbolic Understanding also plays a key role in any of those.

Another possible future line of inquiry concerns the role of IQ. In Study 2 I included this as a control variable and interestingly it emerged with significant relationships with Fine Motor Control but not with Inhibitory Control or Gross Motor Control, in analyses where all these were included. This is intriguing and requires follow up investigation.

With respect to Study 3, clearly more work needs to be done to confirm the partial U-shape which I found. In particular a study with more participants at the low end of the age scale and able to produce pictures with enough figurative representation to be scored for visual versus intellectual realism, are needed (as discussed in 5.3). It would also be valuable, however, to conduct such an study again with Inhibitory Control (and possibly also Symbolic Understanding) included as a variable, given that we have demonstrated its key role in explaining Visual Realism development through the Behavioural Inhibition account. Furthermore, in the light of my speculation concerning possible poverty of development of mental categories as an explanation for an early phase of drawing with visual realism, it would be informative to include a measure of mental category formation. Only then could we ascertain whether in fact the very early tendency (prior to age 4 years) to draw with somewhat greater visual realism is in fact due to inhibition for some reason of a pre-potent tendency to draw with intellectual realism or rather to a lack of the mental categories upon which drawing with intellectual realism depends.

Looking now more broadly, my study is the first to show a link between Inhibitory Control, Fine Motor Control and drawing in typical preschool children. My data suggests that the mediation of Fine Motor Control provides an explanation of the relationship between inhibition and emergence of figurative drawing skills, while this mediation is not the case for visual realism of drawing. Future research needs to bring together data which illuminates the link between inhibition and motor control in the performance of a variety of tasks (not just drawing) across both infancy and childhood, in order to establish a coherent theory. In particular, it needs to be established which tasks are influenced by inhibition only through the mediation of some aspect of motor control, and which are directly impacted upon by inhibition.

Linked to that, an obvious additional broader extension of my work is that there is a need to look at the role of other aspects of the executive function than Inhibitory Control in relation to Fine and Gross Motor Control as they affect the drawing skill variables and indeed other tasks. In particular Working Memory stands out as a further very important component of the executive function whose role needs to be established. An example of its role is to be found in the 'A not B task', where the aim of the task is for the infant to find an object hidden at a new location after finding it before at another location. To be able to find the object at the new location, both Inhibitory Control and Working Memory need to work alongside the motor system (Thelen, Schöner, Scheier & Smith, 2001). The Dynamic Systems theory proposed by Smith and Thelen (2003) highlights the interactions between the executive and motor domains, whereby activity in one domain has cascading effects on the other. Such interactions between these domains are reflected in the close neural connections and co-activation of the brain regions associated with those domains (Diamond, 2000; Koziol et al, 2012).

On top of all the above, I feel that there is a great need for longitudinal studies of child development. At the age of 1, infants usually begin to walk, hence maximizing the role of Gross Motor Control in relation to executive function. By the age of 2, infants are exploring their environment. Later on, Fine Motor Control is more prominent, allowing for the development of skills in preschoolers, such as drawing and dressing. These relationships can be studied in a more refined way, however, where individual differences between children are controlled, by using a within subjects rather than a between-subjects design. A more longitudinal approach should therefore be used in future research to aid better understanding of the inter-relations between

Inhibitory Control and Working Memory, and the two kinds of Motor Control, in their impact on tasks, and all these links may change at different ages. In my study, I included a longitudinal component in the third study but not in the first two, so this remains a gap. Longitudinal studies are, of course, less common in the literature because of the amount of time they take and difficulties associated with subject attrition.

5.6 Conclusion

In conclusion, this study has explored the linked themes of the pattern of the young child's drawing skills development, and the roles played in that by IC and motor control. The main findings are that IC has a direct impact on one kind of drawing skill (visual realism) while it impacts others (figurative representation and detail) via FMC (but not GMC). Along with that, the pattern of development with age and IC of the visual realism drawing skill is J shaped rather than linear.

I look forward to the day when we possess a much more comprehensive theory to explain how specific components of executive function are linked to specific components of motor control in relation to a wide range of tasks all through child development. Although a great challenge, this would surely represent a major step forward in our understanding of cognitive development.

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Appendix A. Sample Consent Form

Study 1

University of Essex

Participant Information Sheet

Dear Parent/Guardian,

For my PhD research I am studying young children. In this study I am interested in how children's ability to draw pictures changes over time and how that might be related to other abilities of the children. Your child will be asked to draw some pictures and to do some tasks to measure some of their other abilities. Those tasks will involve only everyday activities like pointing at pictures, placing blocks in a shape, and folding paper.

We will ask your child’s permission before we begin the study, and they can stop at any point.

The data will be collected in strict accordance with Essex University’s ethical standards, under the supervision of Dr Andrew Simpson (asimpson@essex.ec.uk). The results may be presented at conferences and in academic publications, however, we will only present results averaged over many participants, and your child’s individual scores will never be identifiable. The full data will only be available to the members of the research team, and will not be linked to any personal information that you supplied.

I would like to emphasise that the project is not designed to assess any individual child’s performance in any way. Rather, the aim is to examine some abilities of children of different ages and how they are related. If you would like any more information about this study or its results, please feel free to contact me at rfsalr@essex.ac.uk. I’ll be glad to answer your questions at any time.

Thank you in anticipation for your help.

Reshaa Alruwaili
Department of Psychology
University of Essex

OPT IN FORM: How are IC and Fine Motor Control related to the development of preschool children's Drawing Skills?

I consent for my child...……………………………….. to take part in this study.

______________________________ ______________________________

Parent/Guardian's Name (Printed) Child's name (Printed)

____

Parent/Guardian (Signature)

In addition, we would like to use some of the drawings from this study to help our students learn about child development. If you are content for your child's drawings to be shown to our students please sign below.

____

Parent/Guardian (Signature)

Appendix B. Sample Consent Form Study 2

University of Essex

Participant Information Sheet

Dear Parent/Guardian,

For my PhD research I am studying young children. In this study I am interested in how certain abilities of children are related. Your child will be asked to do some tasks to measure the abilities I am interested in. Those tasks will involve only everyday activities like placing blocks in a shape, finger touching, catching a ball, and walking backwards.

We will ask your child's permission before we begin the study, and they can stop at any point.

The data will be collected in strict accordance with Essex University's ethical standards, under the supervision of Dr Andrew Simpson (asimpson@essex.ec.uk). The results may be presented at conferences and in academic publications, however, we will only present results averaged over many participants, and your child's individual scores will never be identifiable. The full data will only be available to the members of the research team, and will not be linked to any personal information that you supplied.

I would like to emphasise that the project is not designed to assess any individual child's performance in any way. Rather, the aim is to examine some abilities of children of different ages and how they are related. If you would like any more information about this study or its results, please feel free to contact me at rfsalr@essex.ac.uk. I'll be glad to answer your questions at any time.

Thank you in anticipation for your help.

Reshaa Alruwaili
Department of Psychology
University of Essex

OPT IN FORM: How are IC, Fine Motor Control, Gross Motor Control, and IQ associated in preschool development?

I consent for my child...……………………………….. to take part in this study.

______________________________	______________________________
Parent/Guardian’s Name (Printed)	Child’s name (Printed)

____

Parent/Guardian (Signature)

Appendix C. Sample Consent Form Study 3

University of Essex

Participant Information Sheet

Dear Parent/Guardian,

For my PhD research I am studying young children. In this study I am interested in exactly how children's ability to draw pictures changes over time. Your child will be asked to draw some pictures of objects presented to them. Then they will be shown pictures and asked which picture best represents objects which they see. I am hoping you will be able to help me with this on three occasions, six months apart.

We will ask your child's permission before we begin the study, and they can stop at any point.

The data will be collected in strict accordance with Essex University's ethical standards, under the supervision of Dr Andrew Simpson (asimpson@essex.ec.uk). The results may be presented at conferences and in academic publications, however, we will only present results averaged over many participants, and your child's individual scores will never be identifiable. The full data will only be available to the members of the research team, and will not be linked to any personal information that you supplied.

I would like to emphasise that the project is not designed to assess any individual child's performance in any way. Rather, the aim is to examine drawing skills of children of different age. If you would like any more information about this study or its results, please feel free to contact me at rfsalr@essex.ac.uk. I'll be glad to answer your questions at any time.

Thank you in anticipation for your help.

Reshaa Alruwaili
Department of Psychology
University of Essex

OPT IN FORM: Is the development of visual realism in children's drawing linear or U-shaped?

I consent for my child...……………………………….. to take part in this study.

______________________________ ______________________________

Parent/Guardian's Name (Printed) Child's name (Printed)

____

Parent/Guardian (Signature)

In addition, we would like to use some of the drawings from this study to help our students learn about child development. If you are content for your child's drawings to be shown to our students please sign below.

____

Parent/Guardian (Signature)