Do as I say, not as I do: Insights From Behavioural and fNIRS Research Into the Role of Inhibitory Control in Resisting Imitation in Young Children.

Anne L. Franks

A thesis submitted for the degree of

Doctor of Philosophy (PhD)

Department of Psychology

University of Essex

January 2024

Impact of COVID-19

On March 13, 2020, the University of Essex announced a series of 'enhanced protection measures' to prevent the spread of coronavirus amongst students, staff and the public which took effect on Monday 16th March 2020. Included in these measures was the suspension of all face-to-face testing both on and off campus. This measure ended up being in place for a total of 16 months and necessitated a deviation from the original plan of collecting all data face-to-face. This COVID-19 measure caused significant disruption to the progress of this PhD for several reasons.

Firstly, since the data collection for my first study (described in Chapter Two) was split across two testing sessions held on different days, I ended up in a situation where 30 participants had been tested on session one but were not able to be tested on session two. This resulted in the loss of this data since the planned repeated measures analysis required data for all conditions.

In addition, being only part-way through data collection on my first study meant that I was unable to utilise those 16 months to focus on data analysis, publications or writing up and instead had to make significant changes to the trajectory of this thesis. For instance, in Chapter Three I used an existing data set which was associated with various limitations including a lack of control over the amount of valid data available and the tasks included in the analyses. Had I been able to collect the data myself, it is likely that I would have chosen different tasks to work with which may have suited my hypothesis better.

The prolonged period of restrictions also resulted in one of the studies in Chapter Four being presented online rather than face-to-face. This too resulted in several limitations including high levels of non-compliance/distraction and issues with internet connections which made the measure of reaction time too unreliable for analyses.

But despite these limitations and the changes that altered the trajectory of this thesis, I do believe that the final result shows the flexibility and growth that come from working through adversity.

Declaration

I declare that the work presented in this thesis, “Do as I say, not as I do: insights from behavioural and fNIRS research into the role of inhibitory control in resisting imitation in young children.” is my own. I have used the editorial ‘we’ rather than ‘I’ throughout this thesis to acknowledge contributions from my supervisors and the collaborate nature of this empirical research. Any quotations have been distinguished by quotation marks and all sources of information are specifically acknowledged. None of the work in this thesis has been submitted for a higher degree at this or any other University or institution.

Anne Franks

Acknowledgements

This thesis is dedicated to my Mum, Pauline Franks.

Mum was my inspiration, and it was her love of science which undoubtedly fuelled my own curiosity and inquisitiveness. I am painfully saddened that she will not get to share in this achievement with me, as she had been my biggest supporter throughout this arduous journey. It was the immense pride she held for me which gave me the encouragement to finish this thesis. Her love and selflessness as a mother mean that any achievements of mine are a testament to her. It is therefore only befitting that this thesis be dedicated to her memory.

I also owe inexplicable thanks to my supervisors, Dr Carina de Klerk and Dr Andrew Simpson. Thank you both for your unwavering support, guidance, and expertise throughout this entire journey, but especially over the last six months. At a difficult time in my life, you gave me strength, hope, and the self-belief to accomplish this thesis. It simply would not have been possible without you both and I can't thank you enough for that. I am honoured to have been your PhD student.

Andrew, at many times you have believed in me more than I believed in myself. It is impossible not to respect and admire a man who has managed to achieve not one but two theses! You are undeniably an expert within your field, and I feel proud that I have made a unique contribution to this literature under your masterly expertise.

Carina, tijdens mijn doctoraat, was je een mentor, een vriendin, en een rolmodel. Je intellect, werklust, oog voor detail en toewijding aan je studenten is ongeëvenaard.

Ik kan alleen maar streven om meer op jou te lijken. ‘Dankuwel’ lijkt niet voldoende om mijn dankbaarheid uit te drukken voor alles wat je voor mij hebt gedaan.

I am grateful to many people within the Psychology Department, but especially to Dr Nicholas Geeraert for making stats lectures bearable even at 9am on a Monday morning; to Woakil and the Tech team for their programming help; to my fellow PhD students for sharing the ups and downs of PhD life with me; to Trudi and the administrative team; to the Essex Babylab team; and lastly to the Undergraduate and Masters students who have assisted in my studies.

I would also like to thank all of the families who have participated in my studies. Without your contributions, this research would not have been possible.

Special thanks are owed to Mark for being so supportive throughout this entire journey. Whether it was bringing me endless cups of coffee, cooking me dinner, or listening to me complain about juggling a PhD alongside my other jobs, you have been there with me through all of the ups and downs. Thank you so much for your patience, love and understanding through it all and for helping me prioritise what was important.

Finally, I acknowledge my family and friends who have given words of encouragement and have been supportive and understanding of what a huge undertaking this has been. Particular thanks go to Lorna, Emily, Katie, and Ant who have all been willing pilot participants, as well as to Ramy for his unrelenting patience and support.

Table of contents

List of Tables and Figures

Abstract

This thesis examines the debate around the role of domain-general versus domain-specific mechanisms in the inhibition of imitative responses. In other words, whether there are differences between the mechanisms underlying the inhibition of imitative responses as compared with non-imitative responses. While most of the research on this topic so far comes from patients with brain damage to the frontal lobes, here we proposed that given the immature prefrontal cortex in the developing brain, young children are ideal subjects to investigate this topic. Studies in this thesis sought to contribute to this debate by testing the inhibition of imitation in children between the ages of three to five years. Study 1 presented a new inhibitory task in which the rule teaching was standardised. Comparison against a control condition demonstrated that this task was effective even in young children. In Study 2 we investigated the relationship between children's poor inhibitory control and their tendency to imitate using an existing data set. Whilst the planned correlations were not significant, exploratory analyses revealed that, contrary to our expectations, children with better inhibitory control demonstrated greater imitative tendencies. Building on this work, the aim of the final two studies was to design a task with well-matched methodologies to test the inhibition of imitative and non-imitative prepotent responses in young children. Study 3 was conducted online with children aged 3-5 years due to COVID. Based on the findings, Study 4 used this same task to investigate the neural correlates of inhibiting imitative and non-imitative responses in 4-year-olds. We suggest that these results provide tentative evidence of a domain-specific network associated with the inhibition of imitative tendencies. The work presented in this thesis has introduced the study of

imitation inhibition within a developmental population with promising results, providing interesting avenues for future research.

Chapter One

An Introduction to Investigating Inhibitory Control in Young Children

1.1 Introduction

As humans, we are all products of our environment. This creates a need to be adaptable to changing situations and constantly monitor the world around us in order to change our behaviour to respond accordingly. A lot of the time, this control of our behaviour relates to being able to inhibit specific actions. For example, we know that if we want to lose weight, we must suppress the urge to eat the chocolate cake that has been offered to us. Or similarly, when we take offence to someone's insulting comment, we know we will need to bite our tongue if we are not in a place to cause a scene. Or when we have stepped off the curb to cross the road, we must stop abruptly when a car suddenly appears out of nowhere. It is our inhibitory control which allows us to suppress these actions, thoughts, and behaviours that are inappropriate or incompatible with our current goal. Adele Diamond remarks "Without inhibitory control we would be at the mercy of impulses, old habits of thought or action (conditioned responses), and/or stimuli in the environment that pull us this way or that. Thus, inhibitory control makes it possible for us to change and for us to choose how we react and how we behave rather than being unthinking creatures of habit." (Diamond, 2013, pp. 137).

Inhibitory control is just one of several important mental processes, called "executive functions", which together are responsible for goal-directed behaviours. These mental processes enable us to plan, recall instructions, focus our attention on a goal and successfully juggle multiple tasks at once (Diamond, 2013). As adults, most of us are adept at using inhibitory control and controlling our behaviours. However, this is not the case for younger children – we've all heard of the terrible twos! Inhibitory

control takes years to develop (see Petersen et al., 2016) and as such, young children have yet to hone this skill. This is, in part, because our executive functions are facilitated by the prefrontal cortex (PFC), which is characterised by an extended period of development, taking over two decades to reach full maturity (Diamond, 2002; Haartsen et al., 2016). The prolonged development of the PFC has therefore been associated with young children's tendency to show deficits in inhibitory control.

Thus far, research into the development of inhibitory control has primarily focused on young children's ability to inhibit a learned response, such as the tendency to correctly label pictures (e.g. in the Day/Night task; Gerstadt et al., 1994) or to inhibit a physical action such as a button press (e.g. in the Go/No-Go task; Dowsett & Livesey, 2000). However, a phenomenon related to the inhibition of *imitative responses,* that was identified within the adult literature, has so far been overlooked in developmental studies. In the 1960s, neuropsychologist Alexander Luria observed that some patients with prefrontal lesions were unable to stop themselves from copying others' actions, a phenomenon called 'echopraxia' (Luria, 1966). In this way, patients with echopraxia appear to display some of the inappropriate imitative tendencies of young children (Diamond and Taylor, 1996).

With the development of neuroimaging techniques, the 2000's brought about a new interest in the association between the PFC and the inhibition of imitative responses in the adult literature. In a series of seminal studies conducted over the subsequent decade, Marcel Brass and his colleagues set out to establish the role of the prefrontal cortex in association with the inhibition of imitative responses, with particular focus on

echopraxia patients who demonstrate difficulties with this (Brass et al., 2001; 2003; 2005; 2009).

Perhaps surprisingly, they identified that frontal lesion patients who demonstrated impaired performance on the Stroop task did not demonstrate the same impairments on an imitation–inhibition task and vice versa (Brass et al., 2003). This provides evidence of a double dissociation between the inhibition of imitative and non-imitative responses, suggesting that the inhibition of imitative responses might be facilitated by a domain-specific neural network. More generally, the assumption had been that all types of inhibition are underpinned by a domain-general inhibitory network which is part of the Multiple Demand (MD) network and involves areas including the dorsolateral prefrontal cortex (dlPFC) and the inferior frontal gyrus (IFG – Darda & Ramsey, 2019). Keen to investigate the finding of double dissociation further, Brass and colleagues followed their earlier work up with a neuroimaging study (Brass et al., 2005). In this study, they identified that the Stroop task and the Imitation-Inhibition task seem to invoke different cortical and functional mechanisms, with the Imitation-Inhibition task recruiting areas such as the medial prefrontal cortex (mPFC) and the right temporoparietal junction (rTPJ).

Although this double-dissociation has been investigated in adults (Brass et al., 2003; 2005; 2009), thus far, only a few studies have been conducted to investigate the domain-general versus domain-specific debate in relation to the inhibition of imitative responses in young children. Based on the research conducted by Brass and colleagues, one would expect young children who have underdeveloped inhibitory control to look

a lot like the echopraxia patients, showing a pervasive tendency to copy others. Indeed, young children do seem to show a strong tendency to copy other's actions (Horner & whiten, 2005; McGuigan et al., 2007). However, thus far there have been few studies that have looked at the relationship between inhibitory control and imitation inhibition in a developmental population. Given that between the ages of 3-5 years we see a particularly accelerated period of improvement on developmental inhibitory control tasks (Carlson & Moses, 2001; Gerstadt et al., 1994; Simpson & Riggs, 2005a, 2005b), this population may provide particularly useful insights into this debate. Children of this age range are not yet demonstrating ceiling levels of performance on inhibitory control tasks, meaning that they produce a lot of variability in their scores. This, coupled with their developmental prefrontal cortex immaturity make this an ideal population to assess the neural correlates involved in inhibiting imitative vs non-imitative response tendencies.

1.1.1 Research Questions

The overarching aim of the current thesis was to better understand the inhibition of imitative tendencies in young children, and to try to elucidate the conflicting evidence seen in the adult literature. Throughout this thesis, we therefore focus on three predominant research questions. Firstly, 'Q1: What is the best way to measure inhibitory control in young children'; Secondly, 'Q2: Is poorer inhibitory control in children related to a greater tendency to copy others' actions?' And lastly 'Q3: what are the neural mechanisms involved in inhibiting imitative responses? Is the inhibition of

imitative responses ‘special’ in that it involves activation of the social brain network rather than the domain-general inhibitory control network?’.

In order to investigate research questions 1 and 2, it was necessary to first carefully consider the tasks currently used to investigate inhibitory control in young children. Section 1.2.2 provides a detailed discussion of what makes a good measure of inhibitory control. This was taken into account when developing and testing a new inhibitory control task which is presented in Chapter Two, thus addressing the question ‘What is the best way to measure inhibitory control in young children?’. The study presented in Chapter Three is the first to begin to address the question ‘Is poorer inhibitory control in children related to a greater tendency to copy others’ actions?’, by exploring whether there is an association between young children’s score on an inhibitory control task and their tendency to show overimitation. Chapter Four then introduces the final two studies. The first of these is an online behavioural study using a task similar to that introduced in Chapter Two, but with the addition of an imitation-inhibition condition. The second study presented in Chapter Four uses this same task, but this time in a laboratory setting using functional near-infrared spectroscopy (fNIRS) with children aged 4 years. This final study aims to provide answers to research question 3: ‘what are the neural mechanisms involved in inhibiting imitative responses? Is the inhibition of imitative responses ‘special’ in that it involves activation of the social brain network rather than the domain-general inhibitory control network?’. The remainder of this chapter will give an overview of existing behavioural and neurophysiological literature on the inhibition firstly of non-imitative responses, and then introduce the

topic of inhibiting imitative responses. It will also discuss the limitations of previous work and the outstanding questions that motivated the current research.

1.2 Inhibitory Control

Inhibitory control – the capacity to suppress thoughts and behaviours incompatible with current goals – plays an important role in early cognitive development (Davidson et al., 2006; Isquith et al., 2004; Senn et al., 2004). For example, it can predict children's school achievement in mathematics and reading (Blair & Razza, 2007; Bull & Scerif, 2001; Willoughby et al., 2012). One reason that inhibitory control is so impactful on children's development is because it can be used in two different ways: to immediately suppress a goal-inappropriate response or to maintain the suppression of a response over time (Allan & Lonigan, 2014; Carlson & Moses, 2001; Garon, 2016; Simpson & Carroll, 2019). The former is sometimes referred to as cognitive control, response inhibition or inhibitory strength, while the latter is termed delay of gratification, effortful control or inhibitory endurance. Response inhibition enables children's thinking to be flexible (Blakey et al., 2016) and creative (Cassotti et al., 2016), as well as improving their reasoning skills in many domains (Houde & Borst, 2015). Additionally, children with good delay of gratification skills are better able to resist temptation (Kochanska et al., 2001), as well as to make later gains in their social skills (Bassett et al., 2012), well-being (Pauli-Pott et al., 2014), and academic performance (Duckworth & Seligman, 2005). The studies contained within this thesis focus on response inhibition. As such, any further mention of

‘inhibitory control’ will refer specifically to the type of inhibitory control required for response inhibition.

1.2.1 Ways of measuring inhibitory control

The way in which we measure inhibitory control has evolved over the past few decades. This section will provide an overview of some of the most popular types of inhibitory control tasks including the SRC task and the Go/No-go task – both of which are used within this thesis. One of the earliest tests used to measure inhibitory control is the Stroop task. First developed and published by John Ridley Stroop back in the mid-1930s, the Stroop task requires participants to label the colour of the ink that a word (the name of a colour) is written in (Stroop, 1935). In some cases, the colour of the ink is congruent with the word written (e.g. the word ‘GREEN’ is printed in green coloured ink), and in some cases the colour of the ink is incongruent with the word written (e.g. the word ‘GREEN’ is printed in red coloured ink). It was noticed that adult participants struggled more in the incongruent condition than the congruent one, and even when they answered correctly, it would take them longer. This observed delay in reaction time when faced with an incongruent stimulus is known as the Stroop effect. The incongruent trials result in longer response times because they require participants to inhibit the strong tendency to attend to the written word, rather than the colour of the ink it is printed in.

Although the Stroop task is not suitable for use with young children since it requires the participant to be able to read, there are many tasks which have been adapted

for use in developmental studies. One of the most popular categories of task is the Stimulus-Response Compatibility (SRC) task, in which participants are required to produce response A when presented with stimulus *b*, and to produce response B when they are presented with stimulus *a* (Petersen et al., 2016). In this way, SRC tasks are based on the Stroop principals. A classic example of an SRC task suitable for use with young children is the Day-Night task (Gerstadt et al., 1994). In this task, children are instructed to say "day" when they are shown a picture of a black card with a moon on; and to say "night" when they are shown a picture of a white card with a sun on. The Day-Night task also includes a control condition, in which children are instructed to respond "day" when they are shown one abstract picture (e.g. a black background with two white ribbon-like shapes) and to respond "night" to another abstract picture (a black and white chequerboard-like pattern).

The use of a control condition allows researchers to compare performance between the two conditions, and if children perform more poorly on the experimental condition than the control condition, we can be confident that their decreased performance is due to the inhibitory demands of the task, and not something else, such as the working memory demands. The control condition is similar to the experimental condition in that it requires children to learn, remember and apply the task rules (e.g. when you see a chequerboard, say "night"), in exactly the same way as the experimental condition (e.g. when you see a sun, say "night"). However, since there is no prior association between a chequerboard and the word "night", it should not require the use of inhibitory control to prevent the inappropriate response (day) from being made. In the experimental condition, seeing the picture of the sun automatically primes the

response “day”, which must be supressed in order for the correct response “night” to be given instead (Simpson & Carroll, 2019). The Day-Night task is just one example of the numerous types of SRC task used to study inhibitory control in young children.

Another SRC task used to test inhibitory competence in children is the Grass-Snow task (Carlson & Moses, 2001). This task is very similar to the Day-Night task, but rather than the child giving a verbal response to a visual cue, the Grass-Snow task requires children to point to the required visual stimuli when a verbal cue is given (Passler et al., 1985). For instance, when the experimenter says the word “grass”, the child is required to point to the white square, and when the experimenter says the word “snow”, the child is required to point to the green square. Although both the Grass-Snow and Day-Night tasks are originally named after the specific stimuli used, these tasks are generally defined by the *modality* of the stimuli and response they use. In other words, ‘when I say this, you point to this’ is the Grass-Snow methodology whilst ‘when I show you this, you say this’ is the Day-Night methodology. Both methodologies now have numerous iterations in which the methodology remains the same, but the stimuli vary, for instance the Sun/Moon, Black/White, Cat/Dog, Happy/Sad, Yes/No, Bird/Dragon, Boy/Girl, Big/Little, Up/Down, Car/Book, and Red/Blue tasks are all variants of the Day-Night task, while the Rain/Snow, Table/Chair, Fork/Knife, Mommy/Me and the Car/Boat tasks are examples of variants of the Grass-Snow task (see Petersen et al., 2016 for a review). In fact, some of these tasks have been used in different variations which include both the Day-Night and Grass-Snow methodologies, for instance the Sun/Moon, Car/Boat, Table/Chair, Fork/Knife, Red/Blue, and Mommy/Me tasks.

The SRC paradigm of 'produce response A when presented with stimulus *b*, and to produce response B when they are presented with stimulus *a'* is often used in the literature to test 'response inhibition' or 'interference inhibition'. Alongside SRC tasks, exists another type of inhibition, namely 'motor inhibition'. Motor inhibition tasks test participants' ability to refrain from making an action response such as a button press. A popular type of task used to measure motor inhibition is the Go/No-go task. In the Go/No-Go task, participants are required to observe a series of visual stimuli and to respond (often with a button press) on 'Go' trials and refrain from making a response on 'No-go' trials. The 'Go' trials typically occur more frequently, in order to build up a prepotent response. As with SRC tasks, there are many variations of Go/No-go tasks used. For example, some studies require children to press a button when they see a red light ('Go' trial), but to refrain from pressing the button when they see a blue light ('No-go' trial) (Dowsett & Livesey, 2000) while others require children to tap a touchscreen when they see a fish, but to refrain from tapping the touchscreen when they see a shark (Howard & Okely, 2015).

A popular variation of the Go/No-Go task is the 'Simon Says' task. In this task, children are required to perform an action which is commanded and demonstrated by the experimenter but only if it is preceded by the phrase "Simon says". Examples include the experimenter saying "Simon says touch your nose" whilst touching their nose, or "stamp your feet" while stamping their feet. In the first example, children would be required to touch their nose (Go trial), whilst in the second example they would be required to withhold a response (No-go trial) since the command was not preceded with the phrase "Simon Says". The Simon Says task was first seen in the Psychology

literature back in the 1970s (Strommen, 1973). Versions of the Simon Says task include the Bear/Dragon (Kochanska et al. 1996; Reed et al., 1984), Bear/Elephant (Jones et al., 2003), Dog/Dragon (Floyd & Kirby, 2001) and Panda/Lion (Wang et al., 2022) tasks to name a few. In these tasks, children are usually seated in front of two large toy animals and instructed to follow the commands of one toy (Go trials) but not the other (No-go trials).

In summary, researchers have a lot of different tasks at their disposal, but there is evidence that different task variations may be suited to differing age ranges. The following section will discuss the way in which inhibitory control develops over childhood and the subsequent suitability of some of the tasks mentioned in the current section.

1.2.2 The development of inhibitory control

A growing body of literature has demonstrated that some form of inhibitory control is already evident before a child reaches their first birthday (Diamond, 2002; Diamond et al., 2007; Garon et al., 2008; Wolfe & Bell, 2007). In fact, some new evidence suggests that this could even be emerging from as young as 6 months of age (Holmboe et al., 2021). This ability continues to improve right up until early adolescence (Levin et al., 1991; Luna et al., 2004; van den Wildenberg & van der Molen, 2004; Williams et al., 1999), but nowhere is this increase more substantial than the preschool years. A remarkable, rapid improvement in inhibitory control performance occurs between the ages of 3-5 years on behavioural tasks, signifying a

distinct period of accelerated development (Garon et al., 2008; Garon et al., 2014; Holmboe et al., 2021; Reed at al., 1984; Simpson & Riggs, 2005a). For instance, Jones and colleagues (2003) used the Bear/Elephant task to compare three age groups (36–38 months; 39–41 months and 46–48 months). They found *all* children performed well on the 'Go' trials with no age group scoring below 90% accuracy. However, on the 'No-go' trials, the youngest children (36-38 months) scored much lower than the older children in the sample (46-48 months) with scores of 22% and 91% respectively, indicative of this period of rapid growth in inhibitory control between the ages of 3-5 years.

Given this important period of rapid development, many researchers have been keen to study the developmental trajectory of inhibitory control. However, because this period of development is so rapid, most tasks encounter floor and ceiling effects outside a span of just a few years, which means that studying the developmental trajectory of inhibitory control is all-the-more difficult (Petersen et al., 2016). The current thesis focuses on just the age range from three years up until almost six years, since this is the age range in which we see the most substantial improvements in inhibitory control.

In an effort to assess the continuity and age-appropriateness of some of the various tasks used to measure inhibitory control, Petersen and colleagues (2016) conducted a meta-analysis comparing 198 studies. Across these 198 studies, a total of 13 different inhibitory control tasks were tested and a 'useful' age range was determined for each task based on upper and lower limits of 20% and 80% accuracy on each task. Overall, the meta-analysis determined that the useful age ranges of the tasks assessed

generally overlapped one another. For example, the most useful age ranges for both the Day-Night task and the Grass-Snow task are 33 to 71 months and 30 to 69 months respectively (Petersen et al., 2016). This provides good empirical evidence that these tasks are indeed well-suited to measuring inhibitory control in children aged between three to five years.

The analysis also revealed that different variants of the GNG can have quite substantially different age ranges. For instance, the Bear-Dragon task was found to have a suitable age range of 33 to 54 months, whilst the Simon Says task had a useful range of 58 to 86 months. Considering both the Bear-Dragon task and the Simon Says task are based on the GNG paradigm, it seems striking that one task seems so much more difficult than the other (Marshall & Drew, 2014). When comparing these two tasks in more detail, we see that whilst both tasks require children to withhold an action response on the inhibitory trials, the way in which this is done differs. For instance, in the Simon Says task the experimenter both verbalises and performs the commanded action regardless of whether it is a 'Go' trial or a 'No-go' trial. However, in the Bear/Dragon task children are told to follow the commands of one animal every time, and to always ignore the commands of the other animal. Children find the Simon Says task particularly difficult because they must inhibit both their own performance of the commanded action and their tendency to imitate the adult model on some of the trials (No-Go trials) but allow themselves to imitate on others (Go trials). Conversely, in the Bear/Dragon task, the 'Go' and 'No-go' trials are far more distinguishable from one another, likely making them easier to remember. In addition, performance on the Bear/Dragon task may also be aided by the fact that the 'command' animal only verbalises the command, it does

not perform the actions and so the inhibitory demands of the Bear/Dragon task are not as high as those of the Simon Says tasks (Marshall & Drew, 2014).

The review conducted by Petersen and colleagues (2016) highlights the importance of the need to be selective when choosing an age-appropriate inhibitory control task for a developmental population.

1.2.3 Finding a good measure of inhibitory control

Based on the findings of their meta-analysis review – that the *useful* age range of each individual developmental inhibitory control task spans only a few years – Petersen and colleagues (2016) argue that "to make inferences regarding developmental change, we must use equivalently functioning and construct-valid measures across time" (Petersen et al., 2016, p. 44). The authors, therefore, put forward several recommendations for researchers planning to conduct longitudinal research. Whilst the studies in the current thesis are not longitudinal designs, many of the recommendations also seem applicable to cross-sectional research in order to identify the best measure of inhibitory control for the research being conducted. These recommendations include careful selection of the task to achieve the 'purest' measure of inhibitory control, the developmental appropriateness (i.e. a measure that most children of the same age are capable of), and the developmental sensitivity (a measure that provides enough variability to enable the assessment of individual differences). The remainder of this section therefore discusses what makes a 'good' measure of inhibitory control in relation to the current thesis work.

The overarching aim of this thesis was to compare the inhibition of two different response types (e.g. imitative responses and non-imitative responses). In order to make comparisons, it is imperative that the tasks selected for this are not only methodologically similar, but that they are the best possible measure of the construct being tested (i.e. inhibitory control). As seen in section 1.2.1, there are many different tasks available to developmental psychologists, which can make it difficult to choose the best. But when selecting a task for a developmental study, perhaps the most important consideration is the validity of the task (i.e. whether the task is actually measuring the construct of inhibitory control). If a task being used does not tap into the construct wishing to be measured, then it will not make a good measure.

Most of the studies contained within this thesis make use of an SRC task. Perhaps the best way of ensuring that an SRC task is *actually* measuring inhibitory control is with the use of a control condition. A good control condition will be similar to its experimental counterpart in many ways, except that it will not have the inhibitory component. Good performance on the control condition shows that children can cope with the non-inhibitory demands of the task (e.g. the working memory and attentional demands). Therefore, if children perform well on the control condition, but poorer on the inhibitory conditions, the difference in performance can be attributed to the *inhibitory demands* of the task making the experimental condition more difficult than the control condition. Since the inhibitory demands are precisely what one is trying to measure in an inhibitory control task, the ability to compare the difference in performance on the task against a control condition provides a good indication about the efficacy of the task, and therefore how good a measure of inhibitory control it is.

Whilst the majority of the studies in the current thesis use SRC tasks, Chapter Three includes a GNG task. In a GNG task it is only the No-go trials which provide a measure of inhibition, unlike an SRC task where every trial requires inhibition. GNG tasks are different from SRC tasks in that it is possible for participants to score perfectly on the No-Go trials by simply not engaging with the task at all. For this reason, it is important to assess both the 'Go' and the 'No-go' trial accuracy in combination, and to exclude any participants who are either not engaging with the task or responding indiscriminately. To ensure that non-responsiveness is not the reason for a participant's 'good' score, researchers may take participants' average 'Go' score and multiply this with their average 'No-go' score to create an 'impulsivity score' or 'sensitivity index' (e.g. Wiebe et al., 2012). Due to this design then, it is not possible to apply a control condition as in the case of SRC tasks. However, not having a control condition can make it much more difficult to know whether children who perform poorly do so because of the high inhibitory demands of the task, or for other reasons such as the working memory demands. It is for this reason that the current study uses mainly SRC tasks, since the addition of the control condition makes it easier to establish how 'good' a measure of inhibitory control the task is. This is reiterated in Chapter Three which discusses some of the limitations of the GNG task and explains why SRC tasks are used exclusively thereafter.

We now also consider the developmental appropriateness and the developmental sensitivity of the tasks used in developmental studies of inhibitory control, as recommended by Petersen and colleagues (2016). Again, it can be argued that the GNG task has some limitations which SRC tasks do not. As stated above, at most only half

of the trails measure of inhibitory control. In turn, this means that more trials are required in a GNG task than an SRC task in order to obtain the *same* number of inhibitory trials. Having more trials tends to make a task longer, potentially making the GNG task less suited to a younger population who are likely to lose attention much faster. In addition, Simpson & Riggs (2006) demonstrated that the inhibitory demands of the GNG task can be impacted by the amount of time available for children to respond. If the trials are presented too quickly, children will not have sufficient time to respond but if they are presented too slowly then the lack of time pressure can reduce the prepotency of the response and thus affect the inhibitory demands of the task (Simpson & Riggs, 2006). This time pressure is not applicable in SRC tasks such as the Day-Night task, making these tasks more likely to provide a good measure of inhibitory control.

But there is also another type of inhibitory response not measured by the tasks discussed thus far: the inhibition of imitative responses. Thus far, this Chapter has provided an overview of the developmental literature associated with the inhibition of non-imitative responses, such as inhibiting the tendency to label a picture. However, since one of the main aims of the current thesis is to investigate the inhibition of imitative responses in young children, the remainder of this Chapter will review the literature and the tasks which can be used to address this aim.

1.3 Imitation and Inhibition

Imitation refers to the copying of an observed behaviour (Whiten & Ham, 1992). Imitation is believed to play a pivotal role in human development, including the acquisition of motor, communicative, and social skills (Clark, 1977; Meltzoff, 1988; Piaget, 1945; Tomasello et al., 1993). In addition, imitation also serves a social function as it aids in building rapport, cooperation, and affiliative attitudes between individuals (Chartrand & Lakin, 2013) as well as supporting peer-learning (Lew-Levy et al., 2023). Thus, imitation provides a necessary aid for social learning. However, as imitation is supported by a coupling between perception and action (Cross & Iacoboni, 2014), it can also be considered a prepotent response tendency that may need to be inhibited at times. The prepotency of imitation and the subsequent need for use of inhibitory control will be explored in more detail in the following sections.

1.3.1 Imitation and the Mirror Neuron System

In the 1990s, it was discovered that some of the motor neurons in the macaque brain are activated not just during the execution of an action, but during the mere *observation* of the action (di Pellegrino et al., 1992). These neurons became known as "mirror neurons". Since their initial discovery, neurons with similar properties have been found in the human brain (for a review see Caspers et al., 2010), and many studies have provided evidence that whenever we observe someone else's actions, the corresponding motor representations within our own brains are automatically activated (Decety, 1997; Grezes et al., 1998; Iacoboni et al., 1999, Nishitani & Hari, 2002). There

is still some controversy around the initial development of the mirror neuron system (Oostenbroek et al., 2016), but there is evidence that from at least six to nine months of age there is activation motor cortex when infants observe others' actions (Shimada & Hiraki, 2006; Southgate et al., 2009).

This connection between visual and motor representations of actions is therefore thought to support imitation and makes copying others' actions a pre-potent response tendency (Brass & Heyes, 2005; Chartrand & Bargh, 1999; Cross & Iacoboni, 2014; Cross et al., 2013; Crescentini et al., 2011; Iacoboni et al., 1999). Given then, that imitation is a prepotent response tendency, it must require inhibition at times when it is not appropriate to enact every action we observe (Cross & Iacoboni, 2014).

Whilst the developmental literature on imitation and mimicry is abundant, little research has been conducted on how young children *inhibit* their imitative tendencies. However, there are some important findings within the adult literature which have sparked a debate as to whether the neural mechanisms underlying the inhibition of imitative tendencies are separate from the mechanisms underlying other types of inhibition (Brass et al., 2003, 2005; Darda & Ramsey, 2019). These findings may be relevant to both the studies of adults and children alike, though they have not been tested in a developmental population thus far. Given that young children have both notoriously poor inhibitory control (Diamond et al., 2002; Gerstadt et al., 1994) as well as a prolific tendency to imitate (e.g. McGuigan et al., 2007), we propose that studying them will help investigate this debate. Indeed, the focus of Chapter Three is to investigate the relationship between young children's inhibitory control and their imitative tendencies.

In the sections below, the key findings from the adult literature and the subsequent debate that followed are discussed in further detail. After this, the chapter goes on to review the relevant (but limited) developmental literature on imitation inhibition and the neural correlates of inhibitory control.

1.3.2 Key findings from the adult literature

In the 1960s, Alexander Luria noted that many of his patients who had suffered frontal lobe damage had a tendency to copy the actions of others – a condition he termed 'echopraxia' (Luria, 1966). To explore this observation further, Luria created a task designed to measure an individual's ability to inhibit imitative responses. In this task, commonly referred to as 'Luria's Hand Game', the patient is asked to perform an action which is incongruent to the action they are observing the experimenter perform. For instance, when the examiner makes a fist, the patient is required to respond by extending their index finger, and vice versa. Luria found that patients with frontal lobe lesions were less able to inhibit the tendency to perform the same action as the examiner during Luria's Hand Game task, and instead copied the observed actions (Luria, 1966).

Keen to explore this finding further, Marcel Brass and his colleagues sought to shed light on the role of the frontal lobe in the inhibition of imitative responses (Brass et al., 2001; 2003; 2005; 2009). Based on Luria's Hand game, they developed an 'Imitation Inhibition' task which involved participants lifting either their index finger or middle finger in response to a number cue presented on a screen (Brass et al., 2001). Participants were instructed to lift their index finger if a number 1 was displayed, and

to lift their middle finger if a number 2 was displayed. But in addition to the number, the screen also showed a video clip of a hand raising either the index or middle finger. The pre-recorded hand movement in the video clip was either congruent or incongruent to the correct hand movement for each trial. For instance, on congruent trials the observed finger movement matched the instructed finger movement (e.g. lifting the index finger when a number 1 was displayed), and on incongruent trials the observed finger movement opposed the instructed finger movement (e.g. lifting the middle finger when a number 1 was displayed). Brass and colleagues found that on average, participants had a faster reaction time when the finger movement was congruent than when it was incongruent (Brass et al., 2001).

In a follow-up study, Brass and colleagues used this task compared performance on the Imitation-Inhibition task with performance on the Stroop task in both a group of patients with frontal lobe lesions and a healthy control group for comparison (Brass et al., 2003). In this study, they demonstrated that frontal lesion patients who demonstrated impaired performance on a non-imitative inhibition task (the Stroop task) did *not* demonstrate the same impairments on an imitation–inhibition task and vice versa (Brass et al., 2003).

To further investigate this potential double dissociation, Brass and colleagues followed this up with a neuroimaging study (Brass et al., 2005). In this study, they identified that the Stroop task and the Imitation-Inhibition task seem to invoke different neural mechanisms. For instance, during the Imitation-Inhibition task, activation was seen in brain areas such as the mPFC and the rTPJ, whilst the activation was found in

the pre-supplementary motor area (pre-SMA) and the fusiform gyrus during the Stroop task. The only region found to be activated in both tasks was the inferior frontal gyrus (IFG).

Typically, inhibitory control is thought to be supported by a domain-general network of brain regions and taps into the multiple demand (MD) network (Darda & Ramsey, 2019; Duncan, 2010). The MD network includes the IFG and the dorsolateral prefrontal cortex (dlPFC). However, Brass and colleagues' findings contradict this assumption when it comes to the inhibition of imitative responses (Brass et al., 2005). Indeed, the finding of activation of social brain areas including the mPFC and the TPJ provides the first evidence that the inhibition of imitative responses might be somewhat special in that it is facilitated by a different domain-specific network.

Indeed, there are studies that use techniques to suppress or excite specific regions of the brain to then observe the effects. One such technique is transcranial direct current stimulation (tDCS) – a form of non-invasive electrical brain stimulation technique, which provides excitatory stimulation to a specific region of the brain to enhance its function (Hogeveen et al., 2015). By increasing activation to a specific area, researchers can gain an insight into what function(s) become enhanced, which may indicate what that specific brain region might be responsible for. Researchers have found that providing anodal stimulation to the rTPJ using tDCS can indeed improve one's performance on an imitation inhibition task (Hogeveen et al., 2015; Santiesteban et al., 2015). Taken together, these findings provide converging evidence that a domain-specific inhibitory network could be used either alone or in combination with the

domain-general network of inhibitory control during the inhibition of imitative responses.

1.4 The Domain-general vs Domain-specific debate

Darda & Ramsey (2019) sought to further investigate the double dissociation between the inhibition of imitative and non-imitative responses by conducting a meta-analysis. Specifically, they identified and reviewed 12 fMRI studies involving imitation inhibition tasks to investigate whether there was consistent activation of social brain areas such as the mPFC and the TPJ. If so, this would support the work of Brass and colleagues, and favour the idea that the inhibition of imitative responses is supported by a separate, domain-specific network. The results of the meta-analysis were not conclusive. On the one hand, the data showed that across the 12 studies combined, there did indeed appear to be consistent involvement of the rTPJ associated with imitation inhibition, but this was not the case for the mPFC (Darda & Ramsey, 2019). But on the other hand, the meta-analysis revealed consistent recruitment of the brain regions associated with the MD network such as the rIFG and the right superior temporal gyrus during the imitation-inhibition task.

Overall, the authors suggest that the results of the meta-analysis are more in-line with a domain-general theory of inhibition (Darda & Ramsey, 2019). This finding therefore appears to contradict Brass's earlier findings of recruitment of the mPFC and the rTPJ but *not* the MD network during an imitation inhibition task (Brass et al., 2005).

Taken together, the evidence is contradictory, with Brass and colleagues (2003; 2005) finding evidence in support of a *domain-specific* theory of imitation inhibition and Darda and Ramsey's review (2019) finding evidence in support of a *domain-general* theory of imitation inhibition. Since the meta-analysis in 2019 (Darda & Ramsey), no further research has been conducted into the domain-general/domain-specific debate in relation to the inhibition of imitative responses. However, given that this debate remains unresolved, it seems important to expand on this research. We propose that one way of uncovering new answers is to conduct this research with young children who are known for both their prolific imitative tendencies as well as their poor inhibitory control. Similar to the way in which Luria and Brass were interested in echopraxia patients because of their deficiencies, it seems that testing the inhibition of imitative tendencies in a developmental population could also prove to be enlightening.

1.4.1 Studying imitation inhibition in young children

Luria's hand game has been adapted to be more suitable for a developmental population and has been used in many behavioural studies of inhibitory control. For instance, Diamond and Taylor (1996) introduced a tapping task in which children were instructed to tap once (using a wooden dowel) if the experimenter tapped twice, and to tap twice if the experimenter tapped once. When testing an age range between 3½ to 7 years, the authors found that older children were faster and more accurate than younger children on this tapping task, and by the age of 6 years, children reached ceiling level accuracy.

Additionally, Hughes (1998) has also adapted Luria's Hand game in which children are instructed to point their finger when the experimenter makes a fist, and to make a fist when the experimenter points their finger. Since this was a battery study, the composite scores from both the Hand Game and another inhibitory control task were used as a general measure of inhibitory control. In line with the findings from Diamond and Taylor (1996), Hughes also found that there was an age-related improvement in this measure of inhibitory control across the preschool years (1998). This age-related improvement on tasks such as the Hand Game appears to roughly correspond – at least behaviourally – with the developmental trajectory of inhibiting non-imitative responses such as those measured by the Day-Night task (Gerstadt et al., 1994), Grass-Snow task (Carlson & Moses, 2001) and the Go/No-go task (Dowsett & Livesey, 2000).

1.4.2 Comparing inhibitory performance on imitative vs non-imitative tasks

One of the main aims of the current thesis was to compare the inhibition of imitative and non-imitative response tendencies in young children. To do this, we must be selective about the tasks used to ensure that they are as similar as possible. If the tasks are closely matched, there is less likelihood that any differences found in children's performance are due to differences in task demands. This is especially important when aiming to investigate brain functionality, as is the case in Chapter Four. We first provide a review of the tasks which are currently used to assess imitative and non-imitative responses in young children and then consider how closely matched they

are to one another. The section then ends with a summary of the tasks we go on to use in later chapters based on the evidence reviewed here.

Several developmental studies have compared children's performance on imitative vs non-imitative tasks (Diamond & Taylor, 1996; Passler et al., 1985; Watson & Bell, 2013). For instance, Diamond and Taylor (1996) tested a group of children between the ages of 3½ to 7 years on both the Day-Night task and the Tapping task. As expected, children improved on both tasks with age. A comparison of task performance demonstrated that children found the Tapping task easier than the Day-Night task at all age groups above 4 years, and this difference was significant from the age of 5½ and over (Diamond & Taylor, 1996). Furthermore, the authors found that children appeared to show a fatigue effect on the Day-Night task but not on the Tapping task. These results are consistent with the findings from Watson and Bell's (2013) study which demonstrated that children performed better on the Hand Game than the Day-Night task.

At the time, Diamond and Taylor (1996) suggested that perhaps the reason children found the Tapping task easier than the Day-Night task was because overlearned associations such as day and sun, or moon and night have a higher prepotency than mimicking the actions of others. However, the more likely reason children found the Tapping task easier was because the wooden dowel had to be passed back and forth between the child and the experimenter, thus increasing children's time to respond. In this way, they can think about their answer during the time it takes to pass the wooden dowel, and this additional time makes it more likely they will perform the correct action. Indeed, Simpson and Riggs (2006) found that when giving children longer to respond

on a GNG task, they found the 'No-go' (inhibitory) condition almost as easy as the 'Go' (prepotent) condition. This is because the longer response time not only gave children longer to think about their response so as not to accidently press the button on a 'No-go' trial, but this also reduced the prepotency of the 'Go' trial. By reducing the prepotency, this makes the task significantly easier (Simpson & Riggs, 2006). However, the Hand Game demands a more immediate inhibitory response than the Tapping task, since there is no wooden dowel to pass between experimenter and participant. Why then did Watson and Bell (2013) find that this task too seemed easier for children than the Day-Night task?

The evidence suggests that, just as giving children longer to consider their answer before responding can reduce the prepotency of the task, there are other factors which may also influence the prepotency of an imitative response. O'Sullivan and colleagues (2018) found that actions which are commonly performed synchronously (such as clapping or waving) have a stronger prepotency effect than actions which are not performed synchronously (such as pointing or making a fist). The authors suggest that this is because actions which are performed synchronously such as clapping or waving have social significance, and thus tend to be performed more often (O'Sullivan et a., 2018). One predominant theory to explain this is that children develop associations between sensory and motor representations of actions through sensorimotor *experience* (Heyes & Ray, 2000). This associative learning theory suggests that perceptual-motor couplings in the brain develop through the repeated experience of 'seeing and doing' (i.e. correlated sensorimotor experience). Indeed, there is strong evidence to suggest that imitation becomes more prepotent throughout infancy and into early childhood

(Horner & Whiten, 2005; Jones, 2007; Piaget, 1945). Associative learning theory predicts that pointing a finger or making a fist may be less prepotent in young children than actions such as clapping, because children have had less experience of simultaneously observing and performing them (O'Sullivan et al., 2018). Therefore, actions such as pointing a finger or making a fist may be less prepotent in young children than actions such as clapping, because children have had less experience of observing and performing them (O'Sullivan et al., 2018). This provides a possible explanation for why the Hand Game may be easier for young children than the Day-Night task (Watson & Bell, 2013).

Another key difference between the Hand Game and the Day-Night task is that one requires children to give a *motor* response to a visual stimulus, whilst the other requires children to give a *verbal* response to a visual stimulus. This discrepancy between motor responding and verbal responding has previously been shown to be problematic. For instance, Livesey and Morgan (1991) found that in a verbal response condition, young children were able to give the correct (verbal) response, but when required to inhibit a motor response they were unsuccessful. This finding further highlights the importance of aligning the task methodologies as best as possible.

In the current thesis, we therefore propose that the Hand Game is a more suitable task for assessing the inhibition of imitative responses than the Tapping Task. This is because the Hand Game requires a more immediate inhibitory response, thus ensuring that the inhibitory demands of the task remain reasonably high. In addition, whilst the literature described has considered only the Day-Night task, in this work (see Chapters

Two and Four) we use the Grass-Snow task because it may be a better match to the Hand Game. Firstly, the Grass-Snow task requires children to point to the required visual stimuli when a verbal cue is given (rather than requiring a verbal response to a visual cue). In this way, the Hand Game and the Grass-Snow task are alike in that they require a motor response (a hand gesture, or a point). A second, additional benefit to using the Grass-Snow task is that according to Petersen and colleagues' review paper (2016), this task provides a more similar 'useful age range' (30–69 months) to the Hand Game (30–69 months) than the Day-Night task does (33–71 months).

To sum up, having compared the tasks available in the developmental literature, it seems that the Grass-Snow task and the Hand Game are the best options to compare the inhibition of imitative responses with the inhibition of non-imitative responses. Both have the same ''if A then B, if B then A'' rule structure (Simpson & Riggs, 2011) and have been found to be well-suited to children of a similar age range (Petersen et al., 2016). In addition, both demand a motor response from children. For these reasons, the tasks we use in the current thesis are based on the methodologies of the Grass-Snow task and the Hand Game with just a few modifications as described in Chapters Two and Four. In Chapter Four we use these tasks to compare the neural correlates of inhibiting both imitative and non-imitative prepotent response tendencies in young children – a question which is still outstanding.

1.5 Assessing the Neural Correlates of Inhibitory Control

In this section, we first review some of the developmental literature addressing the neural correlates of inhibitory control using various neuroimaging techniques including fNIRS, before then considering the limited evidence for the neural basis of inhibiting *imitative* responses specifically.

1.5.1 Early studies investigating the neural correlates of inhibitory control

The earliest studies investigating the neural correlates of inhibitory control used EEG. For instance, Wolfe and Bell (2004) conducted an EEG study with 4½-year-olds on the Day-Night task. The analysis showed that there was greater alpha power over the medial frontal regions during the inhibitory condition compared to the baseline condition. When applying a median split to children's accuracy scores to create a high inhibitory group and a low inhibitory group, the analysis revealed that the high performing group generally demonstrated greater levels of inhibition than the low performing group (Wolfe & Bell, 2004).

However, whilst EEG has excellent temporal resolution, it has poor spatial resolution, which means that although it is very good at telling us *when* brain activation occurs, it is not very good at telling us *where* it occurs. EEG is therefore not very suited to localisation studies where the precise site of the brain activation is important (Burle et al., 2015). In such instances, other techniques such as functional magnetic resonance imaging (fMRI) are more appropriate. Rather than recording the electrical activity as with EEG technology, fMRI measures the Blood Oxygen Level Dependent (BOLD)

response. At rest, the brains energy demands are met. However, when there is a spike in electrical activity (i.e. neurons firing) in a given area, this is accompanied by an increase in oxygenated haemoglobin to meet the additional energy demands in a process called neurovascular coupling (Nair, 2005). In this way, fMRI is a measure of the haemodynamic response resulting from an increase in neural activity and is thus a more indirect measure of brain activity than EEG (Barth & Poser, 2011). The brain's BOLD response is somewhat slower than its electrical response, as it takes time for the additional oxygen to reach the required area (Nair, 2005). However, what fMRI lacks in temporal resolution, it makes up for in spatial resolution, allowing for more accurate localisation and mapping of active regions of the brain (Dalenberg et al., 2018).

Several researchers have used fMRI to assess brain activation related to inhibitory processes in middle childhood (between the ages of 6 and 12 years) (Casey et al., 1997; Durston et al., 2002; Durston et al., 2006; Rubia et al., 2007). For instance, Durston et al. (2002) compared brain activation in 6- to 10-year-olds against adults during a GNG task. They found that both the children and adults demonstrated an increase in activation within the bilateral ventral PFC, right dlPFC and the right parietal lobe during trials in which inhibition was required (No-Go trials). This is in line with the findings by Casey et al. (1997) who found little differentiation between the activated brain regions in adults and children (aged 7-12 years) during a GNG task as measured with fMRI. These activated regions included the bilateral inferior frontal cortex, middle frontal cortex, orbital frontal cortex and anterior cingulate gyri.

However, with regard to the current study, it is really children aged between 3-5 years that are of the greatest interest, since this age range encompasses the sharpest observed increase in developmental trajectory. Unfortunately, fMRI is not particularly suitable for children this age. Not only is it an expensive and immobile method of neuroimaging in comparison to methods such as EEG, but it also requires a rather high tolerance level from the participant due to the fact that it is a noisy, confined space in which the participant must remain perfectly still to gain an accurate measurement (Lloyd-Fox et al., 2010). In fact, this sensitivity to movement means that functional neuroimaging using fMRI is not possible among populations for which lying still for prolonged periods is problematic, including infants and children up to around five years of age. Thankfully, recent advancements in technology over the last few decades have resulted in alternative neuroimaging methods to localise neural activation in young children such as functional near-infrared spectroscopy (fNIRS).

1.5.2 Using fNIRS to measure inhibitory control

fNIRS works in a similar way to fMRI in that it measures haemodynamic response, or rather, the levels of oxyhaemoglobin and deoxyhaemoglobin in specific areas of the brain. This is done by emitting infrared light from 'source' optodes which are secured in place in a lightweight headcap over the scalp. 'Detector' optodes then measure the amount of infrared light that returns (Lloyd-Fox et al., 2010). Because oxygenated and deoxygenated blood have different optical absorption properties, fNIRS technology can assess changes in blood oxygenation (Jobsis, 1977). We can therefore

deduce that regions which are ‘active’ (and thus are responding to neuronal activation) are those regions which incur an increase in oxygenated blood and a decrease in deoxygenated blood (Villringer and Chance, 1997).

Arguably, fNIRS fills the gap between EEG and fMRI since its spatial resolution is better than EEG (but not as good as fMRI), whilst its sampling rate is better than fMRI (though not as good as EEG). As with any neuroimaging technique, fNIRS too has limitations. For instance, it lacks the capacity to measure beyond a few centimetres into the cortical tissue, it therefore cannot access deeper brain regions such as the amygdala. However, for the current thesis, this is not an issue since the regions of interest reside close to the cortical surface. In addition, fNIRS is far more tolerant of movement than fMRI (Aslin & Mehler, 2005; Cutini & Brigadoi, 2014) and seeing as the headcap can be administered quickly and easily and is generally well-tolerated by young children, fNIRS provides one of the best neuroimaging methods for studying neural activation in young children (Lloyd-Fox et al., 2010). It is for these reasons that we use fNIRS in the current thesis (see Chapter Four).

In the last decade, the number of researchers turning to fNIRS to measure inhibitory control in the developing brain has grown exponentially. One such example is a study by Smith and colleagues (2017) who applied fNIRS whilst children aged 4-10 years completed a GNG task. The study revealed an increase in oxyhaemoglobin and a decrease in deoxyhaemoglobin across the right and left ventrolateral prefrontal cortex (vlPFC) and right and left dlPFC. Whilst activation occurred bilaterally, the authors found greater change in activation in the right hemisphere as compared to the left,

demonstrating right-lateralised activation (Smith et al., 2017). Furthermore, they related the fNIRS activation to task performance and found that better task performance was associated with a greater increase in oxyhaemoglobin whilst worse task performance was associated with higher deoxyhaemoglobin (a sign of deactivation). These findings support a review paper by Diamond (2002) which found that fMRI data implicates the DLPFC and VLPFC in inhibitory control tasks such as the Day-Night task and the Hand Game task in children between the ages of 3-7 years.

Similarly, Mehnert et al. (2013) tested children aged 4-6 years (as well as adults) on a GNG task whilst measuring brain activation using fNIRS. The analysis demonstrated a strong increase in task-induced activation of a fronto-parietal network during the No-Go trials as compared to the Go trials in adults. In children, this activity was already high during Go trials, and the No-Go trials saw a sharp increase in oxygenated haemoglobin in conjunction with a decrease in deoxygenated haemoglobin – the canonical signal of increased neural activation. The researchers went on to review the patterns of activation within the child group to see if there were any changes over this time period (Mehnert et al., 2013). They found that the older children demonstrated increased activation in the right frontal lobe and decreased activation within the left frontal lobe as compared with the younger children in the sample. This finding supports the idea that as the brain matures, it begins to lateralise many of its functions. Research with adults and older children has demonstrated right lateralised brain activation during GNG tasks (e.g. Durston et al., 2002's fMRI study), whilst the infant literature typically notes more bilateral patterns of activation (Wada & Davis, 1977). Over time then, the brain demonstrates plasticity as it shifts from bilateral networks to lateralised ones

through the process of maturation (Johnson, 1999). Given the rapid increase in behavioural performance on inhibitory control tasks between the ages of 3-5 years, it seems likely that this may coincide with anatomical changes occurring within the prefrontal cortex over this period (Kolk & Rakic, 2022).

The evidence presented so far has shown that when children inhibit prepotent response tendencies they seem to activate areas of the multiple demand network, including the dlPFC and the IFG thought to be involved in domain-general processes of inhibition. However, this does not account for the neural correlates of inhibiting imitative response tendencies in young children. Given that young children's behavioural improvements on the Hand Game task are akin to those on non-imitative inhibitory control tasks such as the Day-Night task, it also seems key to review the neural correlates of the inhibition of imitative responses.

1.5.3 Neural correlates of inhibiting *imitative* responses

Unfortunately, the field of research surrounding the neural correlates of inhibiting imitative responses in young children is far sparser than that of non-imitative response tendencies. In fact, we have been able to identify just one study which involves an assessment of young children's neural activation when participating in the Hand Game (Watson & Bell, 2013). Even then, it should be noted that the aim of the study was to assess the contributions of language and temperament to 3-year-old's task performance, not to investigate the inhibition of imitative response tendencies. Using EEG, the authors measured children's neural activation while they performed different

tasks, including the Day-Night task and the Hand Game. Behaviourally children scored significantly better on the Hand Game than on the Day-Night task. When assessing baseline-to-task changes in EEG power across the medial frontal scalp location, it was found that EEG baseline-to-task changes were significantly predictive of performance on the Hand game, but not on the Day-Night task (Watson and Bell, 2013).

However, as previously mentioned, while EEG is adequate for identifying broad areas of activation, it lacks the spatial resolution to pinpoint more precise locations of activation. Therefore, although Watson and Bell (2013) found that EEG activation over the frontal cortex was predictive of performance on the Hand Game but not the Day-Night task, it is not possible to know which specific areas of the brain were responsible for these inhibitory processes. On the face of it, this study seems to suggest that different neural mechanisms may be involved in the inhibitory processes for imitative and non-imitative responses in young children (Watson & Bell, 2013). But since one of the aims of the current thesis is to contribute to the domain-general vs domain specific debate regarding the inhibition of imitative responses, a neuroimaging method which provides better spatial resolution is required. For this reason, we use fNIRS in Chapter Four to compare the inhibition of imitative and non-imitative responses in four-year-old children so as to better understand the neural mechanisms underlying these processes.

1.6 Summary

In summary, inhibitory control is an important executive function, but one which takes years to develop fully (Petersen et al., 2016). The development of inhibitory control has therefore long been of interest to Psychologists and has resulted in a plethora of inhibitory control tasks being created for use with developmental populations. Tasks such as the Day-Night task (Gerstadt et al., 1994) and the GNG task (Dowsett & Livesey, 2000) are popular choices for measuring young children's ability to inhibit a prepotent response tendency. One problem is that many variations of these core tasks now exist, but control conditions are seldom used. Without the use of a control task, one cannot be sure that different variations of these original tasks still provide a valid measure of inhibitory control. Given the abundance of literature on the development of inhibitory control across the preschool years, it seems vital to ensure that inhibitory control tasks do indeed reliably test children's ability to inhibit a prepotent response tendency.

Imitation is another type of prepotent response which at times requires the use of inhibitory control but is commonly overlooked in the developmental literature. Findings from the adult literature have alluded to the inhibition of imitative responses being different from the inhibition of other types of responses (Brass et al., 2003; 2005). Up until that point, it was thought that inhibitory control was a domain-general function, meaning that there is one mechanism underlying all types of inhibition. This brought about a debate as to whether there is a domain-specific inhibitory network which helps

to facilitate the inhibition of imitative responses. The evidence is mixed, leaving the debate unresolved.

Thus far, there have been few studies that aimed to investigate the relationship between inhibitory control and imitation inhibition in a developmental population. Given that between the ages of 3-5 years we see a particularly accelerated period of improvement on developmental inhibitory control tasks (Carlson & Moses, 2001; Gerstadt et al., 1994; Simpson & Riggs, 2005a), this population may provide particularly useful insights into this debate. This is because children of this age range are not yet demonstrating ceiling levels of performance on inhibitory control tasks, and so they produce a lot of variability in their accuracy. This allows researchers to investigate correlations between neural activation and task performance. In addition, young children have an underdeveloped prefrontal cortex, which could be the reason that young children show a pervasive tendency to copy others' actions (Horner & whiten, 2005; McGuigan et al., 2007), as is seen in patients with echopraxia (Luria, 1966). It can therefore be argued that there is a strong case for contrasting the inhibition of imitative and non-imitative response tendencies in young children.

Based on the literature reviewed within this chapter, the studies contained within this thesis aim to answer the following key questions:

- Q1: What is the best way to measure inhibitory control in young children?
- Q2: Is poorer inhibitory control in children related to a greater tendency to copy others' actions?

- Q3: What are the neural mechanisms involved in inhibiting imitative responses? Is the inhibition of imitative responses 'special' in that it involves activation of the social brain network rather than the domain-general inhibitory control network?

1.7 Overview of the present work

The aim of **Chapter Two** is to establish a good measure of inhibitory control in young children, thus addressing research Q1. This chapter presents a new touchscreen inhibitory control task based on the principles of the Grass-Snow task. It also aims to test the suggestion/hypothesis that young children often perform poorly on inhibitory control tasks because they lack the ability to remember the rules of the task.

Chapter Three focuses on the question: 'Is poorer inhibitory control in children related to a greater tendency to copy others' actions?'. In this Chapter an existing data set is used to examine whether there might be a relationship between inhibitory control and imitative tendencies by investigating the relationship between 3-year-olds' performance on two inhibitory control tasks and their tendency to overimitate.

To address the final research question: 'What are the neural mechanisms involved in inhibiting imitative responses? Is the inhibition of imitative responses 'special' in that it involves activation of the social brain network in addition to or rather than the domain-general inhibitory control network?', **Chapter Four** presents two final studies. The first of these is an online study that aims to measure the developmental

trajectories of the inhibition of imitative vs non-imitative response tendencies in children aged 3-5 years. In this study, imitative tendencies are tested with a task based on the Hand Game whilst non-imitative tendencies are tested using the task established in Chapter Two, which is based on the principles of the Grass-Snow task. This study was conducted online due to restrictions caused by the COVID-19 pandemic. In the final study, fNIRS is used to investigate the neural correlates of the inhibition of imitative and non-imitative response tendencies in 4-year-old children using the same task.

Chapter 2

Introducing a new touchscreen task to measure Preschoolers' inhibitory control.

2.1 Introduction

The aim of the current chapter is to identify what makes a good measure of inhibitory control in young children. As discussed in section 1.2.1 (page 8), the development of young children's inhibitory control is most often measured using SRC tasks (see Petersen et al., 2016 for a meta-analysis), which test their ability to achieve rapid suppression of a goal-inappropriate, prepotent response. These tasks require children to produce response A (e.g. say 'day') when they see stimulus *b* (a picture of a moon), and response B (e.g. say 'night') when they see stimulus *a* (a picture of a sun). The two possible responses "day" and "night" therefore become primed. When the image of a sun is shown, the associated response 'day' is triggered. Inhibitory control is then needed to suppress the associated response, so that the goal appropriate response ("night") can be made. Using these tasks, it has been shown that inhibitory control undergoes rapid development between the ages of 3 and 5 years, with younger children showing particularly poor performance (Petersen et al., 2016).

There are four key "early studies" which have used SRC tasks to investigate inhibitory control, two by Diamond and colleagues (Diamond et al., 2002; Gerstadt et al., 1994) and two by Simpson and Riggs (2005a&b). These early studies used a control condition to investigate whether poor performance on SRC tasks could be attributed to the task's memory demands, rather than their inhibitory demands. Since these early studies, SRC tasks have been used in hundreds of published studies, but usually without the control condition. Therefore, the claim that poor performance on all SRC tasks is a

consequence of young children's weak inhibitory control - and not their inability to remember the task rules - rests principally on these four early studies.

On the control condition, children were asked to make specific verbal responses to two abstract pictures – e.g., say "CAT" to one abstract picture and "DOG" to another (Simpson & Riggs, 2005a). This control condition required children to learn, maintain and apply the task rules (see *abstract picture 1* and say "CAT"; see *abstract picture 2* and say "DOG"), in the same way as in the standard, inhibitory condition (see *black* and say "WHITE"; see *white* and say "BLACK"). However, because no names are associated with the abstract pictures, the inappropriate responses are triggered no more than the appropriate responses, and so little inhibition is required to stop the inappropriate responses from being made (Simpson & Carroll, 2019). Good performance on the control condition, suggests that children can cope with the memory demands of SRC tasks. Thus, *poor* performance on the inhibitory condition, alongside *good* performance on the control condition, can be attributed to children's inhibitory weakness with some confidence.

Despite these early studies, there are two reasons to be cautious about assuming that the memory demands of SRC tasks are necessarily always low, and that therefore SRC tasks always provide a good measure of inhibitory control. First, in order for the memory demands of SRC tasks to be low, children must not have to work too hard to learn the task rules. If children struggle to learn these rules, then the memory demands of the task become significant. Because of this, how these rules are taught is crucial. We can be confident that children learnt the rules on the early studies since they performed well on the control conditions. However, it is less clear how well children

learnt the rules in most subsequent research because the control conditions were not administered (e.g., Carlson, 2005). Moreover, many studies provide limited or no information about how the rules were actually taught (e.g. Kim et al., 2013). It is simply assumed that children do learn the SRC task rules, and that subsequent performance reflects the efficiency of their inhibitory control when trying to apply them. In consequence, with most research using SRC tasks, there is some uncertainty about whether children's poor task performance solely reflects their inhibitory weakness or is partially dependent on their difficulty with learning or remembering the task rules. Indeed, there is some evidence that children find the task rules harder to learn when certain combinations of stimuli and responses are used. For example, children may struggle to learn rules when four different colours are used (e.g., see *black* say "YELLOW", see *white* say "GREEN" – Simpson et al., 2005b); or when verbal responses are made to verbal stimuli (e.g., hear *moon* say "SUN", hear *sun* say "MOON" – Simpson et al., 2013).

The second concern reflects a difference between the procedure used in the early studies and most subsequent research. A feature of the early studies was the use of pre-test exclusion criteria following the practice trials – something which was not generally adopted in the majority of later research (e.g., Carlson, 2005; Kim et al., 2013). In the early studies, children were given up to six *practice* trials, and did not proceed to the *test* trials if they did not pass at least half of them. This removed many of the 3-year-olds from these studies. These excluded children might have shown poor performance on the control condition if they had been included in the sample – calling into doubt whether their poor performance on the standard inhibitory condition was due to their

weak inhibitory control. By not adopting these exclusion criteria, subsequent research may have included data from children who would have shown poor performance on the control condition if they had completed it. This implies that, we cannot be sure that young children's performance on SRC tasks only reflects their inhibitory capacity rather than their memory capacity or a combination of both.

The current study

In the current study, we sought to investigate children's performance on a new SRC task called the "Touchscreen Inhibitory Control" (TIC) task. In this Grass-Snow-like task (Simpson & Riggs, 2009), rule learning was incorporated into a touchscreen task. Children watched a video of the experimenter explaining the task rules on the touchscreen, and then took part in practice trials, in which video feedback on their accuracy was given. By incorporating rule learning into the programme-run task, we aimed to create a task in which rule learning could be known to be consistent (rather than depending on the teaching procedure adopted by each experimenter). Children were asked to touch one of two pictures at the bottom of the screen in response to verbal cues spoken by the experimenter in the video. For example, when they heard the experimenter say 'car', children were instructed to touch the picture of the boat instead of the picture of the car (Figure 2.1). In contrast to the early studies, no children were excluded from the sample based on their inability to pass a pre-test. Thus, we aimed to test all children, and not exclude those who might have difficulty learning the rules.

Previous research into the efficacy of interactive on-screen teaching has produced mixed results, particularly with young children (e.g., Baydar et al., 2008; Kostyrka-

Allchorne et al., 2019a; Linebarger et al., 2004; Reiß et al., 2019). At present, the factors which make interactive on-screen teaching effective are poorly understood. In the current study, by administering a control condition, we could directly test whether our on-screen training was effective. If children were able to learn the task rules, then we would expect accuracy on the control condition to be high.

Like the early studies, we measured children's reaction time as well as their accuracy (most research only measures accuracy). It has been suggested that reaction time may be a better measure of inhibitory control in older children (i.e., five years and over), once accuracy reaches ceiling performance (Diamond et al., 2007; Diamond & Kirkham, 2005). We also manipulated whether or not children received feedback on each of the test trials (all participants received feedback on practice trials). This allowed us to investigate whether feedback helps children to remember the task rules and so provide a more accurate measure of inhibitory control, especially younger children who may struggle with the task's memory demands.

The current study tested 3- to 5-year-olds, and used a mixed design, with inhibitory demands and test-trial feedback as the independent variables. This produced four conditions: Inhibition with feedback, Inhibition without feedback, Control with feedback and Control without feedback. We aimed to answer the following three questions. First, and most importantly, would performance on the control conditions be high even in young children? This would suggest the interactive on-screen teaching used in the TIC task was effective, and that performance on the inhibition conditions was providing a pure measure of inhibitory control. Second, would accuracy or reaction time provide the most sensitive measure of inhibitory control in an SRC task with or

without test-trial feedback? That is, which measure accounts for the greatest proportion of variance in performance between inhibitory and control conditions? And finally, what would these data tell us about the validity of previous research that has used SRC tasks to measure inhibitory control in young children?

2.2 Method

2.2.1 Participants

A total of 127 participants were recruited from preschools and primary schools around North Essex and East Suffolk. Of these participants, 97 (43 females) provided sufficient data to be included in the final analyses with an age range between 36 months and 72 months, and a mean age of 53 months (4 years, 5 months; standard deviation = 9.2 months). Details of the exclusions are provided in section 2.2.4.

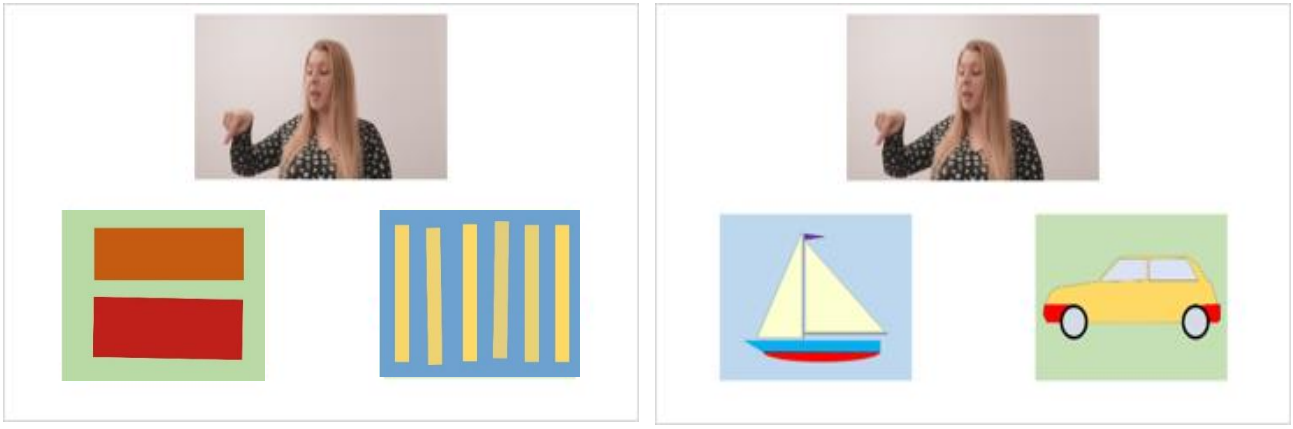
A number of statistical analyses were planned, including correlation. Thus, to ensure that the sample size was large enough to be well-powered for all planned statistical analyses we based the power calculations on an assumption of at least 80% power to detect a medium size correlation (r=.3, alpha=.05) using G*Power (Faul et al., 2009). This determined a required sample size of at least N=84. Participants were predominantly white, but of mixed SES. Ethical approval was gained from the Ethical Committee at the University of Essex, and every child returned a consent form which was signed and dated by their parent/guardian prior to data collection.

2.2.2 Materials

The TIC task was coded in Inquisit 5 (Inquisit 5, 2016) and displayed to participants on a 13" screen Dell touchscreen laptop. The task instructions were provided in video clips which were displayed centrally in the upper half of the screen. In the inhibitory conditions, a video of the experimenter saying a cue word (e.g., "boat") was displayed in the same location as the previous task instruction video. At the same time, a pair of visual stimuli were presented side-by-side beneath the cue video; one image of a boat and one image of a car. The control conditions also displayed a video of the experimenter saying a cue word (e.g., "boy"), whilst a different pair of visual stimuli were presented side-by-side beneath the cue video. This pair of images was 'abstract', consisting of differently coloured shapes layered on top of one another (see Figure 2.1).

Figure 2.1

Figure to show an example of the teaching of the rules for both conditions.



Note: The figure on the left depicts the control conditions whilst the figure on the right depicts the inhibitory conditions. These screenshots are taken during the instruction video in which the experimenter is saying "when I say boy, you point to this picture" during the control conditions, and "when I say car, you point to this picture" during the inhibitory conditions.

2.2.3 Procedures

Participants were tested at their schools or pre-schools individually in either a quieter area within the classroom or in a close-by room. The four conditions were administered across two sessions on different days with two conditions per session. Most sessions were exactly 1-week apart. The order of the conditions was counterbalanced but ensured that children would do one inhibitory condition and one control condition per session and that they were both either Feedback conditions, or both No-feedback conditions within each session. This resulted in four different possible condition orders.

At the beginning of the session, the experimenter introduced themselves to the child, accompanied the child to the testing area and asked the child if they would like to play a "silly game" on the touchpad. The experimenter then asked the child, "Shall we find out what we need to do in this game then?" and loaded the appropriate version of the task on the touchpad. The task instructions were explained in a video that was presented in the top half of the screen while the two stimuli for that condition were displayed side-by-side beneath it (see Figure 1). In the video, the experimenter explained the task instructions for that condition. For instance, in the inhibition conditions, the on-screen experimenter said: "We are going to be playing a silly game. In this game you need to listen to the word I say, and then touch to the right picture. When I say "car", you touch to this picture [*points to the picture of the boat beneath*], and when I say "boat", you touch to this picture [*points to the picture of the car beneath*]."

After the instruction video was played, the experimenter then asked the participant to tap the picture they would need to touch for each of the two verbal cues. For example, in the inhibitory conditions the experimenter would ask "If she says "boat", which picture do you need to touch?" and "If she says "car", which picture do you need to touch?". If the participant responded to either of the questions incorrectly, they were reminded of the correct response for that cue, and the experimenter replayed the instruction video again. If they responded correctly to both, the experimenter would move the task on to the pre-test practice trials by tapping on a small arrow in the bottom corner of the touchscreen.

Each condition started with four pre-test practice trials. On all pre-test trials, regardless of condition, participants were provided with pre-recorded verbal accuracy feedback, for both correct and incorrect responses immediately, following each response. For correct responses, the touchpad displayed a video of the researcher saying: "Well done, you touched the right picture!". For incorrect or no responses (maximum length of a trial was 8 seconds), the video corrected them: "Remember, when I say "boat", touch this picture [the on-screen experimenter points to the car]"). Following the feedback video there was an inter-trial interval of two seconds during which a blank white screen was displayed. The purpose of the pre-test trials was not to exclude children who performed poorly, but to ensure that children were helped to get a good understanding of the task rules before beginning the experimental trials. After the pre-test trials, participants went on to complete 16 experimental trials. The experimental trials were presented in a random order, and each stimulus was presented an equal number of times (eight times each). In the No Feedback conditions, no accuracy feedback videos were provided during the experimental trials. So, the blank inter-trial interval screen was displayed either as soon as participants made a response (correct or not), or once the eight seconds had passed. Each test session (comprising of two conditions) took children roughly 15-20 minutes to complete.

2.2.4 Data Analysis

Accuracy and Reaction Time (RT) scores were recorded by the Inquisit programme. Accuracy was recorded as [1] for a correct response and [0] for an incorrect response, whilst non-responses were marked as [.] and were excluded. RT was recorded

in milliseconds (ms). Accuracy scores and RTs were each averaged to give a mean accuracy score per participant, per condition and a mean RT score per participant, per condition. For the age analysis, children were divided into three age groups: 3 years 0 months to 3 years 11 months (n=29); 4 years 0 months to 4 years 11 months (n=41) and 5 years 0 months to 5 years 11 months (n=27).

Exclusions

RT scores were averaged for each condition. Any individual trials which exceeded 2SD above the mean RT score for that condition were excluded from the analyses, since this suggests that children were not engaging with the task. Additionally, trials in which the RT was less than 300ms were also excluded since this is suggestive of indiscriminate responding, (i.e. tapping continuously or still having their hand on the screen from the previous trial).

Since RT data was only included for correct responses, RT data were only included if participants had responded correctly on at least three trials per condition. This is because without accurate responses, the reaction times are not meaningful. In addition, since all data on four conditions was required for each participant in order to conduct the repeated measures ANOVA, any children who failed to complete all four conditions were excluded from the final sample. Due to COVID-19 and the sudden implementation of the lockdown in March 2020, there were 30 participants who had been tested on session 1 but were not able to be tested again for session 2. Thus, these participants were excluded from the final sample due to having incomplete data sets. There were no additional instances (e.g. sickness or non-compliance) in which children were unable to complete all four conditions.

2.3 Results

2.3.1 Accuracy

Accuracy on the four conditions per age group is shown in Figure 2.2. The data were analysed using a mixed ANOVA with Inhibitory demands (Inhibition, Control) and Test-trial feedback (With, Without) as within-subject factors and age (3, 4, and 5-year-olds) as a between-subjects factor. There were main effects for Inhibitory demands, $F(1,94)=71.817$, $p<.001$, $\eta^2_p=.433$, Test-trial feedback, $F(1,94)=5.838$, $p=.018$, $\eta^2_p=.058$, and age $F(2,94)=33.194$, $p<.001$, $\eta^2_p=.414$. These main effects demonstrate that children were less accurate on the inhibitory conditions than the control conditions, that they had better accuracy when provided with test-trial feedback and that children's accuracy scores improved with age.

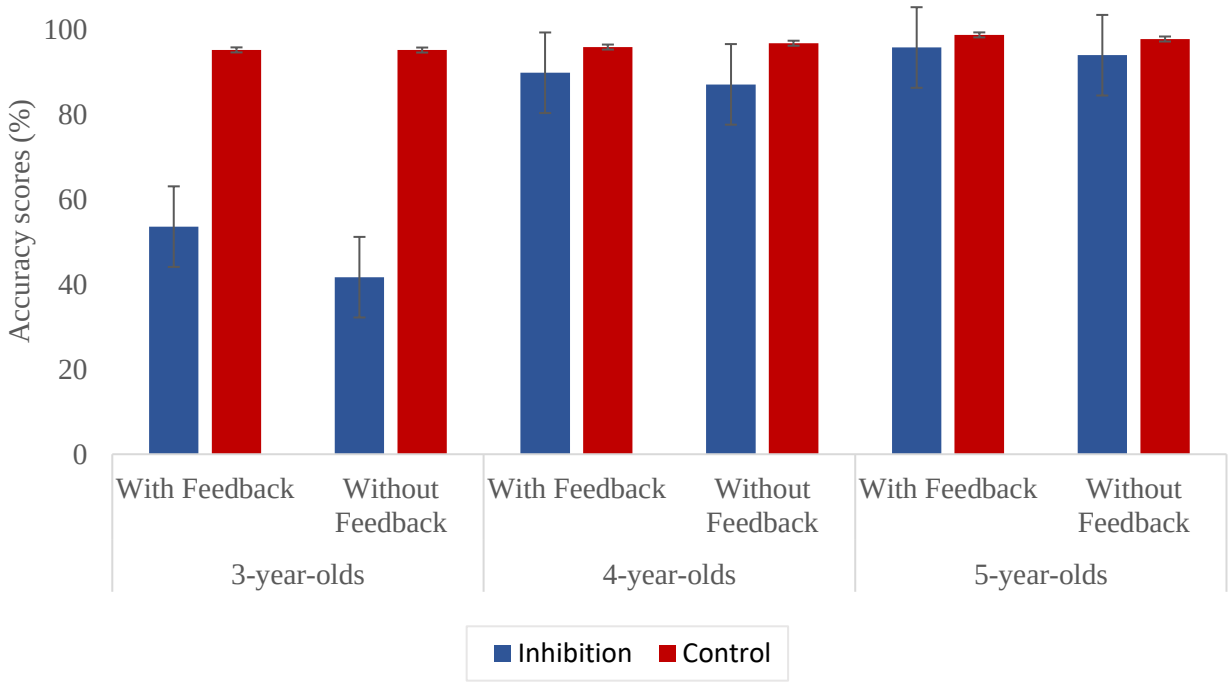
There was a significant interaction between Inhibitory demands and Test-trial feedback, $F(1,94) = 6.414$, $p= .013$, $\eta^2_p=.064$ and Inhibitory demands and Age $F(2,94) = 35.113$, $p= <.001$, $\eta^2_p=.428$ but no interaction between Test-trial feedback and Age $F(2,94) = 1.983$, $p= .143$, $\eta^2_p=.040$. Follow-up t-tests showed that feedback improved accuracy in the Inhibition condition, $t(96)=2.552$, $p=.012$ but had no effect in the Control condition, $t(96)=-.124$, $p=.901$.

Additionally, there was a significant interaction between Age and Inhibitory Demands $F(2,94)=35.116$, $p<.001$, $\eta^2_p=.428$ (see Figure 2.3 for a scatterplot of the relationship between Age and Accuracy scores per condition). To investigate this interaction, the repeated measures analysis was repeated for each of the age groups. This showed that the effect of Inhibitory Demands (worse performance in Inhibition vs.

Control) was significant in all age groups (3-year-olds $F(1,28)=59.023$, $p<.001$, $\eta^2_p=.678$; 4-year-olds $F(1,40)=6.859$, $p=.012$, $\eta^2_p=.146$; 5-year-olds $F(1,26)=6.288$, $p=.019$, $\eta^2_p=.195$).

Figure 2.2

Mean accuracy scores for each age group per condition.



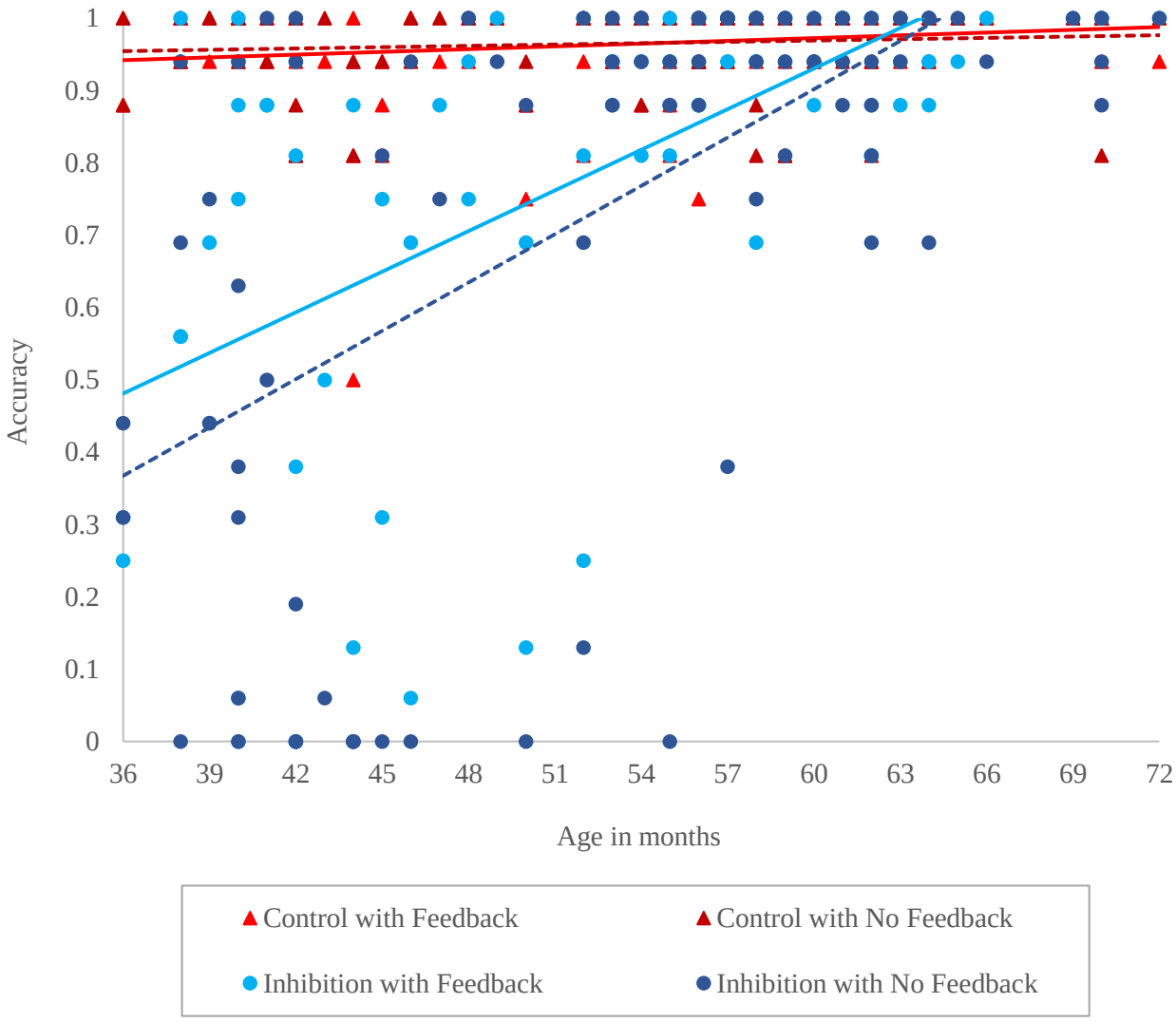
Note. Error bars show Standard error of the mean.

Nevertheless, as can be seen in Figure 2.2, the difference was smaller in the older groups. These follow-up analyses furthermore showed that the effects of Test-trial Feedback and the interaction between Inhibitory Demands and Test-trial Feedback were only significant in 3-year-olds: Test-trial Feedback $F(1,28)=5.059$, $p=.033$, $\eta^2_p=.153$; interaction between Inhibitory Demands and Test-trial Feedback, $F(1,28)=5.552$,

p=.026, η^2_p=.165. These effects were not significant in 4-year-olds: Test-trial Feedback F(1,40)=.267, p=.609, η^2_p=.007; interaction between Inhibitory Demands and Test-trial Feedback F(1,40)=1.252, p=.270, η^2_p=.030). Nor were they significant in 5-year-olds: Test-trial Feedback F(1,26)=2.180, p=.152, η^2_p=.077; interaction between Inhibitory Demands and Test-trial Feedback F(1,26)=.172, p=.682, η^2_p=.007).

Figure 2.3

Scatterplot showing the relationship between accuracy and age.

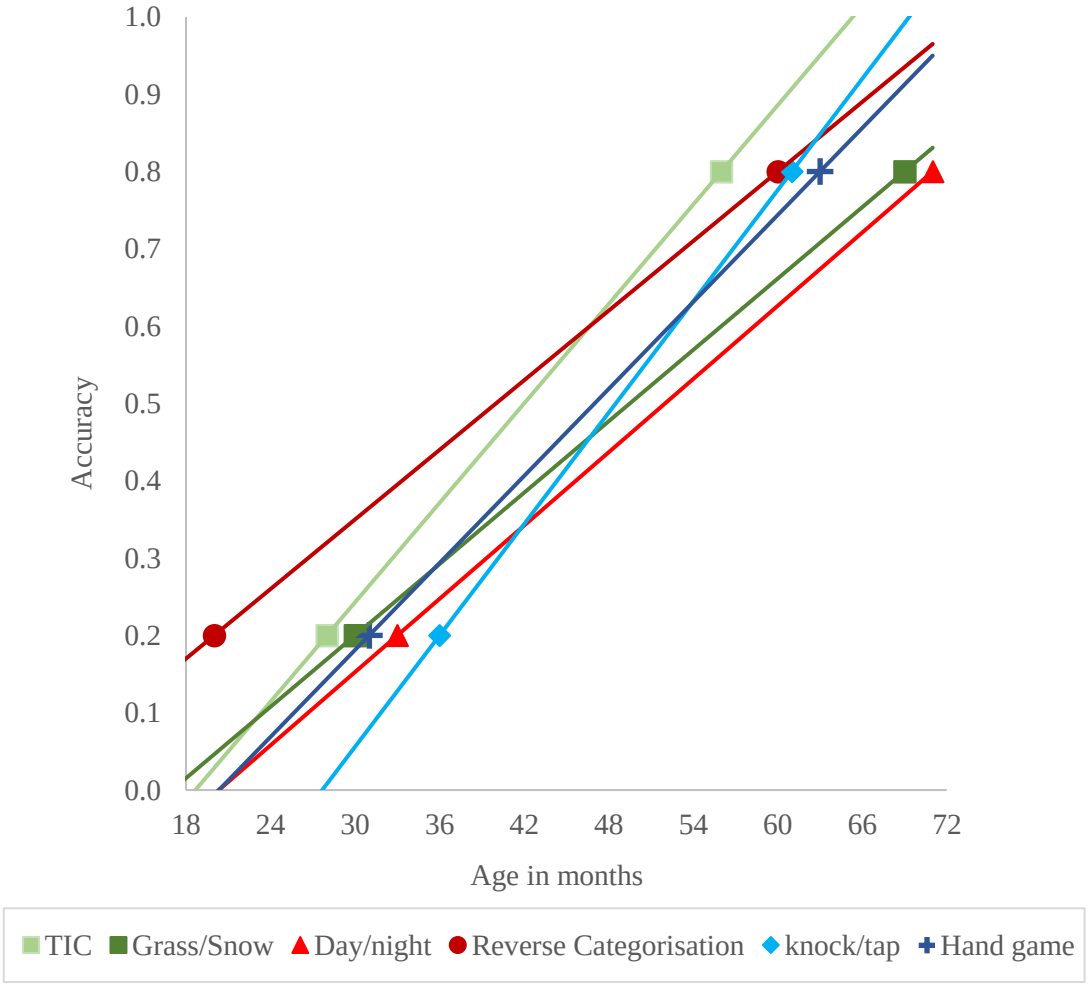


Note. Trendlines show the line of best fit for each condition and are depicted as a light red solid line for the Control with feedback condition; a dashed dark red line for the Control with no feedback condition; a light blue solid line for the Inhibition with feedback condition; and a dashed dark blue line for the Inhibition with no feedback condition.

According to Petersen and colleagues' (2016) suggestion that the useful range of an SRC task is determined by performance levels between 20% and 80%, our TIC task demonstrated a useful age range of 28 to 56 months. Figure 2.4 shows the useful age range of the TIC task in comparison to other similar SRC tasks assessed in the review paper (Petersen et al., 2016).

Figure 2.4

The useful range of the TIC task in comparison to other SRC tasks.



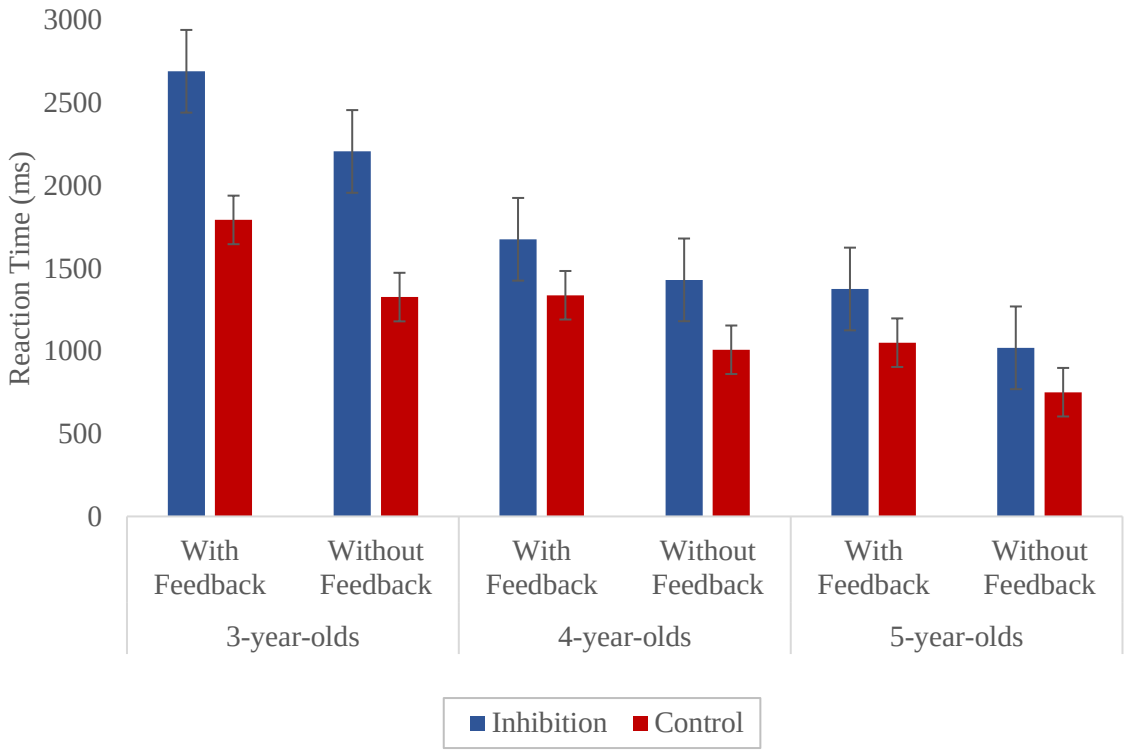
Note. Data for the useful ranges taken from Peterson et al., 2016.

2.3.2 Reaction Times

Reaction time analysis was conducted on correct responses only. For each condition, data were only included if participants had responded correctly on at least three trials of that condition, so that an estimate of their reaction times could be made. Mean reaction times on the four conditions are shown in Figure 2.5.

Figure 2.5

Mean reaction time scores for each age group per condition.



Note. error bars show Standard error of the mean.

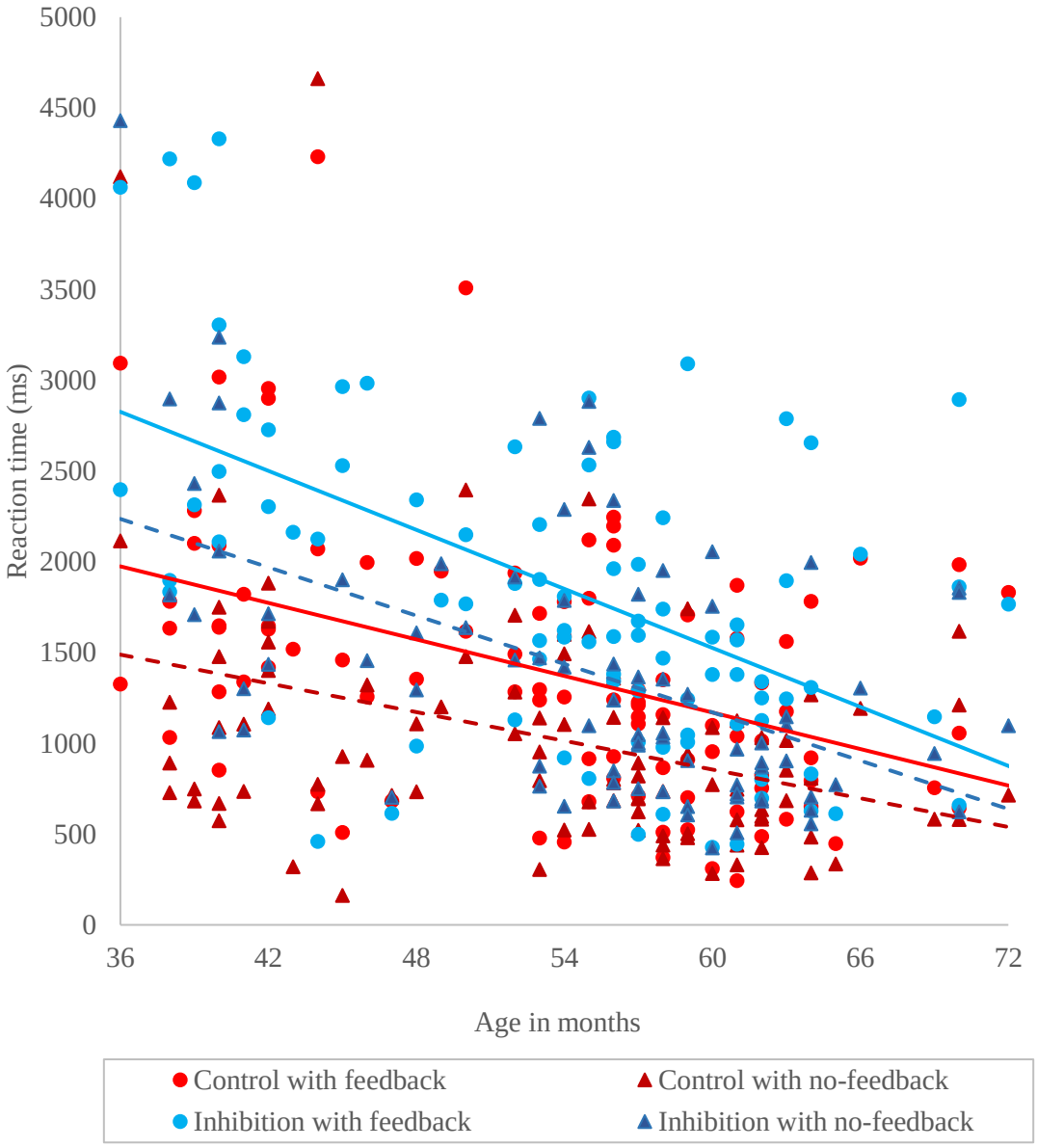
The data were analysed using a mixed ANOVA with Inhibitory demands (Inhibition, Control) and Test-trial feedback (With, Without) as within-subject factors and Age as a between-subjects factor. There were main effects for Inhibitory demands, $F(1,82)=91.676$, $p<.001$, $\eta^2_p=.528$, Test-trial feedback, $F(1,82)=35.977$, $p<.001$, $\eta^2_p=.305$ and Age $F(2,82)=17.267$, $p<.001$, $\eta^2_p=.296$. These main effects demonstrate that children had slower reaction times on the inhibitory conditions than the control conditions, that they had slower reaction times when provided with test-trial feedback (see Figure 2.5) and that children's reaction times improved with age.

There was a significant interaction between Age and Inhibitory demands $F(2,82)=9.132$, $p<.001$, $\eta^2_p=.182$, but not between Age and Test-trial feedback $F(2,82)=.943$, $p=.394$, $\eta^2_p=.022$, or Inhibitory demands and Test-trial feedback $F(1,82)=0.046$, $p=.831$, $\eta^2_p=.001$.

To investigate the effect of Age on children's RT scores for Inhibitory Demands (Inhibition vs. Control), the mixed ANOVA was repeated for correct reaction times for each age group. This showed that the effect of Inhibitory demands (Inhibition vs. Control) was significant in all age groups (3-year-olds $F(1,18)=21.689$, $p<.001$, $\eta^2_p=.546$; 4-year-olds $F(1,38)=53.996$, $p<.001$, $\eta^2_p=.587$; 5-year-olds $F(1,26)=23.447$, $p<.001$, $\eta^2_p=.474$). This demonstrates that whilst reaction times decreased with age, they did so more on the Inhibitory conditions than the Control conditions (see Figure 2.6). That is, the difference between reaction time on the Inhibition and Control conditions became smaller as the age increased.

Figure 2.6

Scatterplot showing the relationship between reaction time and age.



Note. Trendlines show the line of best fit for each condition and are depicted as a light red solid line for the Control with feedback condition; a dashed dark red line for the Control with no feedback condition; a light blue solid line for the Inhibition with feedback condition; and a dashed dark blue line for the Inhibition with no feedback condition.

2.3.3 Order effects

Given that the same stimuli were used in the feedback vs no feedback conditions, we tested to see whether any carryover effects of feedback were present. This was a concern because children may have performed better on the Inhibitory without Feedback condition if they had already received additional feedback in the Inhibitory with Feedback condition in the previous testing session. The analysis showed that the order in which the conditions were presented had no significant main effect on children's accuracy scores $F(3,93)=1.73$, $p=.166$, $\eta^2_p=.053$).

2.3.4 Comparing accuracy and reaction times

Analysis of the relationship between the two measures of inhibitory performance (accuracy and reaction time) is shown in Table 2.1 – both with and without age partialling. This shows a significant negative correlation between accuracy and reaction time on the inhibitory with feedback condition, $r(92)=-.402$, $p<.001$, and also on the inhibition without feedback condition, $r(86)=-.624$, $p<.001$. These correlations remained significant when age was partialled out in the inhibition without feedback condition $r(82)=-.443$, $p<.001$, but not in the inhibition with feedback condition, $r(82)=-.080$, $p=.470$.

Table 2.1

Correlations and age-partialled correlations between the two measures of inhibitory performance.

	Inhibition with feedback (AC)	Inhibition without feedback (AC)	Inhibition with feedback (RT)	Inhibition without feedback (RT)
Age	.594**	.582**	-.507**	-.523**
Inhibition with feedback (AC)		.820**	-.402**	-.607**
Inhibition without feedback (AC)			-.385**	-.624***
Inhibition with feedback (RT)				.529***
Age-partialled correlations				
Inhibition with feedback (AC)		.616	-.080	-.394
Inhibition without feedback (AC)			-.096	-.443
Inhibition with feedback (RT)				.365

Note. AC = accuracy, RT = reaction times for correct responses only.

Note. Asterisks are used to denote the *p* values as follows: ** <.01 ***<.001.

2.4 Discussion

This chapter aimed to identify what makes a good measure of inhibitory control in young children. Performance was compared on four versions of the TIC task: Inhibition with feedback, Inhibition without feedback, Control with feedback and Control without feedback. Accuracy was lower and reaction times were longer on the Inhibition conditions than the Control conditions. These differences were smaller in older children. Test-trial feedback produced slightly higher accuracy, but only on the

Inhibition condition. Reaction times were also longer on both feedback conditions (Inhibition and Control). Accuracy and reaction times were negatively correlated on the Inhibition conditions, even after controlling for age, meaning that children who performed more accurately also tended to do so faster than their peers.

We sought to answer three questions. Firstly, and most importantly, we asked whether children could learn the task rules from the interactive on-screen teaching used in this task. Mean accuracy was about 95% on both control conditions. There was no evidence that accuracy was lower in younger children. So, the data suggests that even the youngest children tested (36-month-olds) were able to learn, remember, and use the TIC task rules. Thus, performance on the two Control conditions shows that the interactive on-screen teaching used in the TIC task was highly effective for children aged between three and five years. This is helpful for us because in Chapter Four we were then able to use a similar version of this task in an online study due to COVID-19.

Secondly, the current study also investigated whether accuracy or reaction time provides the best measure of children's inhibitory control. Both these performance measures were effective. The inhibition variable was uniquely responsible for 43% of variance in accuracy, and 53% of variance in reaction time (comparing Inhibition to Control conditions – partial eta-squared from the mixed ANOVAs). As to which measure is better, following the proposal of Diamond and colleagues (Diamond et al., 2007; Diamond & Kirkham, 2005), we suggest that this depends on the age of the children tested. In a younger sample, under 4½ years of age, accuracy provides a sensitive measure of children's inhibitory control. The inhibition variable uniquely accounted for 52% of variance in accuracy for the younger half of our sample (based

on a median-split of the sample and partial eta squared). In contrast, some young children produced insufficient correct responses to provide an estimate of their reaction time on a condition. 21 of 192 conditions, collected from the younger half of the sample, failed to produce a measure of reaction time (that is produce at least three correct responses on a condition). So, for a younger sample (under 4½ years), accuracy is likely to provide the best measure of inhibitory control.

In the older sample (over 4½ years, the pattern of results was different. For these children, the effect size for accuracy was smaller because of ceiling effects (11% for the older half of our sample); while older children always produced sufficient correct responses to provide an estimate of reaction time (all 196 conditions). So, for an older sample, reaction time is likely to provide the best measure of inhibitory control in this task. Having said this, RT analyses can often be more difficult than accuracy analyses, and in some cases may not always be reliable. For instance, we found that the touchpad did not always register touch on the first attempt (e.g. if the child tapped with a fingernail or tried to tap too early). Some researchers have gotten around this by video recording the testing sessions and recoding any incorrect response times (e.g. Holmboe et al., 2021). However, in a later, online version of this task (discussed in Chapter Four) we tried to code RT data from video footage but found that the footage was too unreliable due to lagging and internet connection issues. Thus, in circumstances such as these, RT data does not always provide a good measure of inhibitory control.

The current chapter also investigated whether the use of test-trial feedback would improve our measure of children's inhibitory control. This could have been the case if giving feedback helped children to remember and apply the task rules. However,

accuracy was at ceiling on the Control condition without feedback, suggesting that children had no difficulty remembering and applying the task rules. So, the addition of feedback could not further reduce the task's memory demands. Nevertheless, accuracy was a little higher on the Inhibition with feedback condition than on the Inhibition without feedback condition (about 5%). One plausible explanation for this relates to the speed of responding in this condition. Children responded about 400ms slower on the Inhibition with feedback condition than on the Inhibition without feedback condition. It is possible that the slower responding reduced the task's inhibitory demands – this has been observed with other SRC tasks (Carroll et al., 2021; Diamond et al., 2002; Ling et al, 2016; Montgomery & Fosco, 2012). It could be that the slower pace of the TIC task when feedback was given on each trial, encouraged children to respond more slowly themselves, and that this in turn reduced the task's inhibitory demands (Kostyrka-Allchorne et al., 2017, 2019b). If this is the case, it would suggest that the task is best administered without feedback when trying to measure inhibitory control. Children's inhibitory control is best measured with a task that taxes this cognitive process as much as possible. Whether or not it is the case that the inhibitory demands of the TIC task are higher without feedback, we certainly obtained no evidence that providing feedback made the TIC task a *better* measure of inhibitory control. For this reason, we drop the use of the Feedback conditions when using this task again in both studies within Chapter Four.

Third, we turn to the implications of the current study to the validity of previous research that has used SRC task accuracy to measure children's inhibitory control. The early studies (Diamond et al., 2002; Gerstadt et al., 1994; Simpson & Riggs, 2005a&b),

which used control conditions, suggested that children were able to learn, remember and apply SRC task rules effectively. This in turn suggested that Inhibition condition accuracy was an effective measure of inhibitory control. The current findings support that conclusion: children again performed very well on our control conditions. This re-enforces the assertion that measuring SRC task accuracy *can* provide an effective way to assess the inhibitory control of young children. Although, of course, we cannot be sure that SRC tasks always have low memory demands, irrespective of how the task is conducted or the sample that is tested.

In conclusion, the current data provide strong evidence that the interactive on-screen teaching used in the TIC task is highly effective. Our data also support the assertion that measuring accuracy on SRC tasks provides an effective estimate of children's inhibitory control, which is very encouraging, given that we want to use this task to make comparisons with the inhibition of imitative responses, as is seen in Chapter Four.

Chapter 3

Investigating the relationship between inhibitory control and overimitation in 3-year-olds.

3.1 Introduction

Children are prolific imitators (Lyons et al., 2007; McGuigan et al., 2011; Want & Harris, 2002; Wood et al., 2013) and it has been suggested that imitation plays a pivotal role in human development, including in the acquisition of motor, communicative, and social skills (Meltzoff, 1988; Piaget, 1945; Tomasello et al., 1993). In addition, imitation serves a social function as it aids in building rapport, cooperation, and affiliative attitudes between individuals (Chartrand & Lakin, 2013). However, there may also be situations in which children's tendency to imitate others' actions makes them less efficient in the completion of goal-directed tasks. Indeed, their pervasive tendency to copy others' actions sometimes makes them copy the actions of others with high fidelity even when they may seem unnecessary; a phenomenon known as 'overimitation' (Lyons et al., 2007).

Overimitation was first observed in young children when Horner and Whiten (2005) presented 3- and 4-year-olds with two puzzle boxes: one opaque and one clear. Children observed an adult model demonstrating a sequence of actions using a tool to retrieve a reward from the box. During this sequence, some of the actions would be causally irrelevant to the model's goal (i.e. inserting the tool into a hole in the top of the box which was not connected to the compartment containing the reward). In the opaque condition, it was not obvious that inserting the tool into the hole in the top of the box was causally irrelevant to achieve the goal. However, in the clear box, the compartments within the box were visible, so children had the opportunity to infer that inserting the tool into the top hole would not be necessary to achieve the goal. The authors found that

children reproduced both the irrelevant and relevant actions, irrespective of whether the box was opaque or clear (Horner & Whiten, 2005).

In contrast, when the same task was presented to chimpanzees, they reproduced the causally irrelevant actions in the opaque condition but *not* in the clear condition (Horner & Whiten, 2005). This study therefore suggests that whilst children demonstrated imitation by following the actions of the model exactly, the chimpanzees instead used *emulation* (i.e. they understood that the meaning of the task was to retrieve the reward, and therefore only copied the *necessary* actions to achieve this). In this way, children's robust use of imitation came at the expense of efficiency. Horner and Whiten's (2005) seminal study instigated numerous theories as to why overimitation occurs and whether it might actually serve a useful function in aiding children's development. In this chapter we will first briefly discuss the most prominent existing theories of overimitation and will then put forward a theory of our own that suggests that poor inhibitory control could also explain the higher occurrence of overimitative tendencies in young children.

The *causal theory* suggests that overimitation is driven by failures in causal encoding (Lyons et al., 2007, 2011). This theory proposes that children overimitate because they lack causal understanding of the task (i.e. they are unable to tell that some of the actions are unnecessary and so they copy them all). Indeed, studies have shown that when the box design is more complex (e.g. contains mechanical mechanisms such as flaps, handles and doors), overimitation is more prominent (Burdett et al., 2018). Additionally, Hoehl and colleagues (2014) found that children were less likely to

overimitate if the irrelevant action was *not* directly associated with the container itself (i.e., clapping their hands) than irrelevant actions that *were* associated with the container (i.e. tapping on the container lid). This suggests that whilst children seem to understand that any actions that are not interactive with the box do not have an effect on their ability to open it, they are less sure about the relevance of the actions that *are* interactive with the box. The evidence that children overimitate with higher frequency when it is ambiguous as to the causally relevant or irrelevant actions therefore provides support for the causal theory of overimitation. In this way, children seem to automatically encode all *intentional* actions conducted by the model as being necessary to achieve the goal (Lyons et al., 2007, 2011).

However, there are circumstances in which children continue to demonstrate high overimitative tendencies, even when presented with an experimenter who performs unnecessary actions (e.g. tapping the lid) on a simplistic and familiar transparent box before retrieving the toy (i.e. a Tupperware box rather than a novel container, with no ambiguous mechanisms; Marsh et al., 2019). Therefore, the *affiliative theory* of overimitation suggests that, rather than being driven by poor causal reasoning, overimitation functions as a social signal that conveys a willingness to interact (Nielsen, 2006; Nielsen et al., 2008; Over & Carpenter, 2009; Tomasello et al., 2005; Uzgiris, 1981). For instance, infants aged 14- to 16-months-old have been shown to overimitate more frequently when the adult model actively engages with them before demonstrating the sequence of actions (Brugger et al., 2007). This adult engagement is therefore likely to increase the child's affiliation to the model. A similar effect can be observed with older children (aged 4+ years) who demonstrate overimitative tendencies more

frequently when being observed participating in the task by the adult model than when the adult model is either turned away and 'distracted' (Marsh et al., 2019) or leaves the room entirely (Nielsen & Blank, 2011). It has been suggested that perhaps children may still hold the belief that even if the model is not observing them, their behaviour might still be monitored (i.e. through the cameras which are recording the sessions) (Marsh et al., 2019). However, a study by McGuigan et al. (2007) found that some 5-year-olds overimitate even when the model's actions are delivered via pre-recorded video footage rather than live, suggesting that perhaps appeasing the model might not be the only motivation underlying children's overimitative tendencies.

A third prominent theory put forward to explain the mechanisms underlying overimitation is the *normative theory*. Kenward et al. (2011) proposed that overimitation might be a result of children perceiving the causally irrelevant action(s) as a social norm which must be followed. After watching a model demonstrate both an unnecessary action and a necessary action to get a marble out of a container, 5-year-old children were asked to describe the actions they planned on taking when it was their turn (Kenward et al., 2011). Despite 90% of children reporting that they knew the unnecessary action was not conducive to achieving the goal, the majority of children still intended to perform it anyway but stated that they were unsure *why* they would do so. This implies that children believed that they *should* perform the irrelevant action, despite understanding that it was causally unnecessary. In another study (Keupp et al., 2013), 5-year-old children watched an adult model performing a sequence of actions including an irrelevant action, and then watched a puppet perform the same sequence but with the omission of the irrelevant action. Not only did children demonstrate high

levels of overimitation (despite having witnessed a more efficient demonstration which did *not* include the irrelevant action), but many actually protested about the puppet performing the sequence 'incorrectly'. Taken together, these studies provide evidence to support the normative theory of overimitation, suggesting that children perceive the intentional actions of the adult model as a behaviour that they are *expected* to replicate, even when more efficient options are available (Kenward et al., 2011; Keupp et al., 2013).

The normative and affiliative theories of overimitation share some similarities in that they both emphasise the social nature of the interactions. There are, nevertheless, some important differences. The affiliative theory is associated with the participant performing the unnecessary action in order to please the model, whilst the normative theory suggests that the participant interprets the unnecessary action as a behaviour that ought to be adhered to (even when its purpose is unclear). In other words, the model has set the parameters for what is socially acceptable in this latter scenario, and not conforming to these would violate social norms. The normative theory therefore could account for instances in which children continue to overimitate despite the adult model not being present (Nielsen & Blank, 2011).

We propose in this study that there may be another potential explanation for overimitation which has so far been overlooked. At the neural level, observing another's action automatically activates the corresponding motor representations in the brain of the observer (Decety, 1997; Grezes et al., 1998; Iacoboni et al., 1999; Nishitani & Hari, 2002 – See section 1.3.1 in Chapter 1 for a detailed explanation). This automatic

activation of the motor cortex during action observation has been suggested to result in imitation being a prepotent response tendency (Wang & Hamilton, 2012). Thus, to prevent the activation of a motor representation from becoming an action outcome, some inhibition may be required to refrain from imitating when it is inappropriate to do so. Indeed, given the evidence, children appear to be selective about the situations in which they overimitate (e.g. imitating *more* when the container is opaque (Horner & Whiten, 2005), or imitating *less* when they have previously observed a more effective strategy (Schleihauf et al., 2018)). This suggests that some individuals are better able to utilise their inhibitory control to adapt to situations in which overimitation may be very inefficient or even maladaptive. We therefore propose that *inhibitory control* may be another factor influencing the occurrence of overimitation which has previously been overlooked.

Given the prepotency of imitative tendencies, the current study aims to explore whether there could be an association between children's inhibitory control and their tendency to overimitate. Despite the fact that both overimitative tendencies and inhibitory control have been shown to increase with age (McGuigan et al., 2007; Nielsen, 2006; Whiten & Custance, 1996), we propose that at a fixed point in time, those who overimitate more may do so because they find it difficult to inhibit copying the observed actions. Evidence to support this idea can be found in the autism literature. Autistic children not only demonstrate significantly lower overimitative tendencies than neurotypical children (Marsh et al., 2013; Vivanti et al., 2017) but they also demonstrate much better inhibitory control (Uzefovsky et al., 2016). However, thus far, no studies

have directly investigated the role of inhibitory control in children's tendency to overimitate.

In the current study, we use a pre-existing data set to investigate whether there is an association between 3-year-olds' performance on an overimitation task based on Marsh et al., (2019) and two different inhibitory control tasks – a Go/No-Go task (Howard & Melhuish, 2017) and a recently developed SRC task: the Early Childhood Inhibitory Touchscreen Task (ECITT; Holmboe et al., 2021). In the overimitation task, the experimenter demonstrated a series of actions (one unnecessary action and two necessary ones) to retrieve a toy from a simple transparent container, such that it was obvious that the unnecessary action was causally irrelevant. One of the key aims of the original study (Marsh et al., 2019) was to look for an audience effect and the dataset that was used here, came from a study that aimed to replicate this finding. As such, two conditions were employed in the overimitation task: direct gaze (where the experimenter would either observe the child open the container) and averted gaze (where the experimenter would turn away whilst the child opened the container). These conditions are not directly relevant to the current study but are reported in the methods section since they are part of the data set being analysed.

Children were scored on whether they imitated the unnecessary action. Overimitation scores were correlated with children's scores on a Go/No-go (GNG) task, in which children were asked to tap the screen when they saw a fish (80% of trials), and to refrain from tapping when they saw a shark (20% of trials) (Howard & Melhuish, 2017). Due to the GNG task design, it was only possible to measure inhibitory control

on the No-go trials, which were far less frequent. In addition, reaction time could not be compared between trials requiring inhibition and trials not requiring inhibition, since the No-go trials required children to inhibit a response entirely, and thus measuring reaction time was not possible. For this reason, we also correlated children's overimitation scores with their scores on a second inhibitory control task: the ECITT (Holmboe et al., 2021). In this touch screen task, the same children were required to press one of two buttons on the screen depending on which one had a 'smiley' face on it. The smiley appeared in one location more frequently than the other (75% of trials) to build a prepotent response for the favoured location. Given that the ECITT required children to make a response for every single trial, it gave us the ability to compare the reaction times for trials requiring inhibition against trials not requiring inhibition. Reaction time scores provide greater variability than accuracy scores alone, perhaps providing a more suitable measure of inhibitory control to correlate with overimitation scores than is possible with the Go/No-go (GNG) task.

We hypothesised that 3-year-olds who perform better on the inhibitory control tasks (GNG task and the ECITT) would be less likely to demonstrate overimitative tendencies (i.e. they would be better able to inhibit the tendency to replicate unnecessary actions to achieve an action goal). Thus, we predicted that there would be a negative relationship between inhibitory control and overimitation. In this way, we therefore predicted a negative correlation between children' performance on the GNG task and their scores on the overimitation task, but a positive correlation between children's performance on the ECITT and their scores on the overimitation task. This is because

the ECITT is reverse coded which results in a higher ECITT score being indicative of poorer inhibition (this is described in further detail in section 3.2.4).

3.2 Method

3.2.1 Participants

All children in the study were aged around 3 at the time of testing (with a range of 35 to 40 months). The data set was collected in 2017-2018 at Birkbeck College, University of London as part of a longitudinal study in which children completed a battery of tasks. Parental consent was given prior to data collection. The sample size was pre-determined by the data set already collected (this data was analysed during the COVID-19 pandemic when it was not possible to collect new data to investigate the relationship between inhibitory control and overimitation). In total, valid data were obtained from 47 children on the overimitation task, 40 children on the Go/No-go (GNG) task and 45 children on the ECITT. Out of these, 39 participants (female N=21) had valid data on *both* the overimitation task and the GNG task and 44 participants (female N=23) had valid data on *both* the overimitation task and the ECITT, allowing for the two correlations to be conducted.

3.2.2 Overimitation Task

Overimitation Stimuli

A total of six different transparent containers were used, each with removable lids and no hidden mechanisms. These included a tall, upright, transparent container with a green silicon seal and a lip on one side for easy opening; a transparent rectangular Tupperware box with a lick-lock on each side; a round, transparent saucepan-like container with a long handle and a lid which sat on the top secured with an elasticated band; a transparent drinking bottle with a screw-top lid, a similar but smaller transparent drinking bottle with a screw-top lid, and a transparent jug with a handle and a blue push-in lid. The toys included a car, a frog, two different balls, a man and a crab respectively.

Overimitation Procedure

Three cameras recorded the session, one angled on the child, one angled on the experimenter and one angled to capture both the child and the experimenter. During the experiment, children were sat on their parent's lap at a table opposite the experimenter. Children were presented with four different transparent containers in turn, each with a toy inside. Each toy was always placed in the same container each time, and the containers were always presented in the same order. The experimenter placed the first container on the table (a tall, upright, transparent container with a green silicon seal and a lip on one side for easy opening). The experimenter said to the child: "I have a car in this box. I'm going to show you how to get the car out of the box, and then it's going to be your turn. Can you watch carefully?". The experimenter then demonstrated a sequence of three actions to open the container and remove the toy. Of the three actions,

two were always necessary and the other was always unnecessary. For instance, the experimenter would turn the container the right way up, tap on the lid of the container three times and take the lid off to get to the toy. After demonstrating the procedure, the experimenter then reset the container under the table out of the child's view before placing it back on the table and instructing the child "When I say 'go', I would like you to get the car out of the box as quickly as you can." The instructions were the same for each of the four containers ("when I say 'go', I would like you to get the [toy] out of the box as quickly as you can"). In the direct gaze conditions, the experimenter would remain engaged in what the child was doing and would observe them opening the container. In the averted gaze condition, the experimenter would say 'go' and then immediately look away and rummage in a bag off to the side of them, so that the child was aware that the experimenter was not observing them do the task. The order of conditions was counterbalanced, so that during each session, two overimitation trials were accompanied by direct gaze and two by averted gaze but which container was accompanied by direct or averted gaze varied between participants.

Following the first four experimental trials, there were two further trials in which the children were instructed to copy the experimenter exactly, as an assessment of children's ability to remember the actions they observed. First, the experimenter would say to the child "let's play a different game now. Can you copy me?" The experimenter would then demonstrate an action and ask the child to copy the action. These actions included tapping the side of their nose with their index finger, wiggling their earlobe, knocking on the table and tapping/touching their elbow on the table. After this, two further transparent containers were presented, each containing a toy. The experimenter

said to the child “I’m going to open some more boxes now, and this time I want you to do everything the same way that I do”. The experimenter placed the container on the table and demonstrated a sequence of actions, again with two necessary actions and one unnecessary action. The only difference was that this time the children were instructed to copy the experimenter’s actions exactly. She again reset the container underneath the table out of view before giving the child a turn. Once the child had retrieved the toy, the experimenter asked them if the unnecessary action (e.g. banging the container on the table, or tapping the lid) was silly, or not silly. Following this, they then asked if one of the necessary actions (e.g. removing the lid, or tipping the toy out of the container) was silly, or not silly. As with the first four trials, each of these two trials were also conducted with either direct or averted gaze from the experimenter, and the order was counterbalanced so that each child had one direct gaze and one averted gaze, but across all children 50% had averted gaze on the first trial and 50% had averted gaze on the second trial.

Overimitation Data analysis

Responses were coded from the video recordings to determine whether or not the children displayed overimitative behaviours. Only the first four trials were used for data analysis since children were specifically instructed to copy in the final two trials, and as such these acted as memory control conditions. Each trial was coded as [1] if the child made a purposeful and definite attempt to replicate the unnecessary action while retrieving the toy from the container. If they did not attempt to replicate the unnecessary action, this was coded as [0]. Non-responses were excluded. In addition, any trials that

involved parental interference (2 trials) or experimenter error (2 trials) were excluded (e.g. if the experimenter omitted the unnecessary action and therefore there was nothing to overimitate). The data were coded by two coders. Coder 1 coded all videos and coder 2 coded a subset of the videos (20%). Intercoder reliability was high (α = .983). The data from coder 1 were used in the final analysis. Since each child did two direct gaze and two averted gaze trials, scores were averaged separately so that each child had a direct gaze overimitation score and an averted gaze overimitation score.

3.2.3 Go/No-go Task

Go/No-Go Procedure

The Go/No-go task was taken from the Early Years Toolbox (Howard & Melhuish, 2017) and was presented on an Apple iPad Air 2 touchscreen tablet. Cameras were set up at various angles to record the session for later video coding purposes. Children sat on their parent's lap at a table, while the experimenter sat adjacent to the child. The experimenter held up the tablet upright and horizontally, propped up on the table in front of the child. The experimenter instructed the children to tap the screen when they saw a fish ('catch' the fish). This was followed by five practice trials on the Go (fish) trials. The experimenter then instructed children not to tap the screen if they saw a shark ('don't catch' the shark). They then received five practice No-go (shark) trials. Children were reminded of both rules and practiced a further ten mixed trials (consisting of 80% Go trials and 20% No-go trials) before the instructions were repeated once more. Feedback was provided by way of an auditory tone on the practice trials

only. The actual trials consisted of 75 stimuli (80% go trials and 20% no-go trials) split into three testing blocks of 25 trials – each time separated by a brief break and a recap of the instructions once again. Stimuli were presented in a pseudo-random order ensuring that (1) each block always began with a Go trial and (2) that there were never more than two consecutive No-Go trials. Each trial stimulus (fish or shark) was displayed for 1500ms and was separated with an intertrial interval of 1000ms.

Go/No-Go Data analysis

Children were deemed to have responded accurately if they responded on the Go trials (i.e. tapped the screen when they saw a fish) and if they withheld a response on the No-Go trials (i.e. did not tap the screen when they saw a shark). The accuracy scores were then used to calculate an impulsivity score for each child (see Howard & Melhuish, 2017) by multiplying their average Go accuracy score (to account for the prepotency built up) with their average No-go accuracy score (as an index of the child's ability to inhibit the prepotent response).

Go/No-Go exclusion criteria

Trial exclusions were as follows: [1] child was turned away from the iPad and clearly distracted or no longer engaging with the task; [2] if the child had their finger still on the screen from the previous trial; [3] parental or experimenter intervention (e.g. parent held the child's hand back to prevent them from responding on a no-go trial; the researcher moved the touchpad away to prevent the child from tapping the screen on a no-go trial; or parent/experimenter prompting a response on a go trial); [4] any Go trials with a reaction time less than 300ms.

Whole trial blocks were excluded if children's 'No-go' average trial accuracy was less than 20% *and* average 'Go' trial accuracy exceeded 80% over the duration of a block, as this was likely to be a result of indiscriminate responding - i.e. the child always pressed the screen, regardless of whether a fish or shark was displayed. This resulted in a total of 3 blocks being excluded. Likewise, blocks in which accuracy was less than 20% and no-go trial accuracy was higher than 80% were also excluded (14 blocks), as this was indicative of non-responsiveness. These exclusion criteria resulted in N=7 children having one block excluded, and N=5 children having two blocks excluded. To be included in the final sample, children were required to have at least one valid block out of the three, which all children did with the exception of N=4 children who refused to participate in the task at all. After exclusions, N=40 children provided valid data.

3.2.4 Early Childhood Inhibitory Touchscreen Task (ECITT)

ECITT Procedure

The procedures followed during data collection on the ECITT task were the same as those reported in Holmboe et al. (2021). The task was presented on an Apple iPad Air 2 touchscreen tablet (the same tablet as used in the Go/No-go task). Children sat on their parent's lap at a table, while the experimenter sat adjacent to the child, as in the Go/No-go task setup. The experimenter held up the tablet in portrait orientation, resting it on the table. The task started with three practice trials in which a smiley button was displayed in the centre of the screen. Children were told to tap the button and when they

did, a short, animated video appeared on the screen. Each animation lasted between 3.75 and 4 seconds. These practice trials were followed by 32 experimental trials, in which there were two blue buttons (17 x 24 mm), one above the other. One of the blue buttons had a smiley face on and the other did not. The child was told to tap the smiley face ("press the happy face"), which appeared in one of the locations (top or bottom) 75% of the time (prepotent trials) and the other location 25% of the time (inhibitory trials). The prepotent location (top or bottom) was counterbalanced across participants. The experimental trials were randomised with the exception of the following constraints: experimental block always began with 3 trials in the prepotent location in order to establish the prepotency, there was a maximum of 2 inhibitory trials in a row, and a maximum of 5 prepotent trials in a row (Holmboe et al., 2021). If the child made the correct response (i.e. pressed the button with the smiley face on), an animated video would play. If the child responded incorrectly (pressed the plain blue button), the screen would remain blank for 1 second before proceeding to the next trial. The task was self-paced and would only proceed to the next trial once the child had made a response.

ECITT Data Analysis

Both accuracy and reaction time were measured by the touchpad. However, since the results of the original study demonstrated that children had reached a ceiling effect for accuracy by the age of 2½ years for accuracy (Holmboe et al., 2021) reaction time was used as the main measure of inhibitory control for the purpose of this analysis. The reaction time data recorded by the task were checked against the video footage so that

corrections could be made where necessary (e.g. the child pressed with a nail and their initial response was not registered by the iPad).

A difference score was derived as an indicator of inhibitory performance (Holmboe et al., 2021). Using only the RT scores for correct responses, the median RT for the prepotent trials (trials in which the smiley was in the prepotent location) was subtracted from the median RT for the inhibitory trials (trials in which the smiley was in the less frequented location). A higher RTD score was therefore indicative of poorer inhibitory control. The median was chosen over the mean because it is less affected by outliers, and so is commonly used in developmental research (e.g. Davidson et al., 2006).

ECITT exclusion criteria

Trials were excluded under the following criteria: [1] Reaction times under 300ms (N=8) or over 5000ms (N=0) were deemed invalid and excluded from the analysis; [2] Parental influence (e.g. parent pointed directly to one of the response locations, nudged towards a response or prevented the child from making an inaccurate response) (N=3); [3] Experimenter influence (e.g. experimenter pointed directly to one of the response locations, nudged towards a response or prevented the child from making an inaccurate response) (N=6); or [4] accidental touches (e.g. brushed the screen with their arm/hand by accident). In addition, [5] any children who achieved less than 60% accuracy across the prepotent trials were excluded from the sample, because if the child was pressing the two buttons randomly they would not have built up a prepotent response tendency for the primed location, and therefore the results would be unlikely

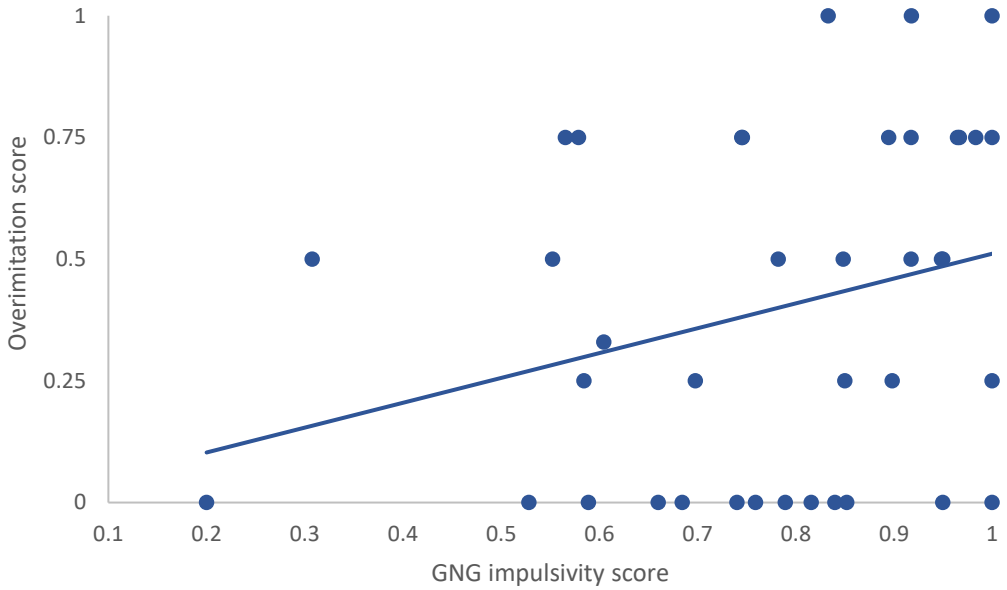
to reflect response inhibition (Holmboe et al., 2021). However, there were no occurrences of this in our sample (N=0).

3.3 Results

Firstly, a paired samples t-test was conducted to compare whether there was an effect of condition (direct versus averted gaze) in the overimitation task. This revealed no significant difference in overimitation between direct gaze (M=.38, SD=.38) and averted gaze (M=.40, SD=.40) conditions; $t(46)=.36$, $p=.719$. Since there was no effect of condition, we calculated the average score for the two conditions combined, producing an overall mean overimitation score for each child. We then used this average overimitation score to run a correlation with children's impulsivity score on the Go/No-go task and ECITT. Pearson's correlations demonstrated no statistically significant relationships between children's performance on the overimitation task and the impulsivity score on the Go/No-go task $r(39)=.28$, $p=.082$ (see Figure 3.1) or their RTD score on the ECITT, $r(44)=.02$, $p=.894$ (see Figure 3.2).

Figure 3.1

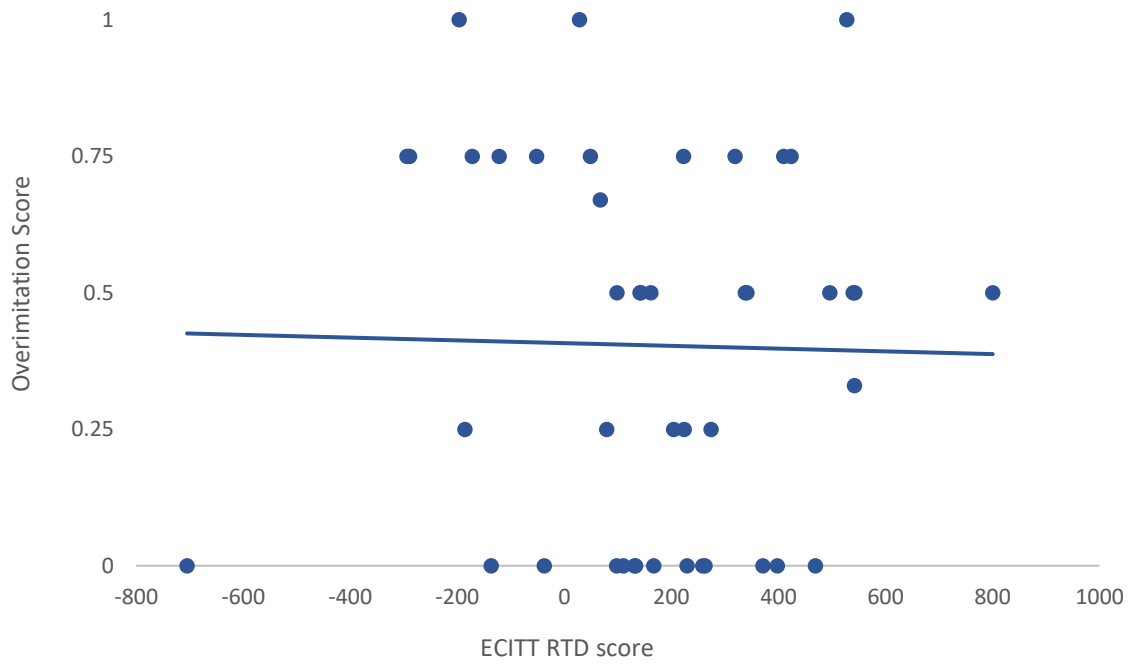
Scatterplot of the relationship between children's scores on the overimitation task and their impulsivity score on the Go/No-go task.



Note. The overimitation score reflects a percentage of overimitation over the four trials.

Figure 3.2

Scatterplot of the relationship between children's scores on the overimitation task and their scores on the ECITT task.



Note. The overimitation score reflects a percentage of overimitation over the four trials.

Note. The reaction time difference (RTD) score is calculated by subtracting children's median RT score on the prepotent condition from their median RT score on the inhibitory condition.

However, as can be seen in Figures 3.1 and 3.2, the absence of an effect may have been driven by the presence of several influential data points. To curb the impact of these influential points – especially given the small sample size – we created grouping variables based on a median split of children's inhibitory control scores, to investigate the overimitative tendencies of children with high and low inhibitory control. We created median split variables for the GNG task and the ECITT. This

resulted in a high inhibitory control GNG group (N=20) and a low inhibitory control GNG group (N=19) and a high RTD score [1]group (N=22) and a low RTD score group (N=22). To investigate whether there were any significant differences between the overimitation scores of children in these groups, independent samples t-tests were conducted. Children in the high inhibitory control group based on the GNG task performance demonstrated significantly higher levels of overimitation (M=.51, SD=.35) than those in the low inhibitory control group (M=.28, SD=.31), $t(37)=-2.19$, $p=.035$, $d=.70$. For the ECITT groups, there were no statistically significant differences in overimitation scores between the high RTD score group (M=.44, SD=.36) and the low RTD score group (M=.37, SD=.31), $t(42)=.71$, $p=.483$.

3.4 Discussion

Given that 3-year-olds have notoriously underdeveloped inhibitory control, the current study investigated whether the tendency to overimitate relates to inhibitory control abilities. To our knowledge, this was the first study to investigate the relationship between inhibitory control and overimitative tendencies in 3-year-olds. It was theorised that overimitation may be the result of the prepotent tendency to copy observed actions; a tendency which one might need to suppress through the use of inhibitory control at times when it is not appropriate to imitate.

[1] Note that a high RTD score indicates poorer inhibitory control in this case.

Two correlations were carried out to investigate (a) the relationship between children's scores on the overimitation task with their scores on the GNG task and (b) the relationship between children's scores on the overimitation task and the ECITT. Neither correlation was found to be significant, suggesting no relationship between inhibitory control and overimitation. However, due to the relatively small sample size, influential data points could have been skewing the results (but were not significant enough to be considered outliers and were therefore not removed from the analysis). For this reason, further exploratory analyses were conducted.

In these exploratory analyses, a median split grouping variable was created for each measure of inhibitory control. When comparing overimitation scores in the high scoring GNG group against the low GNG group, we found a significant difference. No differences were found between the high and low RTD groups based on the ECITT task. Children with higher scores on the GNG task tended to show greater levels of overimitation than children who scored lower on the GNG task. This finding contradicted our prediction that we might find a negative relationship between children's scores on the overimitation task and the GNG task.

Our prediction had been that children with better inhibitory control might make use of inhibition to suppress their overimitative tendencies. However, our results indicated that children with better inhibitory control (on the GNG task) actually overimitated more. One possibility for this finding is that children who have better inhibitory control may have better executive function (EF) in general. Indeed, having good working memory (WM) would certainly allow children to better remember and

execute the sequence of actions demonstrated by the model, whilst having good inhibitory control would mean that children are able to perform better on both the ECITT and the GNG tasks. In this way, good overall EF skills may increase the likelihood of children scoring highly on the inhibitory control tasks as well as remembering and replicating the sequence of actions in the overimitation task.

The literature shows that inhibitory control (Carlson, 2005; Garon et al., 2014; Gerstadt et al., 1994; Kochanska et al., 2000; Murray & Kochanska, 2002; Simpson & Riggs, 2005a), WM (Cowan, 2014; Diamond et al., 1997; Hughes, 1998; Simpson & Riggs, 2006) and overimitation (McGuigan et al., 2007; Nielsen, 2006; Whiten & Custance, 1996) all increase with age. Possibly, as children's EF improves, they are better able to remember the sequence of actions observed, resulting in greater overimitation with age. Similarly, in our study children with more advanced EF abilities may have been better able to remember the sequence of actions, leading them to show higher levels of overimitation.

However, we acknowledge that creating median split grouping variables is controversial since this can increase the likelihood of a type 1 error (in which a true null hypothesis is incorrectly rejected) as well as adversely affect the statistical power of the analysis (McClelland et al., 2015). We conducted the median split analyses in the current study to lessen the impact of the influential data points – a common practise in developmental psychology (Davidson et al., 2006). These data points were perhaps more influential given that the study was underpowered (power calculations determined that a sample size of 67 participants would have been necessary to detect a correlation

with a medium effect size). After exclusions were applied, the sample sizes were just 44 and 39 participants for the ECITT/overimitation and GNG/overimitation analyses respectively. This makes it difficult to know whether there was simply no effect present to detect, or whether the sample size was just too small to detect it. Unfortunately, since the data analysis took place during the COVID-19 pandemic, we were not able to collect additional data to supplement these results. Therefore, we suggest that the current findings should be interpreted with caution.

There are two possible reasons for the absence of a difference in overimitation between children in the high and low RTD groups based on the ECITT scores. Firstly, reaction time was used as a measure of inhibitory control in the ECITT task because previous research had shown that children's accuracy levels were already at ceiling performance at this age (Holmboe et al., 2021). However, we found in Chapter Two that on other inhibitory control tasks (i.e. our TIC task), RT is not a good measure of inhibitory control in children under the age of 4½ years. This is because RT scores can be highly variable in younger children. Too much variability renders the data somewhat meaningless, because it does not adequately reflect the developments made in inhibitory control in young children in the same way that accuracy scores do. In this way, perhaps RT was not really the best measure of inhibitory control in the ECITT, but rather the only one.

Secondly, the task requirements of the ECITT and the overimitation task may differ too much to draw meaningful comparisons. For instance, the ECITT measures children's ability to respond to stimuli by switching from the prepotent location to the

alternative location. This is quite different from the overimitation task which measures children's ability to refrain from performing a physical action (i.e. unnecessarily tapping on the lid of a container before lifting the lid off). These methodological differences potentially result in very different WM demands as well. As discussed earlier in this discussion, the overimitation task is likely to have fairly high WM demands for children as young as three years since they are required to remember and perform an entire sequence of actions as demonstrated by the experimenter. On the other hand, the WM demands of the ECITT were specifically designed to be as low as possible since this task was originally created to test inhibitory control in much younger children (~18 months; Holmboe et al., 2021). If the WM demands of the two tasks are indeed very dissimilar, then it is possible that the WM demands of the overimitation task could outweigh the inhibitory demands of the ECITT. This suggests that the overimitation task may not be the best task to measure children's imitative tendencies.

To sum, the aim of the current study was to investigate whether there was a relationship between 3-year-olds' scores on two inhibitory control tasks and an overimitation task. We found that children who scored highly on the GNG task also showed greater levels of overimitation than children who scored lower on the GNG task. We suggest that these unexpected findings may reflect the fact that children with better EF may be better able to remember the sequence of actions resulting in greater levels of overimitation. However, as this study was underpowered, and these results based on a median split analysis, future research will need to confirm these findings.

An existing data set was used in the current study since the COVID-19 measures to prevent the spread of the virus prohibited face-to-face testing at that time. These measures limited the ability to choose/design the tasks for the current study in relation to the specific research question. Had we been able to collect our own data, it is likely that we would *not* have chosen an overimitation task as a measure of children's imitative tendencies. We suggest that a task that requires a more immediate suppression of one's imitative tendencies would be more beneficial to use in research into the role of inhibition in suppressing prepotent imitative responses. Indeed, inhibitory control may be more likely to be employed in situations in which children need to inhibit a faster response, for instance when inhibiting the tendency to copy someone else's actions in real time. This is why in Chapter Four we used an imitation inhibition paradigm to investigate this question further.

Chapter 4

An investigation into the inhibition of imitative vs non-imitative response tendencies in young children

4.1 Introduction

The aim of the current chapter was to investigate the inhibition of imitative tendencies in young children. The study of imitation inhibition accelerated in the 2000s when Brass and colleagues (2001, 2003, 2005 & 2009) found evidence in the adult literature to suggest that the inhibition of imitative responses may be supported by a domain-specific social brain network (including the TPJ and mPFC). This account of imitation inhibition was contraindicative to the pre-existing notion that *all* inhibitory functions are supported by a domain-general inhibitory mechanism thought to be associated with the multiple demand (MD) network (Aron, 2004; Duncan, 2010).

In their seminal studies, Brass and colleagues tested participants with frontal lesions on both the Imitation Inhibition task and the Stroop task (2003, 2005). In the Imitation Inhibition task, participants were required to raise either their index finger or their middle finger in response to a number displayed on the screen (i.e. lift index finger when a '1' is shown and lift middle finger when a '2' is shown). Also shown on the screen was a video of a hand mirroring the position of the participant's hand. There were three conditions: baseline, congruent, and incongruent. In the baseline condition, the video of the hand remained motionless, and the participant simply responded to the numbers on the screen as instructed. In the congruent condition, the hand on the screen raised the correct finger in response to the number shown (i.e. raised an index finger when the number '1' was shown). In the incongruent condition, the hand on the screen raised the opposite finger to the one that was required (i.e. raised an index finger when the number '2' was shown) (Brass et al., 2003; 2005).

In Brass and colleague's (2005) Stroop task, participants were instructed to place their index and middle fingers of both hands onto four buttons. Each button corresponded to a different possible colour response (e.g. green, red, yellow and blue). Participants were then shown a stimulus colour word on a screen (e.g. 'GREEN' in the colour *blue*). They were told to press the button which corresponded to the colour the word was written in (i.e. blue), not the colour the word spelled out. A reminder of which button corresponded to which colour was displayed on the screen at all times. Participants were tested on three conditions – a baseline condition in which a series of X's was shown in a colour on the screen (e.g. 'XXXX' in the colour *blue*); a congruent condition in which the stimulus word matched the colour (e.g. 'BLUE' in the colour *blue*) and an incongruent condition in which the stimulus word did not match the colour (e.g. 'GREEN' in the colour *blue*) (Brass et al., 2003).

For both the Imitation Inhibition task and the Stroop task, a difference score was calculated (by subtracting the number of errors made in the congruent condition from the number of errors made in the incongruent condition). Using these difference scores, Brass and colleagues (2003) found that while the participants with frontal lesions performed significantly poorer than healthy controls on both tasks, performance on the two tasks did not correlate *within* the frontal lesion group. That is, those individuals who displayed the poorest performance on the imitation-inhibition task were not the same as those who displayed the poorest performance on the Stroop task and vice versa (Brass et al., 2003). The fact that patients with frontal lesions can be impaired on one of these tasks and not the other suggests that there may be a double dissociation of these

functions. This would suggest that the inhibition of imitative responses may tap into an additional domain-specific network of inhibition specific to imitation inhibition.

To follow up on this finding, Brass and colleagues (2005) conducted an fMRI study with healthy participants to compare performance on both the Stroop task and the imitation-inhibition task. This study showed that comparison of the incongruent and congruent trials on the Stroop task revealed activation of several frontal regions, including the pre-supplementary motor area and the posterior prefrontal cortex. In contrast, during the imitation-inhibition task, participants demonstrated activation in different regions of the prefrontal cortex including the ventral premotor cortex and anterior medial prefrontal cortex (mPFC). In addition, multiple regions of the parietal cortex were activated during the imitation-inhibition task including the precuneus, cuneus, angular gyrus, right temporo-parietal junction (rTPJ), and the anterior cingulate gyrus and posterior cingulate gyrus, while participants did not appear to demonstrate any activation in the parietal cortex during the Stroop task (Brass et al., 2005).

Of particular importance is the finding of activation of the mPFC and the rTPJ during the imitation inhibition task; which has since been replicated in later studies by Brass and colleagues (Brass and Heyes, 2005; Brass et al., 2009). Both regions are part of the social brain network, with the rTPJ being implicated in distinguishing between actions generated by the self and others (Quesque & Brass, 2019), and the mPFC being thought to be responsible for carrying out self-generated action when faced with observing an incongruent action generated by someone else (Brass et al., 2009). Evidence from tDCS studies suggests that providing anodal stimulation to the rTPJ

using tDCS can improve one's performance on an imitation inhibition task (Hogeveen et al., 2015; Santiesteban et al., 2015). This provides evidence to support Brass and colleagues' claim that a domain-specific inhibitory network involving the rTPJ and the mPFC could be used either alone or in combination with the domain-general network of inhibitory control during the inhibition of imitative responses.

Conversely, the domain-general account argues that one mechanism is responsible for all types of inhibitory control, including the inhibition of imitative responses. This account proposes that inhibitory control is facilitated by the multiple demand (MD) network, which includes the inferior frontal gyrus (IFG), and dorsolateral prefrontal cortex (DLPFC) and is activated whenever we are required to inhibit prepotent response tendencies (Aron et al., 2004; Aron et al., 2014; Bunge et al., 2002; Darda & Ramsey, 2019). Given that Brass and colleagues *also* found the rIFG to be activated during both the Stroop task and the Imitation Inhibition task (Brass et al., 2005), it could make sense to attribute successful inhibition of any responses (including both imitative and non-imitative) to the recruitment of the rIFG. However, this argument fails to explain the finding of double dissociation where some patients with frontal lesions performed well on one task but poorly on the other. One would expect that if a participant's frontal lesion was affecting their rIFG, this should have caused them to perform poorly on both tasks not just one of them. Thus, this double-dissociation has fuelled the debate as to whether the inhibition of *imitative* responses may tap into a domain-specific inhibitory network in addition to the well-established domain-general MD network identified by so many other inhibitory control and executive function studies (Darda & Ramsey, 2019).

In an effort to shed light on this debate, Darda and Ramsey (2019) conducted a meta-analysis to review the existing literature, identifying and reviewing twelve fMRI studies in which adults took part in an imitation-inhibition task. Across these twelve studies they looked for evidence of consistent activation of social brain areas such as the mPFC and the TPJ. Such a finding would support the theory that inhibiting imitative responses might be carried out by a separate domain-specific network, and not by the domain-general MD network responsible for other types of inhibition. The meta-analysis (Darda & Ramsey, 2019) revealed that across the twelve studies there did not appear to be consistent involvement of the mPFC during the imitation-inhibition task, although there was evidence of the involvement of the rTPJ, consistent with the domain-specific theory. At the same time, the analysis also identified consistent recruitment of the MD network across the 12 studies (Darda & Ramsey, 2019), which is consistent with the domain-general theory.

However, there are several important points to be taken into consideration before drawing any substantial conclusions from the results of the meta-analysis. Firstly, the TPJ is a functionally heterogenous brain region – it is involved in a range of different processes both social and non-social (Corbetta et al., 2008; Krall et al., 2015, 2016; Lee & McCarthy, 2016; Schuwerk et al., 2017). One such process is to do with resolving spatial conflict. The majority of imitation inhibition tasks have used the original finger lifting task used by Brass and colleagues, but this task makes it difficult to disentangle whether participants' responses are impacted by the inhibitory requirements of the task (i.e. do not copy the other person's actions, but do the alternative response) or the spatial compatibility of the task (i.e. do not mirror the spatial location of the finger movement,

but lift the adjacent finger). The suggestion that this task contains a spatial compatibility component has also been confirmed by subsequent research (e.g. Bertenthal et al., 2006). It is for this reason that Darda & Ramsey (2019) propose that it is possible that the activation of the TPJ identified in their meta-analysis could be a result of participants resolving spatial conflict rather than controlling imitative tendencies. Given that the Stroop task does not have this same spatial conflict issue, it is difficult to assess whether activation of the TPJ on the Imitation Inhibition task is associated with resolving spatial conflict specific to this task, or whether it is associated with the inhibition of imitative tendencies.

Another potential issue when making comparisons between these two tasks is that despite both tasks being well-matched in terms of responses (e.g. lift one of two fingers in the imitative-inhibition task and lift one of four fingers in the Stroop word-colour task), the stimuli presented are very different. For instance, in the Stroop word-colour task participants see a word on the computer screen, whilst in the imitation-inhibition task they see a video of a hand with a number superimposed on top. The mere observation of another's hand action may be enough to activate social brain regions such as the mPFC and the TPJ, meaning that it can be unclear whether activation of these regions is because of an automatic response to a social stimulus, or whether these areas may additionally play a role in the *inhibition* of imitative responses.

The current study attempts to get around this issue by making the presentation of the stimuli in both tasks 'social' by way of a video clip of the experimenter either performing an action (imitative condition) or saying a word (non-imitative condition).

This allows for a more direct comparison between the inhibition of imitative and non-imitative responses since only one task requires the *inhibition* of an imitative response, but both are likely to activate the social brain networks associated with the observation of others' actions.

Furthermore, the current research is conducted with a developmental population. Given the distinct period of rapid improvement seen in children's performance on inhibitory control tasks such as the Go/No-go task (Dowsett & Livesey, 2000; Weibe et al., 2012), the Stroop-like Day-Night task (Diamond et al., 2002, Gerstadt et al., 1994), and the Hand Game (Watson & Bell, 2013), we proposed that testing children aged between 3-5 years might reveal more tangible results than conducting the same study with adults. This is in part due to the fact that most adults perform at ceiling levels of accuracy on inhibitory control tasks, and therefore the only useful measure of ability is reaction time. Whereas if we study these same tasks in developing children, we should observe more variation in accuracy, making it easier to investigate whether performance on the Imitation Inhibition task and Pointing Inhibition task correlate or differ. Based on a meta-analysis by Petersen and colleagues (2016) which showed that children perform at ceiling on the Hand Game at an earlier age than on either the Day-Night task or the Grass-Snow task, we expected that children may find the Imitation Inhibition task a little easier than the Pointing Inhibition task in the current study.

Previous neuroimaging literature focusing on the inhibition of imitative responses in young children is limited. In fact, we have been able to identify just one study (Watson & Bell, 2013) which has measured children's brain activation with EEG

whilst performing both the Day-Night task and an Imitation Inhibition-like task (the Hand game). In the Day-Night task, children were required to say "sun" to a picture of a moon and say "moon" to a picture of a sun. In the Hand Game, three-year-old children were instructed to place their palm flat on the table when the experimenter made a fist, and to make a fist when the experimenter placed a palm flat on the table. EEG activation in the alpha range (6-9Hz) during the performance of these tasks was compared to activation during a baseline task during which children watched a cartoon. The results showed that alpha activation over medial frontal channels significantly predicted performance on the hand game but not on the Day-Night task (Watson & Bell, 2013). The findings could be reflective of activation of the mPFC which would be more in line with a domain-specific account of imitation inhibition. However, since EEG lacks the spatial resolution to pinpoint specific areas of brain activation, we cannot determine mPFC involvement with any level of certainty. For this reason, the neuroimaging study presented in this chapter (Study Four) uses fNIRS which has much better spatial resolution properties to overcome this issue.

In the current chapter we developed two new screen-based inhibitory control tasks suitable for children aged between three to five years in which the designs of the imitative and non-imitative inhibition tasks were as closely matched as possible (see Figure 4.1). In the Imitation Inhibition task (based on the Hand Game), children watch a video of the experimenter performing a hand action (either holding up their index finger or their fist) and are instructed to perform the opposite action. In the Control condition, children were required to hold up a fist to one abstract picture and hold up a finger to the other abstract picture. In this way, our task does not have the issue of spatial

compatibility as seen in previous Imitation Inhibition tasks used with adults, meaning that any activation of the TPJ identified during this task was likely to be related to the inhibition of imitative tendencies rather than spatial compatibility effects. In the Pointing Inhibition task (based on the Grass-Snow task), children were instructed to point to the opposite picture to the one that was labelled by the experimenter on the screen. This way, the structure of the two tasks is very closely matched, as in both tasks, children observe a 'social stimulus' – i.e. a video of the experimenter saying a word or performing a hand action – and perform an arm/hand action as a response (either pointing at the stimuli or making a hand action). In the Control condition, children were required to point to one abstract picture when the word "cat" was said, and the other abstract picture when the word "boy" was said. In each of the Control conditions, the working memory demands of the tasks remained the same but did not require the need for inhibition. This allowed us to specifically isolate neural activation related to inhibiting the tendency to imitate versus the tendency to point to the labelled object. The findings are reported in Study Three.

4.2 Study Three

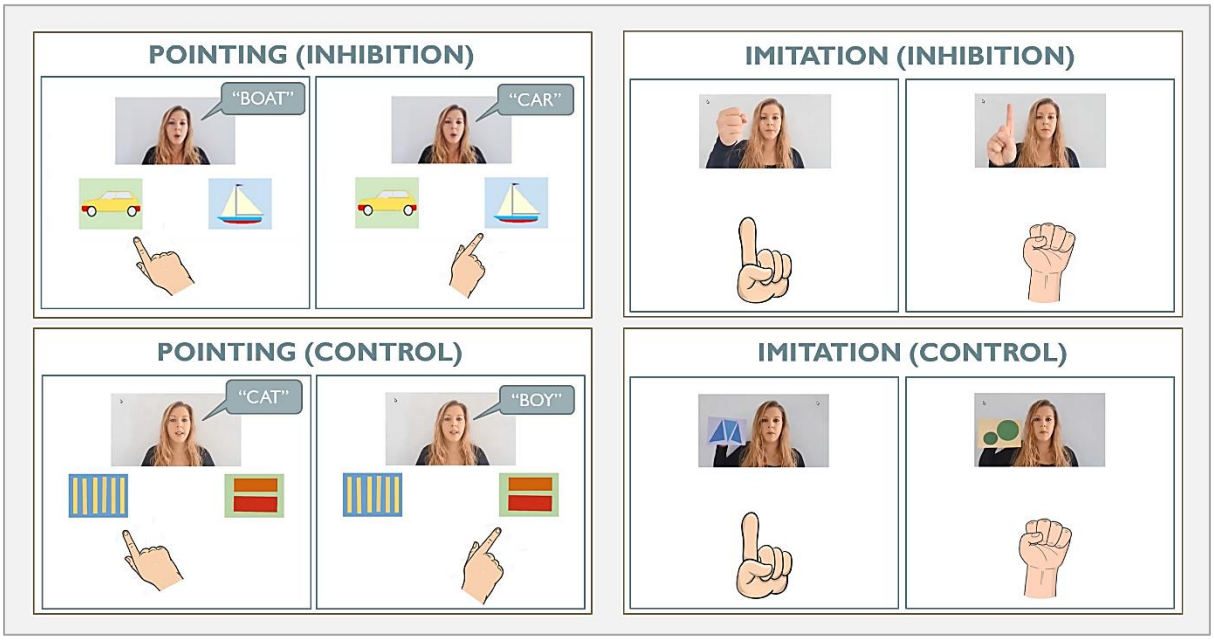
In Study Three, we tested the efficacy of our new tasks involving closely matched inhibitory and control conditions to compare children's inhibition of imitative and non-imitative responses. To test children's response inhibition, we used a condition based on the Grass-Snow task. In this condition, we asked children to point to a picture of a boat when the experimenter said "car", and to point to a picture of a car when the

experimenter said “boat” (see Figure 4.1). Since children were required to respond by pointing, we refer to this as the ‘pointing inhibition’ condition. The pointing inhibition condition was paired with a control condition (pointing control), in which children were asked to point to abstract picture 1 when the experimenter said “boy” and to point to abstract picture 2 when the experimenter said “cat”. In this way, the two pointing conditions are identical in terms of WM with the exception that inhibitory control is only required on the pointing inhibition condition, not the pointing control condition. This is because in the pointing inhibition condition, children must inhibit their tendency to want to point to the image cued by the stimuli, and instead opt for the other response.

To test children’s imitation inhibition, we used a condition based on the imitation-inhibition task. In this condition, we asked children to make a fist when the experimenter held up a finger, and to hold up a finger when the experimenter held up a fist. This condition is referred to as the ‘imitation inhibition’ condition. The imitation inhibition condition was also paired with a control condition (‘imitation control’), in which children were asked to hold up a fist when they saw abstract picture 3 and hold up a finger when they saw abstract picture 4 (see Figure 4.1). In this way, the two conditions are identical with the exception that inhibitory control is only required on the imitation inhibition condition, not the imitation control condition. This is because in the imitation inhibition condition, children must inhibit their tendency to want to copy the actions of the experimenter, and instead opt for the other response. Due to the COVID pandemic and the inability to test participants face-to-face, the study was conducted over Zoom.

Figure 4.1

A diagram depicting the required responses for each pair of stimuli per condition.



4.3 Method

4.3.1 Participants

84 of the 121 participants tested provided sufficient data to be included in the analyses (see exclusion criteria in section 4.3.4 for details). Of these 84 participants, 33 were male with an age range of 36 to 72 months with a mean age of 55 months (mean age = 4 years, 7 months; standard deviation = 10.36 months). A power calculation using G*Power (Faul et al., 2009) was conducted, determining a required sample size of at least 82 participants; assuming a power of at least 80% to detect a medium-sized correlation (*r*=.3, alpha=.05). Ethical approval was gained from the Ethical Committee at the University of Essex. Participants were recruited via social media, word of mouth,

and advertising through preschools. Parents/guardians gave online consent prior to proceeding with the study.

4.3.2 Materials

The task was coded in Inquisit 5 (Inquisit Lab, version 5.0.14.0, 2016) then uploaded to the Inquisit website (millisecond.com) so that the task was web accessible. Every testing session took place using the Zoom platform (Zoom Video Communications, version 5.17.11, 2024) which allowed the researchers to record video footage not only of the child taking part, but also of the task itself. Footage of these two views were recorded simultaneously as one video file, which later allowed for video coding. For the task to run from the website, the player installer 'Inquisit Player' needed to be downloaded and installed on each device at the beginning of the testing session. Since participants took part at home, we had no control over the make or model of the device used or its screen size or picture quality (Inquisit would automatically run the experiment in full screen mode and therefore rescaled to account for different participant screen resolutions). The only criterium for the device was that it had to be a computer or laptop since the Zoom parameters did not allow for mobile phone or tablet devices.

During the task, each condition started with a pre-recorded instruction video in which the researcher explained the rules of the 'game'. The instruction video took up around a quarter of the screen and was located centrally in the upper half of the screen. The stimuli for all conditions consisted of a video clip of the researcher. In the pointing

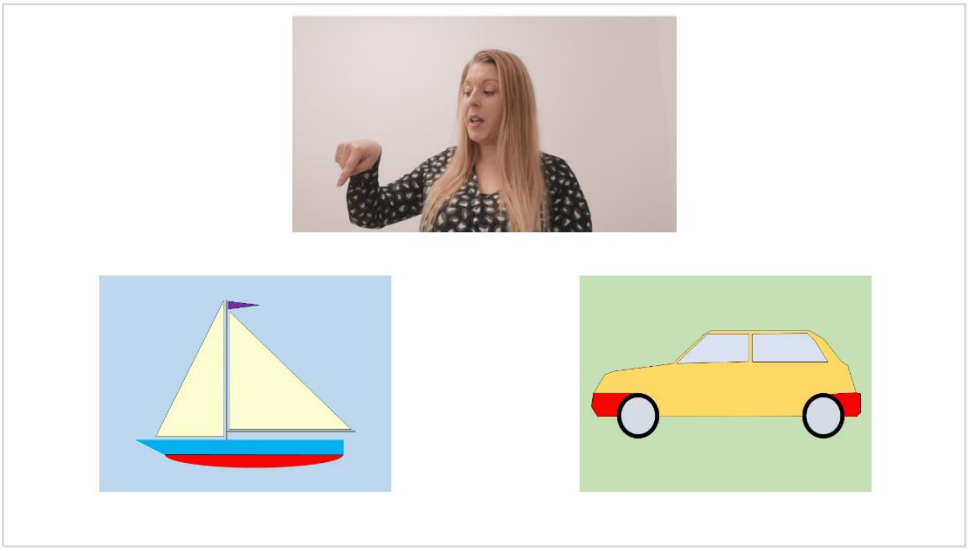
conditions, a pair of images was also displayed, side-by-side beneath the stimulus video. Children were required to respond by pointing to one of the two pictures (a boat and a car in the pointing inhibition condition, and two abstract images in the pointing control condition, see figure 4.1). In the imitative conditions, the children were not required to point, but rather to make one of two possible hand gestures. As such, there was nothing displayed below the stimulus video during these conditions.

4.3.3 Procedures

Participants were tested online in the presence of a parent/guardian at a time which suited them. At the beginning of the session, the experimenter greeted the parent and child via Zoom and provided a web link to the task. The link allowed parents to download the software Inquisit Player in order to run the task. Next, the parents were required to provide online consent, following which the experimenter took control of the participant's screen remotely to control the task. The experimenter asked the child "shall we find out what we need to do in this silly game?" and played the instruction video for the first condition (see figure 4.2). For instance, in the Pointing Inhibition condition, the on-screen experimenter would say "We're going to play a silly game. In this game, you need to listen to the word I say, and then point to the right picture. If I say "boat", you point to this picture [*experimenter points toward the bottom right of the screen where the picture of the car is displayed*] and if I say "car", you point to this picture [*experimenter points toward the bottom left of the screen where the picture of the boat is displayed*]".

Figure 4.2

A screenshot taken from the video clip of the researcher explaining the task instructions for the Pointing Inhibition condition.



Note. Here, the researcher is saying "when I say car, you point to this picture".

Following the instruction video, the experimenter asked the child to confirm the correct answer. For instance, on the Pointing Inhibition condition, the experimenter would ask the child "So if she says "boat", which picture do you need to point to?". The images remained on the screen allowing the children to point to them. If the child responded correctly to both stimuli, the experimenter proceeded to the practice trials. However, if the child responded incorrectly, the experimenter replayed the instruction video.

Each condition had six practice trials (three of each stimuli) presented in a randomised order. For every practice trial (regardless of condition), children were

provided with on-screen accuracy feedback. If they responded correctly, the experimenter would select the correct feedback video (via a button press on the keyboard) saying “Well done! You pointed to the right picture!”, or “Well done! You did the right action!”. If the child responded incorrectly, the researcher initiated a video that reminded the child of the task instructions (e.g. “Remember, when I say *boat*, you point to this picture [points to the car]” for the pointing inhibition condition or “Remember, when I do this [makes a fist with one hand], you do this [makes a finger with the other hand]” for the imitative inhibition condition).

Following all six practice trials, participants completed 16 experimental trials during which no feedback was given for any of the conditions. The experimental trials always contained eight presentations of each stimulus, but these were presented in a random order. Trials were separated with a 2-second blank inter-trial interval (a plain white screen). The task was self-paced, and once the child had made a response, the experimenter pressed a key to move on to the next trial. The order of conditions was counterbalanced between participants and were separated with a brief break to allow for praise to be given, and if necessary, a few minutes rest before moving on to the next condition. Once all four conditions were completed, the experimenter thanked the parent and child for taking part, and also provided instruction on how to uninstall the Inquisit player.

4.3.4 Data Analysis

We had intended to measure both accuracy and reaction time, but due to issues with internet connection and both visual and audio lagging, it was determined that the video footage was too unreliable for reaction time analyses. Therefore, only accuracy scores were coded using the video recordings of each testing session. Accuracy scores were averaged to give a mean accuracy score per participant, per condition. Accuracy was coded as [1] for a correct response and [0] for an incorrect response. Non-responses were excluded, as were any trials involving either parental interference or experimenter error (e.g. parents nudging the child towards the correct response or giving leading prompts). For the age analysis, children were divided into three age groups: 3 years 0 months to 3 years 11 months (N = 26); 4 years 0 months to 4 years 11 months (N = 29) and 5 years 0 months to 5 years 11 months (N = 29).

Exclusions

Any children who performed below chance levels (<50%) on either of the control conditions were excluded from the final data sample (N=6), as this suggested that they did not understand the task instructions. Nine participants were excluded because of experimenter error, (e.g. the experimenter forgot to use Zoom's 'record' function so there was no footage of the task to analyse). A further 8 participants were excluded from the final sample because the footage was not sufficient to analyse due to internet connection and lagging. Finally, there were an additional 14 participants who attempted the study but were not able to get through all four conditions, resulting in an incomplete data set. The average age of these 14 participants was 40.76 months (3 years 4 months)

with a range of 36.32 to 47.84 months (3 years 0 months to 3 years 11 months). This demonstrates that it was the youngest children within the sample (all under 4 years) that struggled to get through the task the most and ended up being excluded from the final analysis.

After these exclusions, the total number of participants included in the final sample was 84, with data being collected by a total of seven researchers. Each researcher coded the data they collected. One of the seven researchers was the PhD candidate who collected and analysed valid data from 23 children. Of the remaining 61 children, a subset of around 16% (N=10) were double coded by the PhD candidate. Two of the six researchers demonstrated lower intercoder reliability (70% and 80% respectively) than the others (>90%), and as such, these data were re-coded by PhD candidate. Only the re-coded data was used in the final analyses.

4.4 Results

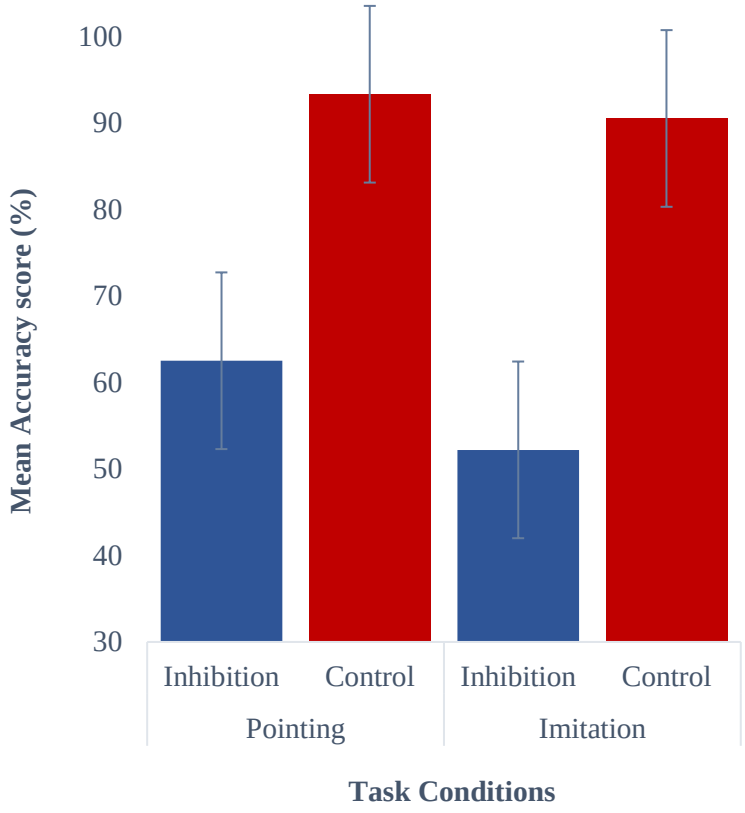
A mixed measures ANOVA with Task (pointing vs. imitative) and Inhibitory Demands (inhibitory vs. control) as within-subjects factors, and Age as between-subjects factor was conducted to determine whether there were any differences in accuracy scores between the inhibition of imitative and non-imitative prepotent response tendencies either at the group level or per age. As expected, we found a significant main effect of Age on overall performance, $F(2,81)=19.549$, $p<.001$, $\eta^2_p=.326$ as well as a significant main effect of Inhibitory Demands (inhibitory vs

control), $F(1, 81)=42.172$, $p<.001$, $\eta^2_p=.342$, but no significant main effect of Task (pointing vs. imitation), $F(1, 81)=1.406$, $p=.239$, $\eta^2_p=.017$, nor a significant interaction between Task (Pointing vs. Imitation) and Inhibitory Demands (Inhibition vs. Control), $F(1, 81)=.982$, $p=.325$, $\eta^2_p=.012$. This shows that children's scores improved with age, and that children's scores were lower on the inhibitory conditions than the control conditions, but that feedback did not improve children's scores.

As can be seen in Figure 4.3, overall, the average accuracy scores were higher on the control conditions (pointing control M=.95, SD=.09; imitation control M=.95, SD=.09) than the inhibitory conditions (pointing inhibition M=.82, SD=.29; imitation inhibition M=.78, SD=.34).

Figure 4.3

Bar graph to show average accuracy scores for all conditions across all participants.



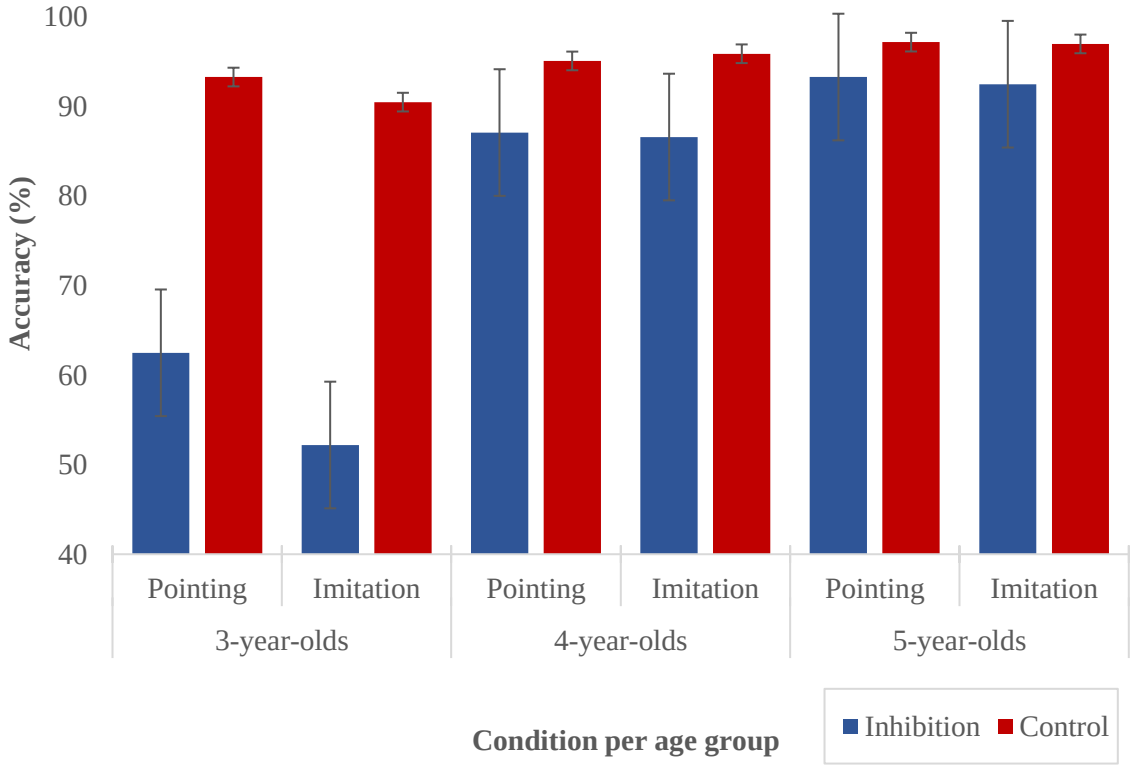
Note. Error bars show standard error of the mean.

The analysis also revealed a significant interaction between age and task, $F(2,81)=14.086$, $p<.001$, $\eta^2_p=.258$. Follow-up repeated measures analyses per age group, showed that the main effect of Inhibitory Demands was significant at each age (3-years-olds $F(1,25)= 25.803$, $p<.001$; 4-year-olds $F(1,28)= 8.342$, $p=.007$; 5-year-olds $F(1,28)= 5.124$, $p=.032$). However, as can be seen in Figure 4.4, the significant interaction between Age group and Inhibitory Demands is driven by the fact that the

difference between the inhibitory and control condition gets smaller as children get older.

Figure 4.4

Bar graph to show average accuracy scores for all conditions per age group.

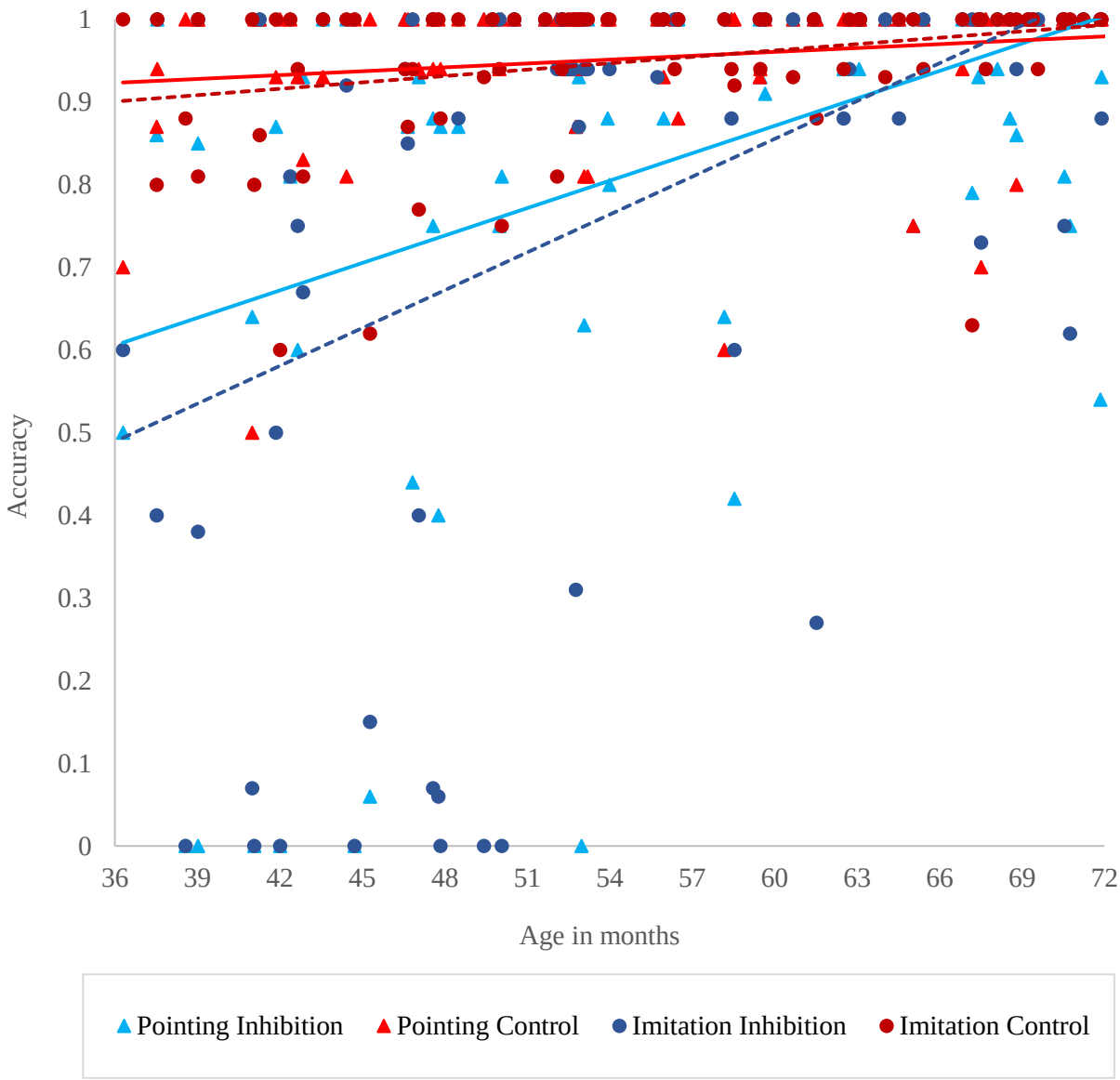


Note. Error bars show standard error of the mean.

Three-year-olds had significantly lower accuracy scores compared to the other age groups (four-year-olds and five-year-olds), $p<.001$, but the difference between four- and five-year-olds was not significant, $p=.873$. Overall, these behavioural results suggest little difference in performance between the two inhibitory conditions (Imitation Inhibition and Pointing Inhibition – see figure 4.5).

Figure 4.5

Scatterplot to show trend in average accuracy scores per condition over age.



Note. Trendlines show line of best fit for each condition. These are depicted as a light red solid line for the Ponting Control condition; a dashed dark red line for the Imitation Control condition; a light blue solid line for Pointing Inhibition condition; and a dashed dark blue line for the Imitation Inhibition condition.

4.5 Discussion of Study Three

In Study Three, we tested three-, four-, and five-year-olds on an Imitation Inhibition task and a Grass-Snow-like task in an online study to investigate the inhibition of imitative and non-imitative response tendencies. As expected, we found that for both tasks, children performed significantly better on the control conditions than the inhibitory conditions at all age groups. This is consistent with previous literature showing a large difference between the inhibitory and control conditions (Diamond et al., 2002; Gerstadt et al., 1994; Simpson & Riggs, 2005). We did not find any significant differences in children's performance between the pointing and the imitation tasks either at the group level or between age groups. By the age of 5, children's performance seemed to be approaching ceiling with less than 5% difference in performance between each of the experimental conditions (Pointing and Imitation) and their corresponding Control conditions.

The similarity in children's performance between the two tasks is consistent with (but not proof of) the domain-general account of imitation inhibition. However, we cannot exclude the possibility that there are two different neural mechanisms that support the types of inhibition required for the Pointing task and the Imitation task which happen to develop simultaneously. In order to make any claims about the underlying neural mechanisms supporting the inhibition of imitative responses, further testing with neuroimaging study is required. Hence, Study Four aims to test the inhibition of imitative and non-imitative responses using fNIRS in children around the

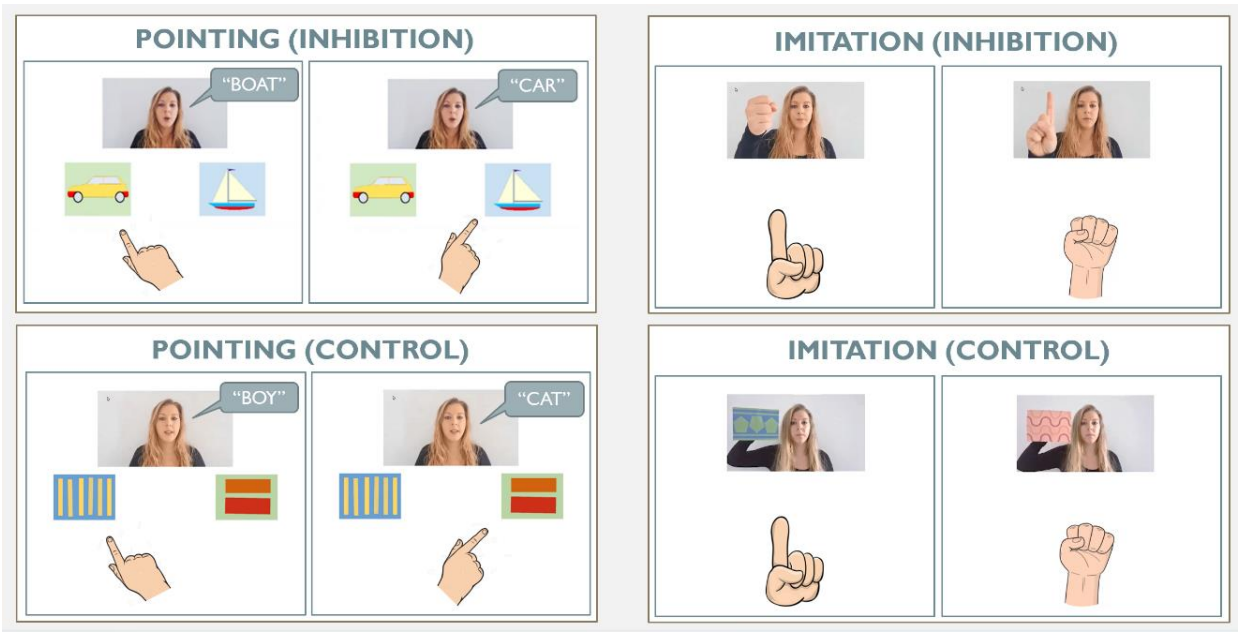
age of four. This age was chosen since the 5-year-olds were reaching ceiling performance.

4.6 Study Four

The aim of Study Four was to use fNIRS to see whether there were any differences in the brain areas activated in 4-year-old children during the Imitation Inhibition condition and the Pointing Inhibition condition. The task remained the same as in Study Three, except for a few minor changes. Firstly, we had some concerns that the shapes used in the imitation control condition were too suggestive of the action required (e.g. the triangles are a pointy shape and require participant to hold a finger up, whilst the circles are a round shape and require participants to hold up a fist). For this reason, we created different abstract images. We also switched the responses in the pointing control condition around for counterbalancing purposes. If performance remained roughly the same between Studies One and Two on the pointing control condition, then we can be assured that the stimuli are indeed neutral and not aiding children in their responses. Figure 4.6 shows the responses required for each pair of stimuli.

Figure 4.6

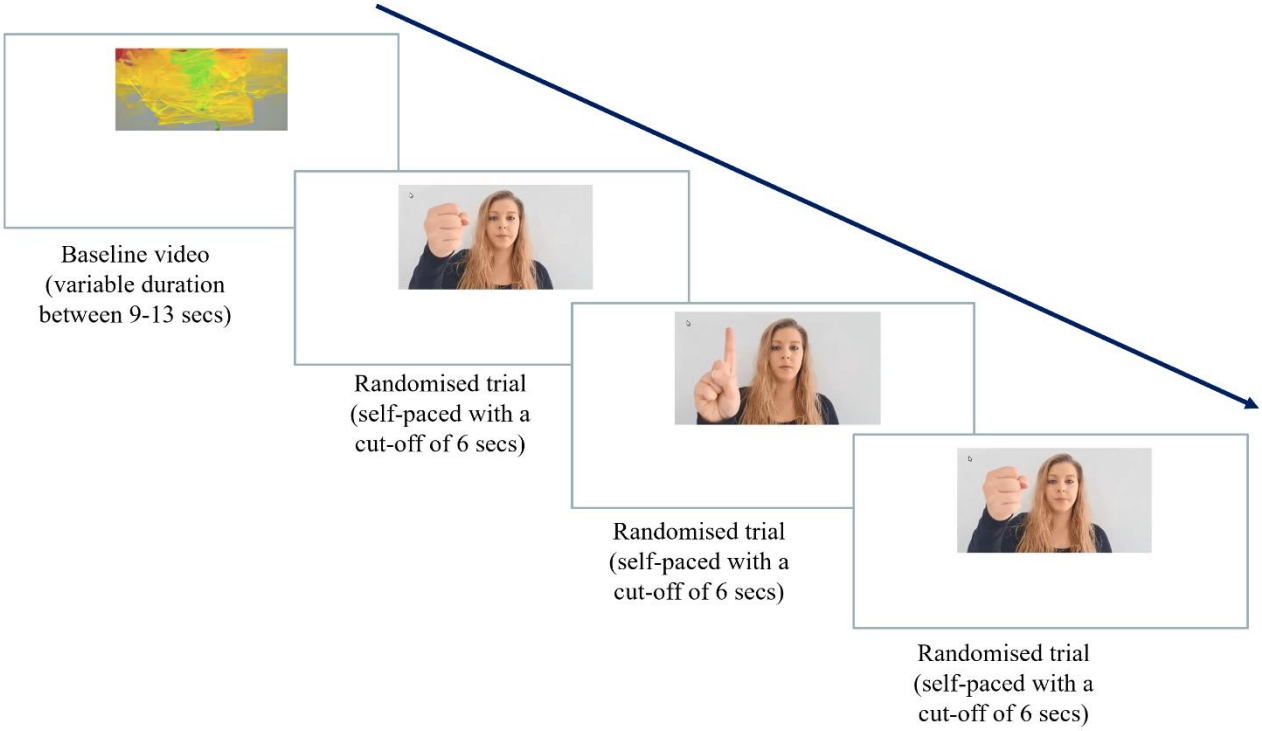
Diagram depicting the required responses for each pair of stimuli for each of the four conditions in Study Four.



To allow us to measure haemodynamic responses we incorporated a block design (see Figure 4.7). Six blocks of 3 trials were presented in each condition. These trial blocks were alternated with baseline blocks during which children observed coloured swirling patterns on the screen in the same location that the video stimuli were presented (see figure 4.8 for an example of the baseline condition). Based on the previous findings by Watson and Bell (2013) as well as the findings from the adult literature (Brass et al., 2003, 2005), we expected that the imitation inhibition task may involve the mPFC and TPJ, while the pointing inhibition task would primarily result in activation in the IFG and the dlPFC.

Figure 4.7

Illustration of the block design.

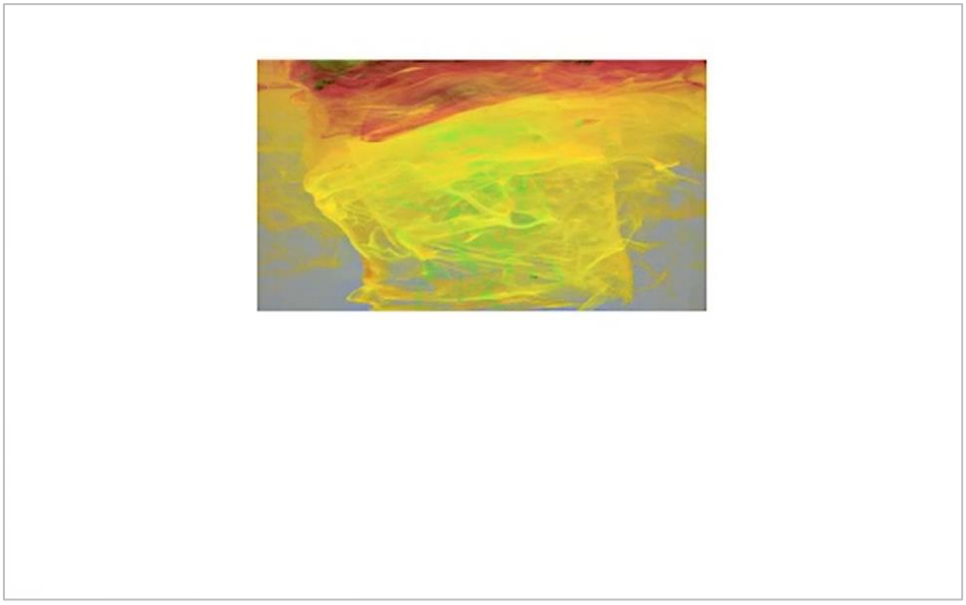


Note. The example shown here depicts an example of the Imitation Inhibition condition.

Note. Each block consists of a baseline video followed by three experimental trials. Each condition is made up of 6 blocks.

Figure 4.8

Clip taken from a baseline video.



4.7 Method

4.7.1 Participants

Participants were recruited via social media, word of mouth, and advertising through preschools. A power calculation using G*Power (Faul et al., 2009) was conducted, determining a required sample size of at least 32 participants; assuming a power of at least 80% to detect an interaction between task, condition and location (region of interest). A total of 39 participants participated in the study (M= 47.32 months, range 44–51 months; 19 girls). Of these, 31 participants provided sufficient data to be included in the final analysis (M= 47.52 months, range 44–51 months; 16 girls). (See section 4.7.5 for more detail regarding the exclusion criteria). Ethical approval was gained from the Ethical Committee at the University of Essex. Parents provided written consent before beginning the study.

4.7.2 Materials

The task was recoded from Inquisit 5 into MATLAB (The MathWorks Inc., 2017) to allow it to run smoothly alongside the fNIRS setup. The task was run by the experimenter from a DELL desktop computer displaying both the MATLAB script as well as the software OBS studio (Bailey, 2017) to record the participants via a webcam. A second, 27" monitor screen was linked up adjacently displaying the stimuli. Only the second screen was visible to the participant. A Logitech webcam was linked up to the computer and recorded through OBS studio. OBS was set up so that the footage was recorded both from the webcam and the second screen. These were recorded simultaneously side-by-side into one video file and to allow for later video coding purposes.

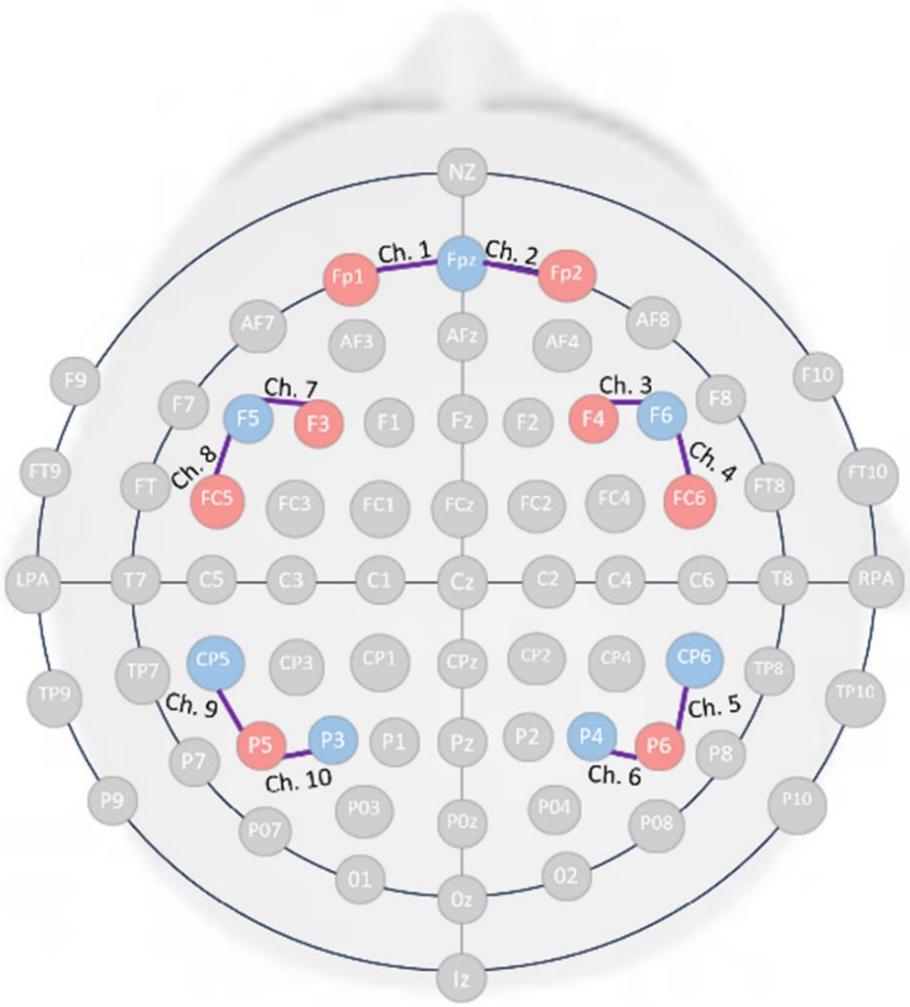
4.7.3 fNIRS data acquisition

Data were collected using a NIRx NIRSport system (NIRx, Medical Technologies, LLC) containing 8 sources and 8 detectors that enabled near-infrared light to be sent from the machine to sources located in an array on the scalp, held in place with a NIRx head cap. To accommodate individual differences in head circumference at age 4, sizes 50cm, 52cm and 54cm NIRx head caps were used. Infrared light was emitted at wavelengths of both 760 and 850nm and recorded using the NIRx software Aurora. Of the available sources, 8 sources and 7 detectors were used in the current array resulting in 10 channels in total (see figure 4.9).

Our array was designed in NIRSite (NIRSite 2.0, NIRx Medical Technologies, LLC) and previous literature was used to determine the corresponding EEG 10-10 positions based on our chosen regions of interest (ROI). Probe geometry therefore consisted of two channels across the mPFC (Fpz-Fp1 and Fpz-Fp2 - Hanlon et al., 2013; Hosomi et al., 2019; Nakamura & Kawabata, 2015), two channels over the IFG (one each side: F6-FC6 and F5-FC5 - Holland et al., 2011; Jacobson et al., 2012; Nobusako et al., 2017; Schroeder et al., 2022), two channels over the DLPFC (one each side: F3-F5 and F4-F6 - Nejati et al., 2018; Schroeder et al., 2022; Zheng et al., 2018) and two channels over the TPJ for each hemisphere (CP5-P5, P5-P3, CP6-P6 and P6-P4 – Bardi et al., 2017; Ye et al., 2015; Santiesteban et al., 2012; Sowden et al., 2015; Zheng et al., 2018). The task presentation computer was linked directly to the NIRSport in order to enable triggers to be recorded within the fNIRS data.

Figure 4.9

Diagram to show location of sources, detectors and channels on an EEG 10-10 mapping system.



Note. Sources are shown in red, detectors in blue and channels are depicted by a connecting purple line.

Note. mPFC is measured by channels 1 & 2, the right and left IFG are measured by channels 4 & 8 respectively, the right and left dlPFC are measured by channels 3 and 7 respectively, the rTPJ is measured by channels 5 & 6, and the left TPJ is measured by channels 9 & 10.

4.7.4 Procedure

The experimenter introduced themselves to the parent and child and invited them into the testing lab. Once the parent had completed the demographic survey and signed the consent form, the head cap was placed on the child's head to check the fit and adjusted as necessary (head circumference was provided in advance of the session, but on one or two occasions was incorrect and the cap had to be switched for a different size). Photographs were taken from three different angles (right profile, left profile and front) so that accuracy of cap placement could later be confirmed.

Children were then instructed to sit on their parent's lap, watch the computer screen and listen carefully to what they needed to do. The experimenter selected the required condition (order of conditions was counterbalanced between participants) and the children watched the task instruction video. As in Study Three, children were then given the opportunity to watch the video again if required, otherwise they moved on to the randomised 6 practice trials (3 of each stimulus) where accuracy feedback was provided. The practice trials remained the same as experiment 1 (6 practice trials, each with accuracy feedback). Following the practice trials, children completed the experimental trial blocks. A cut-off of 6000ms was added, so if no response was made, the next trial would begin automatically. Each block was separated with a baseline video. There were 12 possible baseline videos which were selected by the task at random. The baseline videos were varying lengths, anywhere between 9-13 seconds duration to ensure that children were not able to anticipate the upcoming block (so as to avoid any activation prior to the stimulus presentation). In between conditions, children were given a sticker for encouragement and at the end they received a certificate for

participating. The ‘winning’ of a sticker at the end of each ‘game’ was used as encouragement to continue. Data collection was conducted solely by the PhD candidate.

4.7.5 Behavioural Data Analysis

The OBS footage was used for data analysis as it contained a screen recording of the participant’s monitor screen as well as a view of the child (via the webcam). This enabled the experimenter to see what the child could see, and how they then responded. As in study Three, accuracy scores were averaged to give a mean accuracy score per participant, per condition. Accuracy was coded as [1] for a correct response and [0] for an incorrect response. Non-responses were excluded, as were any trials involving either parental interference or experimenter error (e.g. parents nudging the child towards the correct response or giving leading prompts). If any blocks contained 2 or more non-responses, these blocks were subsequently excluded from the fNIRS analysis. Of the 31 valid data sets included in the final sample, the majority (N=28) were video coded by an assisting researcher to determine each child’s accuracy score. Of these 28, 10% (N=3) were double coded by the PI with an intercoder reliability score of 96% based on accuracy coding.

Exclusions

Any children who performed below chance levels (<50%) on either of the control conditions were excluded from the final data sample (N=3), as this suggested a lack of understanding of the task. An additional 4 children attended the lab but refused to participate as they did not want to put the cap on. Finally, one further participant was

excluded from the final data set as they needed to use the toilet halfway through the session and so the cap was removed and replaced. This meant we could not be 100% sure that the cap was replaced in exactly the same location, and thus we could have been measuring slightly different brain areas between the first and second sessions. Because of this, we would have been unable to determine whether any difference in activation was because of the task, or because of the cap placement, which resulted in the participant being excluded from the final sample.

4.7.6 fNIRS Data Analysis

Video coding

We firstly wanted to exclude any baseline sessions during which the participant was distracted, moving, talking, or looking at either their own hands, their parent, or the experimenter for more than 40% of the baseline duration. This is because if a child is talking or looking at a social stimulus, this may result in unwanted brain activation which could skew the final result, given that we are specifically comparing social vs non-social stimuli. The Observer® XT (version 15 [*computer software*], Noldus Information Technology) was used to code the video footage of each session, enabling us to exclude any periods of time that the child was off task during each baseline. From this data, it was then possible to calculate the total percentage of time a child was on-task. Any baselines in which the child was on-task for less than 60% (i.e. distracted for more than 40%) were excluded from the data set. Of the 31 participants in the final

sample, 22 were coded by the PhD candidate and 9 were coded by another researcher. All 9 of these were checked by the PhD candidate, and 5 were re-coded.

Data preprocessing

Data were pre-processed using HOMER2 (Huppert et al., 2009) a MATLAB software package (The MathWorks Inc., 2017). Exclusion markers were added to indicate which blocks were to be excluded due to too many non-responses as well as indicating any baselines to be excluded, as per the video coding analyses. Our preprocessing steps were similar to those of de Klerk et al. (2018): channels with a raw intensity smaller than .001 or larger than 10 were excluded, and motion artefacts were corrected using wavelet analyses with an interquartile range of .5. Hereafter, the data were band-pass filtered (high-pass: .01 Hz, low-pass: .80 Hz) to attenuate slow drifts and high frequency noise. The data were converted to relative concentrations of oxygenated (HbO_2) and deoxygenated haemoglobin (HHb) using the modified Beer-Lambert law. The required differential path length factors (DPF) were calculated using Scholkmann and Wolf's (2013) general DPF equation ($DPF(\lambda; A) = \alpha + \beta A\gamma + \delta\lambda^3 + \varepsilon\lambda^2 + \zeta\lambda$) to account for both age and wavelength(s) used. This determined that for children aged 4 years, a DPF of 5.469 was required for a wavelength of 760, and a DPF of 4.406 was required for a wavelength of 850. Relative changes in HbO_2 and HHb, were computed for 22-second-long epochs starting 2 seconds before the onset of each block. The decision to measure a 20 second trial block was based on the video coding which determined that this was the average block length. After data preprocessing, 3

channels (out of a possible 310) were excluded due to excessive motion artefacts, across 2 participants.

4.8 Results

4.8.1 Behavioural Accuracy

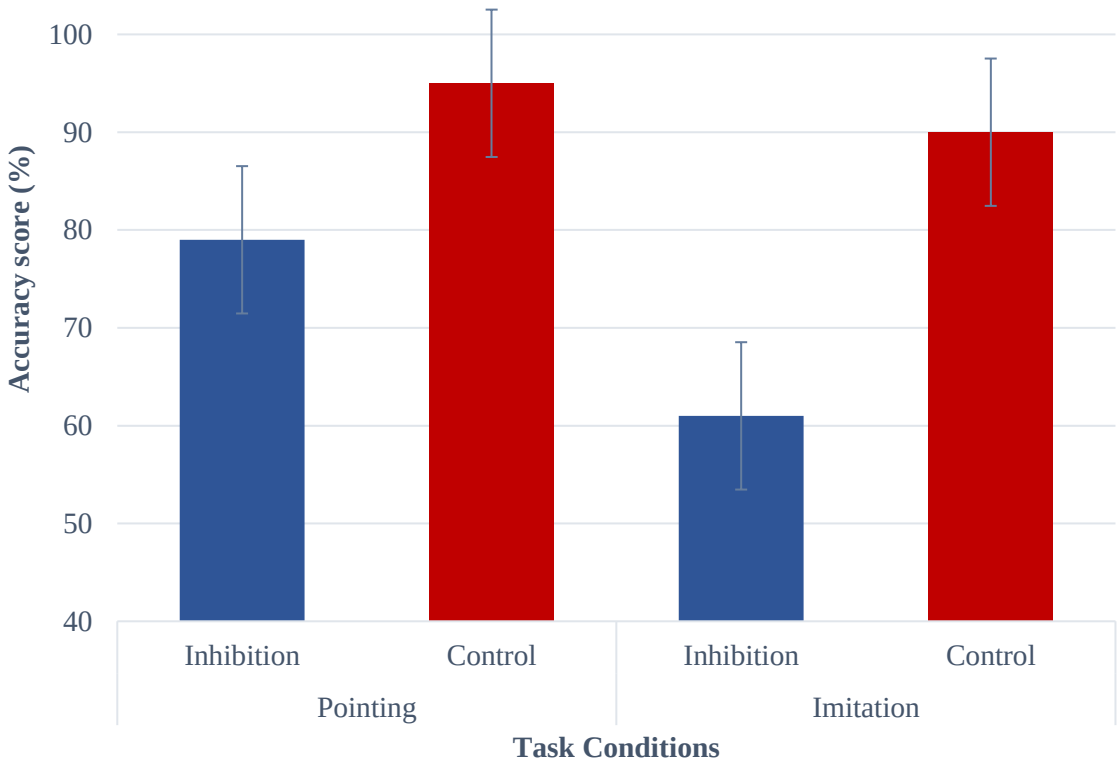
We first analysed the behavioural performance of the participants. A mixed ANOVA with Task (pointing vs. imitative) and Inhibitory Demands (inhibitory vs. control) as within-subjects factors was conducted to determine whether there were any differences in accuracy scores between the inhibition of imitative and non-imitative prepotent response tendencies. The analysis revealed a significant main effect of Inhibitory Demands, $F(1, 30)=21.972$, $p < .001$, $\eta^2_p=.423$. There was also a significant main effect of Task, $F(1, 30)=8.079$, $p=.008$, $\eta^2_p=.212$, with children performing better overall on the pointing task than the imitation task. There was no interaction between Inhibitory Demands and Task, $F(1, 30)=2.948$, $p=.096$, $\eta^2_p=.089$.

As can be seen in Figure 4.10 the average accuracy scores were higher on the Control conditions (pointing control M=.95, SD=.11; imitation control M=.90, SD=.08) compared to the Inhibitory conditions (pointing inhibition M=.79, SD=.24; imitation inhibition M=.61, SD=.40). Though performance on the two inhibitory conditions (pointing inhibition and imitation inhibition) was fairly similar, a Pearsons correlation revealed no significant correlation $r(31)=.234$, $p=.205$. Although should this study be

replicated again in the future with a larger sample size, this correlation should be run again to confirm this finding.

Figure 4.10

Bar graph to show average accuracy scores for each condition.

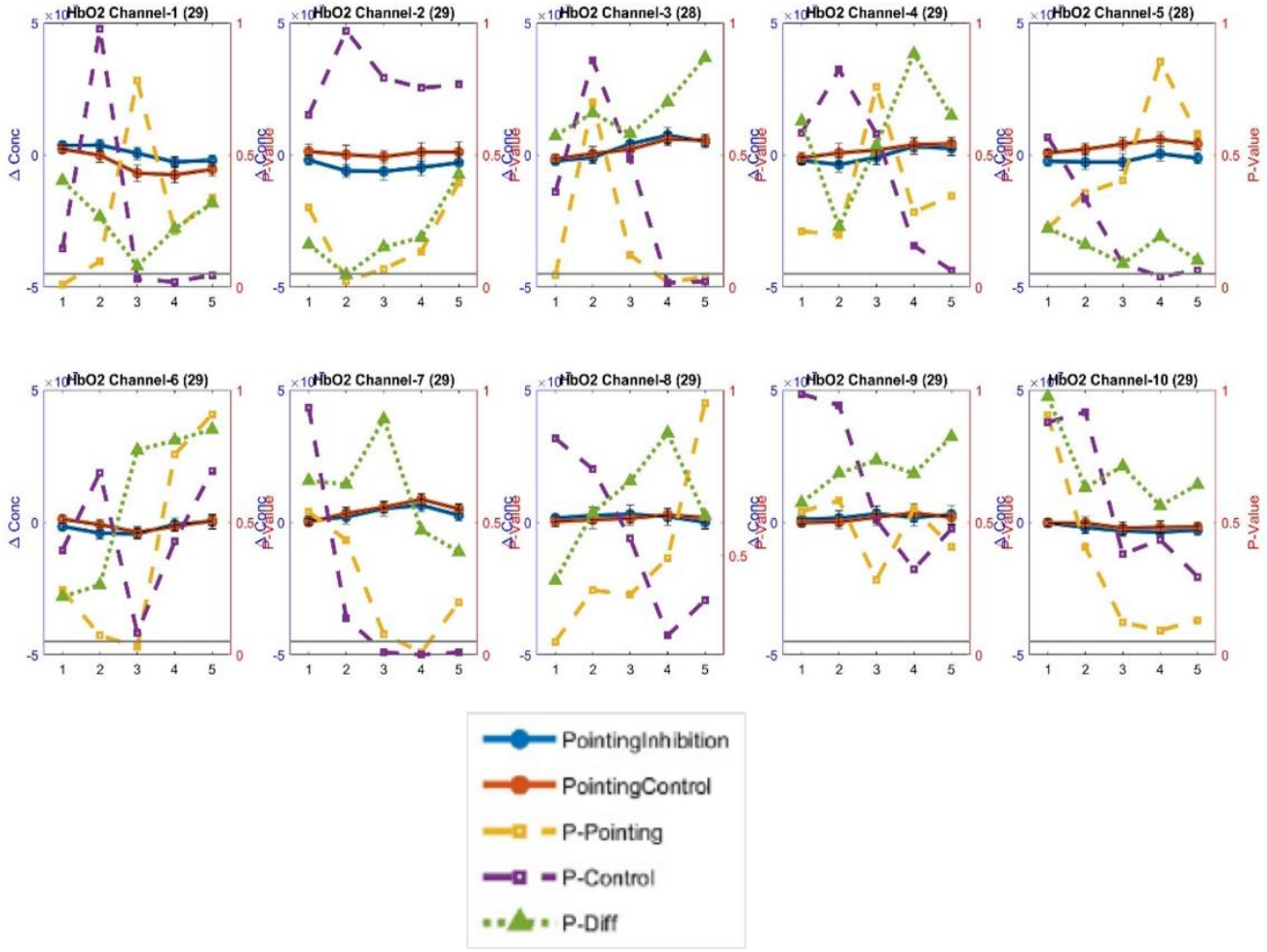


4.8.2 fNIRS

We initially planned to analyse the fNIRS data by using the difference in oxyhaemoglobin between the inhibition and control conditions. However, as can be seen in Figures 4.11 and 4.12, we had an unexpected situation in which the control conditions caused greater haemodynamic responses than the inhibitory conditions. This makes the interpretation of differences between these conditions more difficult (as less negative differences would indicate greater activation in the inhibitory conditions) and therefore we report here the comparison of the inhibitory conditions only.

Figure 4.11

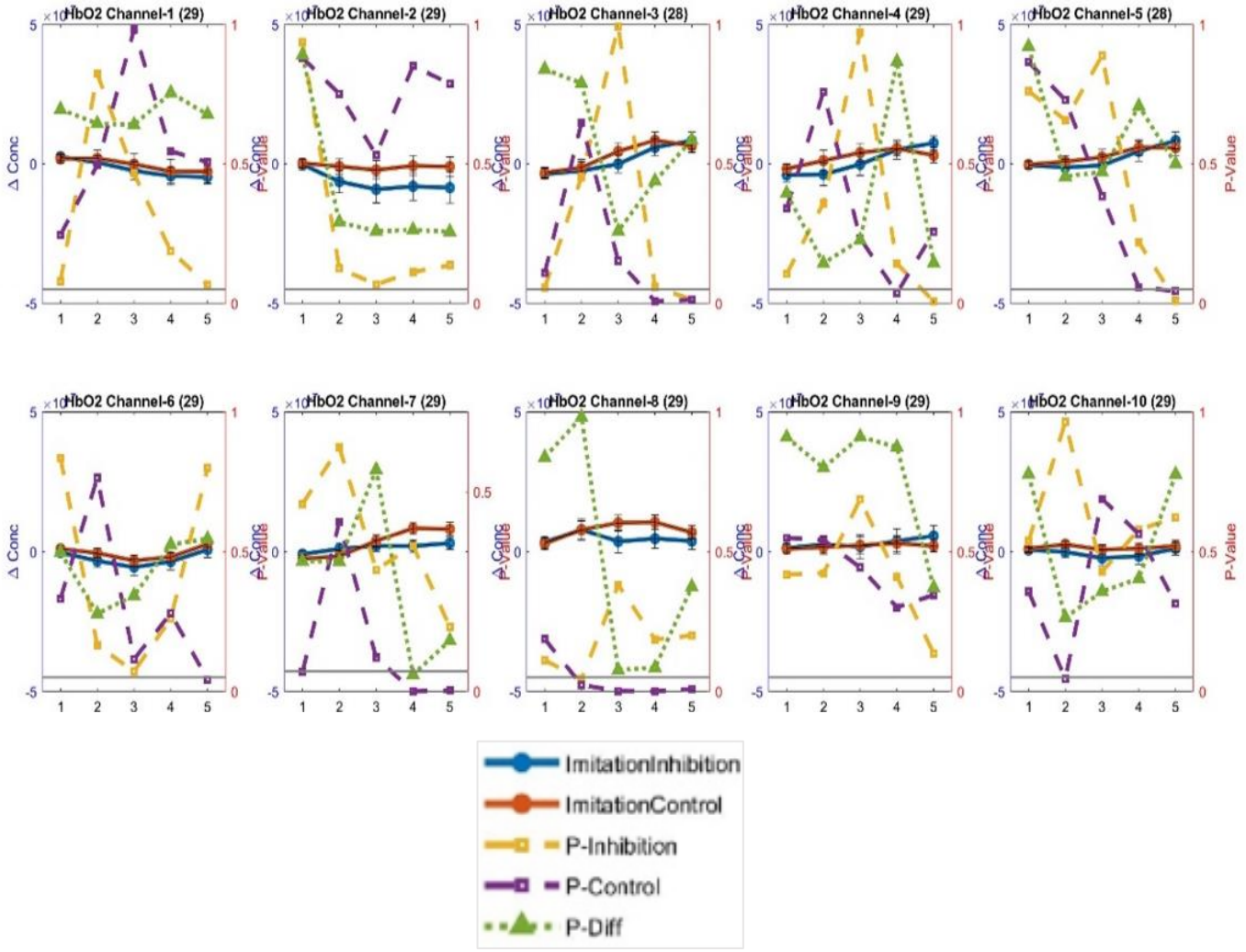
Plots to compare the concentration of oxygenated haemoglobin (HbO_2) between the Pointing Inhibition condition and the Pointing Control condition for each channel.



Note. The left y-axis plots the HbO_2 concentrations (data shown in solid lines) whilst the right y-axis plots the p-value (data shown in dotted lines). The five time bins are plotted on the x-axis to show changes in concentration over time. Dotted lines below the 0.5 p-value marker denote a significant difference in activation between conditions.

Figure 4.12

Plots to compare the concentration of oxygenated haemoglobin (HbO_2) between the Imitation Inhibition condition and the Imitation Control condition for each channel.

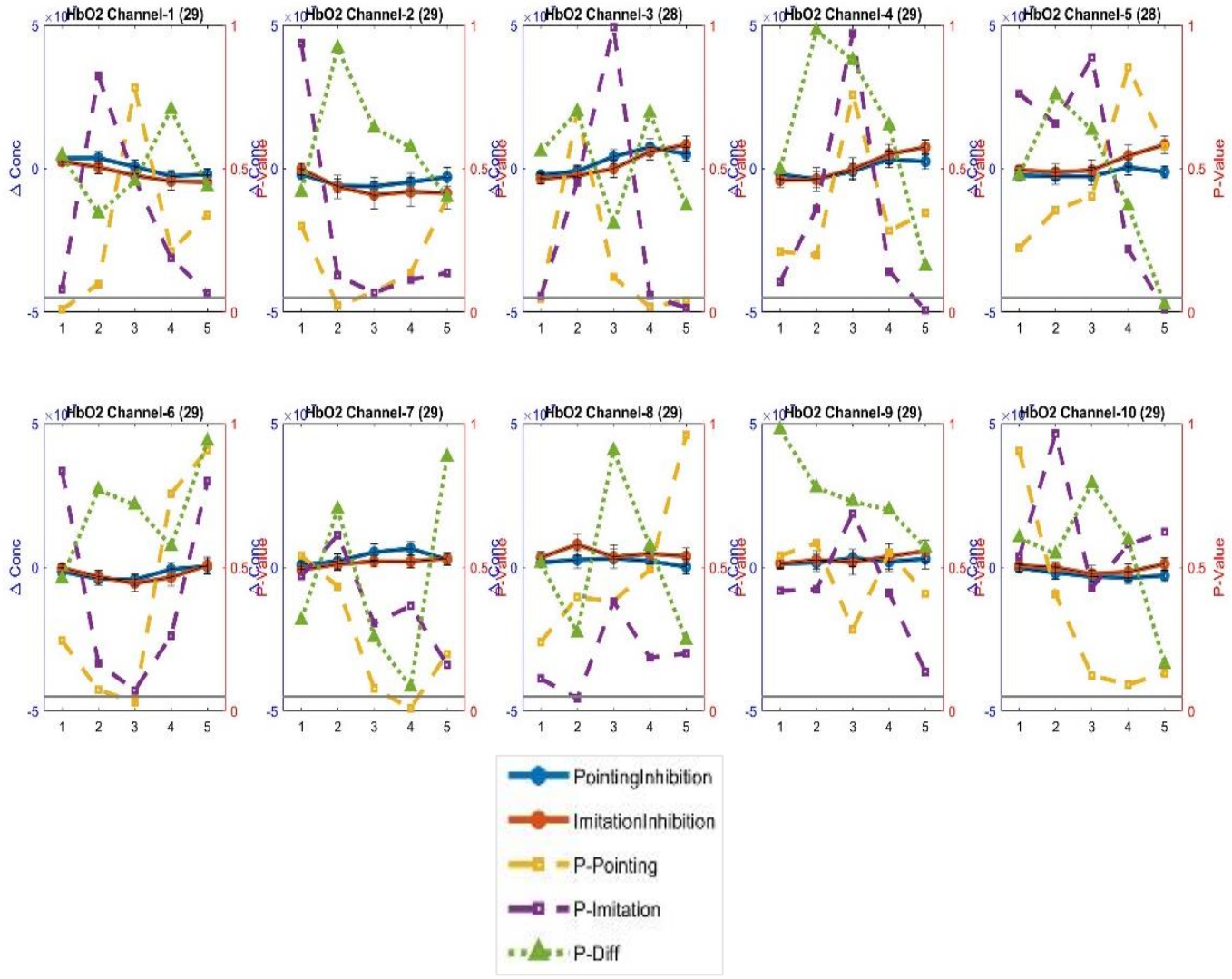


Note. The left y-axis plots the HbO_2 concentrations (data shown in solid lines) whilst the right y-axis plots the p-value (data shown in dotted lines). The five time bins are plotted on the x-axis to show changes in concentration over time. Dotted lines below the 0.5 p-value marker denote a significant difference in activation between conditions.

To investigate the neural activation specifically related to inhibiting responses, first we quantified the mean haemodynamic concentration changes for both HbO_2 and HHb during 5, four-second time bins following trial onset, similar to de Klerk et al., (2018). Hereafter, we performed repeated measures analyses with the 5 time bins and the two conditions (Pointing Inhibition vs Imitation Inhibition) as within subjects factors for each of the ten channels. This analysis aimed to identify channels which incurred a significant HbO_2 increase (Figure 4.13) or a significant HHb decrease (Figure 4.14) from baseline when both conditions were considered together (as evidenced by a significant main effect of time). This analysis revealed that 5 out of the 10 channels showed a significant haemodynamic response (See Table 4.1).

Figure 4.13

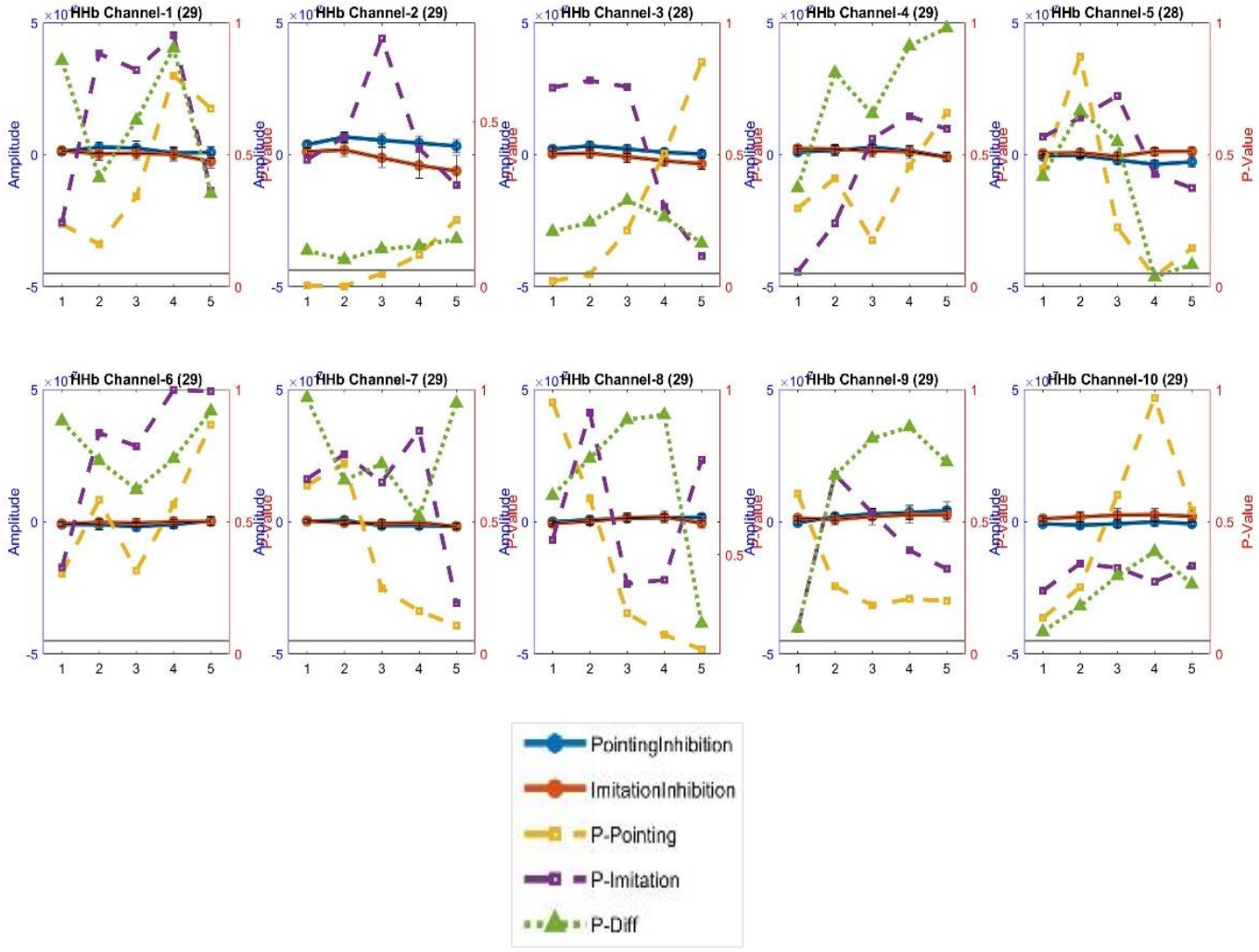
Plots to compare the concentration of oxygenated haemoglobin (HbO_2) between the Pointing Inhibition condition and the Imitation Inhibition condition for each channel.



Note. The left y-axis plots the HbO_2 concentrations (data shown in solid lines) whilst the right y-axis plots the p-value (data shown in dotted lines). The five time bins are plotted on the x-axis to show changes in concentration over time. Dotted lines below the 0.5 p-value marker denote a significant difference in activation between conditions.

Figure 4.14

Plots to compare the amplitude of deoxygenated haemoglobin (HHb) between the Pointing Inhibition condition and the Imitation Inhibition condition for each channel.



Note. The left y-axis plots the HHb amplitudes (data shown in solid lines) whilst the right y-axis plots the p-value (data shown in dotted lines). The five time bins are plotted on the x-axis to show changes in amplitude over time. Dotted lines below the 0.5 p-value marker denote a significant difference in activation between conditions.

Table 4.1

Table to show channels which demonstrated a significant main effect of time ($p < .05$).

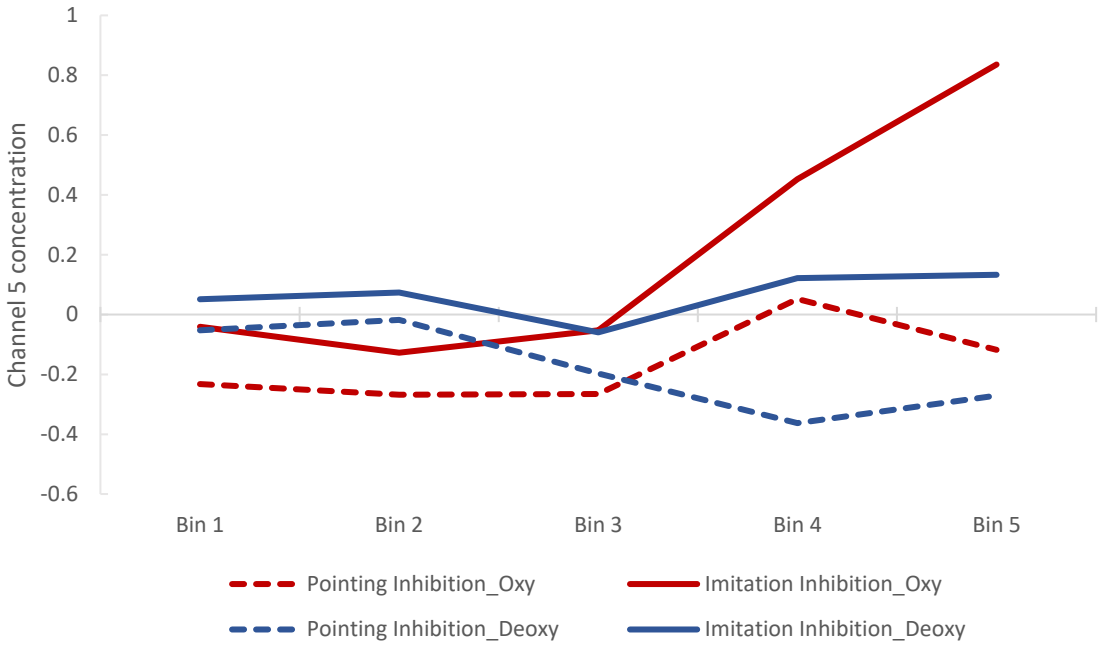
Channel	Location	Signal	Statistics
Channel 2	Right mPFC	HHb	$F(4, 112) = 2.617$, $p = .039$, $\eta^2_p = .085$
Channel 3	Right dlPFC	HbO_2	$F(4, 108) = 11.551$, $p < .001$, $\eta^2_p = .300$
Channel 3	Right dlPFC	HHb	$F(4, 108) = 3.634$, $p = .008$, $\eta^2_p = .119$
Channel 4	Right IFG	HbO_2	$F(4, 112) = 8.031$, $p < .001$, $\eta^2_p = .223$
Channel 5	Right TPJ	HbO_2	$F(4, 108) = 3.440$, $p = .011$, $\eta^2_p = .113$
Channel 7	Left dlPFC	HHb	$F(4, 112) = 2.603$, $p = .040$, $\eta^2_p = .085$

Repeated-measures analyses were then conducted on each of these pre-selected channels to assess whether there were differences in the haemodynamic response *between* the two conditions. For only one of these channels (rTPJ) we found a trend towards a greater HbO_2 response in the Imitation Inhibition condition compared to the Pointing Inhibition condition (channel 5: interaction between time and condition, $F(4,108) = 2.245$, $p = .069$, suggestive of a greater increase in the HbO_2 response to the Imitation Inhibition condition over the analysis period).

However, as can be seen in Figure 4.15, the oxy increase in the Imitation Inhibition condition over this channel is accompanied by an increase in deoxy as well. Canonical patterns of activation would consist of an increase in oxy that is accompanied by a decrease in deoxy (Hakim et al., 2022). However, since we find an increase in both oxy and deoxy simultaneously, this makes this finding much more difficult to interpret and may be indicative of noisy data over this particular channel.

Figure 4.15

Concentration of oxyhaemoglobin and deoxyhaemoglobin on the inhibitory conditions for Channel Five.



Note. Each time bin denotes a four second block.

4.9 Discussion of Study Four

The aim of Study Four was to investigate the neural correlates of inhibiting imitative and non-imitative responses in four-year-olds. As with Study Three, we similarly found a main effect of Inhibitory demand in the behavioural analysis, with children performing significantly better on the control conditions than the inhibitory conditions on both tasks. We also found that overall, children performed significantly better on the pointing task than the imitation task (a trend which was also seen in Study Three but did not reach significance).

With regards to the fNIRS analysis, we observed greater activation on both control conditions (as seen in Figures 4.11 and 4.12). Typically, one would expect that the conditions found to be most challenging for participants *behaviourally* would elicit a greater neural response, but here we find the opposite. One possible explanation is that children managed to make the WM demands of the inhibitory conditions easier by consolidating the instructions down to one rule: 'point to/do the opposite'. This is not possible on the control conditions, because no such 'opposite' response exists. Thus, in the control conditions, children are forced to remember two rules: 'give response *a* for stimuli B and give response *b* for stimuli A'. This reasoning may indeed explain why behaviourally, children performed better on the control conditions (suggesting that they found these easier likely due to the low *inhibitory* demands), and yet the control conditions elicited greater activation than the inhibitory conditions (suggesting a great cognitive (WM) demand).

Because of the observation that the control conditions elicited a greater increase in activation than the inhibitory conditions (as compared to the baseline), we decided *not* to calculate a difference score (i.e. control condition minus inhibitory condition) for each task as we had originally planned. Instead, we used only the inhibitory conditions (Pointing Inhibition and Imitation Inhibition) to make comparisons. The repeated measures analyses revealed that both tasks elicited significant activation of the right and left dlPFC, the right mPFC, the right IFG and the right TPJ. Of these five channels which showed a significant haemodynamic response overall, four demonstrated no significant difference between the Pointing Inhibition condition and the Imitation Inhibition condition. However, the fifth channel – located over the rTPJ – *did* demonstrate a difference between the two tasks, with the Imitation Inhibition task trending towards a greater HbO_2 response than the Pointing Inhibition task. Whilst it did not reach statistical significance, it is interesting that this difference was observed in the rTPJ – an area demonstrated to play a role in the inhibition of imitative responses but not non-imitative responses. It is important to note though that whilst there was a strong increase in oxygenated haemoglobin, there was also an *increase* in deoxy. This is an atypical finding, since a canonical haemodynamic response would see the increase in oxy accompanied by a *decrease* in deoxy. This topic is discussed further in Chapter Five.

As a result of this atypical finding, these data are more difficult to interpret. Having not found a *significant* difference between the two tasks, we cannot provide evidence to support the domain-specific account of imitation inhibition. However, the trend towards greater activation during the Imitation Inhibition task does not provide

evidence to support the domain-general account either. Given that this trend does not occur in any of the other channels which demonstrated a significant haemodynamic response overall, we attempt to explain this finding: one potential explanation is that there was more noise over this channel (channel 5) during the Imitation Inhibition task, causing both deoxy and oxy to be high. However, this channel did not show a significant amount of motion artefact after correction. Alternatively, it could be that the oxy response is real, but a larger sample size is needed to detect this effect. Whilst we do not want to overstate the importance of this finding, it is also prudent not to dismiss it too fast, especially given the fact that the rTPJ has been proposed to be involved in the inhibition of imitative responses but not non-imitative responses (Brass et al., 2003, 2005). Further research is warranted to see whether this finding replicates on a larger scale. A larger sample size would also enable us to conduct adequately powered correlational analyses between the two tasks.

Whilst the NIRSport has excellent applications for use with young children due to its lightweightness and robustness to movement, the setup available to us only had 8 sources and 8 detectors. These parameters made it very difficult to create an array to cover the bilateral regions of interest (ROI) required for this study; with some regions being covered by just a single channel (dlPFC and IFG). Given the inconsistencies in the literature regarding the precise localities of brain areas, it would be beneficial in future to use a system with more sources and detectors. This is particularly important given that the design of fNIRS means that we are measuring the area of the cortex *between* the source and the detector, rather than the location of the optodes themselves. Having more available optodes would therefore allow us to design an array in which

each ROI is overlapped by multiple channels and thus we are less likely to miss any significant activation should it be present. Of course, we could have dropped one of our ROI's which would have freed up another pair of optodes bilaterally to add a channel over another region, however all four of our ROI's demonstrated significant activation compared with the baseline at least unilaterally (mPFC, DLPFC, IFG and TPJ). Given that all of these regions are notable in the domain-general/domain-specific debate, we feel that further investigation is required with a larger optode array to better establish their role in the inhibition of imitative responses. One final consideration is that like any neuroimaging technique, fNIRS too has its limitations. The most significant limitation of fNIRS in relation to Study Four is that one cannot be certain that the optodes are *only* picking up activity in the targeted regions of interest. There are several reasons for this. To begin with, fNIRS technology lacks the ability to penetrate more than a couple of centimetres into the cortical tissue (Lloyd-Fox, 2010; Quaresima & Ferrari, 2019). The depth of light penetration is dependent on the optode proximity: sources and detectors placed closely together will measure only a shallow depth, while optodes placed further apart will measure deeper cortical tissue. However, if placed too far away, the near infrared light will bounce around the tissue until almost complete absorption, rendering any measurements useless. In the current study, all source-detector pairs in Study Four were located adjacently (see Figure 4.9), and no channels were excluded due to insufficient signal which suggests that the optodes were placed close-enough together to gain good NIRS signal. However, another contributing factor is that every child's head size and shape differs (hence the use of 4 different cap sizes). This means that, despite good cap placement, the precise location of each brain region may not

correspond precisely with external anatomical landmarks across the skull. Thus, on children with larger heads, the same optode array may be measuring a slightly deeper area of cortical tissue than children with smaller heads, since the source-detector pair are slightly further apart. Without taking MRI scans of each child's brain anatomy to cross-reference against the regions which were found to be activated during the task, one cannot be 100% certain that any activation found during the task is solely from the regions of interest being targeted by the optodes. Of course, MRI is contraindicated in children of this age range for the reasons discussed in section 1.5.1. Therefore, despite its limitations, fNIRS was chosen as the neuroimaging technique of choice for Study Four because of its suitability for young children and its superiority over other techniques such as EEG in localising areas of brain activation during a functional task.

4.10 General Discussion and Comparisons

The overall aim of this chapter was to compare the neural correlates of inhibiting imitative and non-imitative response tendencies in young children. In Study Three we first examined the behavioural results of a new task based on the TIC task used in Chapter Two. Having found this new task to be a good measure of both the inhibition of imitative and non-imitative responses in Study Three, Study Four used this task again with fNIRS to investigate the neural correlates. A comparison of the behavioural results demonstrated that children performed significantly better on the control conditions than the inhibitory conditions in both studies. This alludes to the fact that the task is indeed

measuring young children's ability to inhibit a prepotent response tendency, since the control conditions are designed such that they do not have an inhibitory component.

In addition, it seems that children may have found the imitation task more difficult than the pointing task across both studies, though the difference between children's scores only reached significance in Study Four. If anything, this finding is inconsistent with the literature, with Petersen and colleagues suggesting that children should find the Hand Game *easier* than the Grass-Snow task (Petersen et al., 2016). However, given that the tasks were as closely matched as possible in Studies Three and Four, we suggest that perhaps this difference might be driven by the prepotency of the actions requiring inhibition. According to the literature, the prepotency of an action (e.g. pointing or making a finger/fist) is somewhat determined by one's experience of observing and performing it (Heyes, 2011). Indeed, there is evidence to suggest that because making a fist or a finger are generally not actions which are performed synchronously, they are often less prepotent (O'Sullivan et al., 2018) which could account for why children found the pointing inhibition task easier than the imitation inhibition task in the current study.

In addition, a few minor changes were made to the task between studies Three and Four. These included making modifications to the stimuli used in the Imitation Control condition to ensure that the abstract shapes were not too pointy or round given that the required responses were a finger and a fist. The stimuli used in the Pointing Control condition were also counterbalanced. However, as a result of the counterbalancing, where Abstract Picture 1 (blue background with 6 vertical yellow

rectangles) had previously been associated with ‘cat’ it was now associated with ‘boy’. We realised that the pre-existing association between the word *boy* and the colour *blue* could therefore have made the Pointing Control condition easier in Study Four than it had been in Study Three. On comparing the Pointing Control conditions between the 4-year-old group in Study Three and the 4-year-old children who participated in Study Four, the difference was negligible (0.1%). There was however a slight difference (5.9%) between children’s scores on the *Imitation Control* conditions between studies Three and Four. Therefore, the pointy and round abstract shapes used in Study Three may indeed have been providing children with a cue as to the correct answer, which could account for the slightly higher performance compared with Study Four.

Another interesting comparison between the two studies is that children seemed to find Study Three more difficult than Study Four, as evidenced by the high drop-out and exclusion rates. Putting aside the exclusions associated with internet connection issues and experimenter errors, the exclusion rate was still higher in Study Three than Study Four. For example, in Study Three, six children were excluded due to poor performance on the control conditions compared with three children in Study Four. In addition, in Study Three, fourteen children were excluded because they were unable to stay on-task for the duration of the four conditions, resulting in incomplete data sets. In contrast, in Study Four, all children who attended the lab successfully completed all four conditions, with the exception of four children who did not contribute any data because they did not tolerate the fNIRS cap.

Perhaps the most notable difference between the studies was not the task itself, but the fact that Study Three was conducted online whilst Study Four took place in a laboratory setting face-to-face. It was necessary to conduct Study Three online due to the COVID-19 measures in place at the time of testing. However, it seems that children found participation under these circumstances more challenging. It is very difficult to know exactly which aspects were more difficult, and these may not have been the same for each child. But perhaps the most likely reason for children's poorer adherence to the task in the online study is the higher likelihood of distractions in the home environment to draw away their attention. In many of our online testing sessions, there were other siblings and family members present, and in some cases the parents ended up periodically leaving the room. These home distractions are likely to have played a role in preventing children from being able to fix their attention on the task for its entirety and as such resulted in many children being unable to provide sufficient data across all four conditions. Having said that, it is also possible that because Study Three contained a wider age range than Study Four, there were a higher number of younger children in the sample, which could have accounted for the high level of exclusions seen. In fact, all fourteen participants who failed to complete all four sessions were under the age of 4.

In Study Three, age was used as a variable to look at performance between three different age groups: children aged three (3y, 0m – 3y, 11m), four (4y, 0m – 4y, 11m) and five (5y, 0m – 5y, 11m). On the other hand, Study Four was a cross-sectional study in which we investigated children *centred* around the age of four. We therefore recruited children aged 48m (4y, 0m) ± 3m either side, resulting in an age range of 45m (3y, 9m)

to 51m (4y, 3m). Given that our age criteria for Study Four overlaps *two* of the groups within our sample for Study Three, it makes behavioural comparisons between the two tasks more difficult. Comparisons between the studies thus far have focused on the 4-year-old group from Study Three. However, the age range tested in Study Four is not only narrower than the 4-year-old group in Study Three (6m instead of 12m) but also shifted towards a younger population (3y, 9m – 4y, 3m instead of 4y, 0m – 4y, 11m). This difference could account for the slight decrease in performance seen across *all* conditions as compared to the slightly older 4-year-old group in Study Three.

In summary, this chapter has discussed the findings from two Experiments: an online behavioural study and a follow-up fNIRS study using the same task. Here, we developed a new task with which to compare the inhibition of imitative and non-imitative response tendencies in young children. Our findings have demonstrated not only good efficacy of the task but have also shown glimpses that there might be something 'special' about the inhibition of imitative tendencies.

Chapter 5

General Discussion and Conclusion

5.1 General discussion

As humans, we are all products of our environments. This creates a constant need to suppress any behaviours that are maladaptive to the current situation. Supressing our behaviours requires the use of inhibitory control – an important executive function which sees a particularly substantial period of development between the ages of three to five years. The overarching aim of this thesis work was to shed light on the development of inhibitory control and the extent to which it is applied when inhibiting imitative responses. One problem is that inhibitory control is difficult to measure since it cannot be easily isolated from other executive functions such as WM. Early studies of inhibitory control using SRC tasks employed a control condition to try and best measure the WM demands of the task (Diamond et al., 2002; Gerstadt et al., 1994; Simpson & Riggs, 2005a&b). Since these early studies, the control conditions are seldom used, though the assumption remains that SRC tasks are always a good measure of inhibitory control. In addition, much of the existing literature provides little or no information about the way in which young children are taught the rules of the task, which could also have an impact on their performance. In light of the replication crisis (Shrout & Rodgers, 2018), one of the key aims of this thesis was test the assumption that SRC tasks provide a good measure of inhibitory control, and to standardise the way in which children are taught the rules of an SRC task.

Another key aim of the current thesis was to investigate whether there is an association between the inhibition of imitative and non-imitative prepotent response tendencies in young children. Inhibitory control is defined as a domain-general process,

and so it is often assumed that there is a single neural network specifically dedicated to the process of inhibition (Aron et al., 2004). However, research from the adult literature has challenged the assumption that this domain-general process is used for inhibiting all types of response. Based on an observation made by Luria (1966) that patients with prefrontal lesions demonstrated heightened imitative tendencies, Brass and colleagues (2003; 2005; 2009) sought to investigate whether this effect was due to a lack of inhibitory control. In their seminal research, they demonstrated a double dissociation between the inhibition of imitative and non-imitative responses in patients with frontal lesions (i.e. those patients who demonstrated deficiencies inhibiting imitative responses did *not* necessarily demonstrate deficiencies inhibiting non-imitative responses; Brass et al., 2003). In the current thesis it was argued that by studying young children, we might gain useful insights into the current debate given their developmental immaturity and resulting variability. Based on Brass and colleagues' findings, one might expect young children who have underdeveloped inhibitory control to display behaviours similar to those of echopraxia patients, showing a pervasive tendency to copy others. This led us to question whether poorer inhibitory control in children could be related to a greater tendency to copy others' actions.

The final aim of this thesis was to investigate the neural mechanisms involved in inhibiting imitative responses. Following on from their findings of double dissociation, Brass and colleagues (2005) conducted neuroimaging studies which implicated a domain-specific neural network, mainly involving social brain areas, underlying the inhibition of imitative responses. This suggested that there might be something 'special' about the inhibition of imitative response tendencies (Brass et al., 2005). Whether or

not imitation inhibition is facilitated by a domain-specific network or not has been debated in the adult literature with mixed results (Darda & Ramsey, 2019). Thus far, no studies have sought to investigate the inhibition of imitative responses in young children. In the current thesis, we introduced to study of imitation inhibition to the developmental population with the hope that this might provide valuable insights into the inhibition of imitative responses.

In summary, the four studies contained within this thesis aimed to answer the following key questions:

- Q1: What is the best way to measure inhibitory control in young children?
- Q2: Is poorer inhibitory control in children related to a greater tendency to copy others' actions?
- Q3: What are the neural mechanisms involved in inhibiting imitative responses? Is the inhibition of imitative responses 'special' in that it involves activation of the social brain network rather than the domain-general inhibitory control network?

The remainder of this chapter will first present a summary of the main findings of this thesis, and then go on to relate these findings back to the research aims as well as the wider literature. This chapter will also consider the limitations of the studies contained within this thesis and provide some potential directions for future research.

5.2 Addressing the Research Questions

5.2.1 Research Question One

In the wake of the replication crisis (Shrout & Rodgers, 2018), one of the aims of the current study was to unequivocally establish a good measure of inhibitory control. Chapter two presented children aged three, four, and five years with a new SRC task (the TIC task) which was based on the principles of the Grass-Snow task. In this task, children's performance on four conditions was compared: Inhibition with feedback, Inhibition with no feedback, Control with feedback and Control with no feedback. In the feedback conditions, children were given accuracy feedback after every experimental trial as a constant reminder of the rules, in an effort to reduce the WM demands of the task for young children. We also integrated the rule teaching into the task itself, in an effort to standardise the way in which young children are taught the rules of an SRC task.

The results of the TIC task demonstrated that overall, accuracy was lower and reaction times were longer on the Inhibitory conditions than on the Control conditions. These differences were larger in younger children. Accuracy on the control conditions was consistently high across all age groups (3-, 4-, and 5-year-olds). The finding that children performed poorly on the inhibitory condition but highly on the control condition, suggests we can be confident that the TIC task was truly measuring the construct of inhibitory control.

Regarding the use of feedback to test the WM demands of the TIC task, the results suggested that whilst providing accuracy feedback improved children's scores

on the Inhibitory conditions, it made no difference to their scores on the Control conditions. This is likely because performance was already close to ceiling, even in the 3-year-old group. Given children's high performance on the control condition at all ages, we were able to demonstrate that providing accuracy feedback was *not* beneficial for young children, since even the youngest children in the sample (36-month-olds) were already able to remember and apply the rules of the task. In addition, we also found that providing accuracy feedback resulted in *slower* reaction times for all age groups.

We suspect that the time it took to provide accuracy feedback in-between trials meant that the trials in the No-Feedback conditions were more fast-paced than the trials in the Feedback conditions, which may have contributed to the increased accuracy and slower reaction times seen in the Feedback conditions. Indeed, previous research has suggested that slower responding reduces the inhibitory demands of the task (Kostyrka-Allchorne et al., 2017, 2019b). Children's high accuracy on the control conditions coupled with their slower responding on Feedback conditions led to the conclusion that providing accuracy feedback was not beneficial, and thus the feedback condition was omitted on later versions of the task as seen in Chapter Four.

We did, however, find that standardising the task instructions was beneficial. By doing this, every child is taught the rules in exactly the same way, creating a consistency not seen in previous inhibitory control studies. Children's high levels of performance on the control conditions was an indicator that even children as young as 36 months were able to learn and apply the task rules. Moreover, when applying Petersen and colleagues' (2016) "useful age range" (as measured between 20% and 80% accuracy)

to the TIC task, we are able to determine that the task may be suitable for children as young as 28-months-old. Comparison of the TIC task to other similar tasks described in the Petersen review (2016) suggests that the developmental trajectory in accuracy is consistent with these other tasks, with the TIC task demonstrating an upper limit of 56 months (figure 2.4 shows a plot of these trajectories for visual comparison). With the exception of the Reverse Categorisation task, the TIC task may be slightly easier than some of the other tasks. However, our data also show that using reaction time as an additional measure enables the useful age range of the TIC task to be extended, making it a good measure of inhibitory control from a child's third birthday up until their sixth.

To summarise, the use of a control condition in the TIC task enabled us to draw several conclusions. Firstly, we were able to determine that the working memory demands of the task were low for even the youngest children in the sample (36-month-olds), meaning that they were able to remember and apply the TIC task rules. Secondly, we were also able to demonstrate that our standardised rule teaching was effective for all children. Taken together, these data provided good empirical evidence that the TIC task is indeed a good task with which to measure inhibitory control in young children.

5.2.2 Research Question Two

The second research question of this thesis was 'Is poorer inhibitory control in children related to a greater tendency to copy others' actions?'. It is clear from the literature that children are prolific imitators, to the extent that they will imitate *unnecessary* actions, even at the expense of the efficiency of the task (McGuigan et al.,

2007). There is also research to suggest that imitating the actions of another person is a prepotent response tendency since observing an action has been shown to activate the corresponding motor representations of the action within the brain of the observer (Iacoboni et al., 1999). Given that prepotent response tendencies require the use of inhibitory control in order to be suppressed when necessary, we proposed that there could be a link between children's inhibitory control capabilities and their tendency to overimitate.

The aim of Chapter Three was to investigate this possible association between inhibitory control and imitation in young children. Due to the COVID-19 pandemic and the inability to collect new data at that time, the use of an existing data set was necessitated. In this data set, three-year-olds' imitative tendencies were measured using an overimitation task in which children are observed to see if they copy the unnecessary action performed by an adult model. Children's scores on two different inhibitory control tasks - a Go/No-go (GNG) task and the Early Childhood Inhibitory Touchscreen Task (ECITT; a spatial compatibility task) were correlated with the number of instances in which children demonstrated overimitative tendencies. We had hypothesised that children who demonstrate higher overimitative tendencies might do so because they lack the inhibitory control to be able to suppress this prepotent tendency to imitate.

The analyses did not find a correlation between the overimitation task and either of our measures of inhibitory control (the GNG task and the ECITT). However, the analysis was significant when a median split grouping variable was created to assess the difference in children's overimitation scores between the high scoring GNG group

and the low scoring GNG group. Somewhat surprisingly, it was found that children who scored higher on the GNG task demonstrated *higher* overimitative tendencies, not lower as predicted. In light of this result, one of the explanations put forward in Chapter Three was that children with good inhibitory control (with higher scores on the GNG task) may also have good WM. Having better WM might therefore enable children to better remember and then re-enact the sequence of actions demonstrated by the adult in the overimitation task. Thus, as children's executive function develops, so too might their ability to score higher on the GNG task and their likelihood of demonstrating greater overimitative tendencies (by being able to better remember the sequence of actions).

Because of the issues surrounding the use of a median split grouping variable (McClelland et al., 2015), we acknowledged that this interpretation must be tentative. However, it did seem to hint at a possible association between inhibitory control and imitation which warranted further investigation, which we went on to do in Chapter Four. However, given that most inhibitory control tasks test an immediate inhibitory response to a stimulus, it was considered that the overimitation task might not be the best task to use to assess the inhibition of a prepotent imitative response. For this reason, the studies in Chapter Four used better-matched tasks to investigate the inhibition of imitative and non-imitative responses in young children.

5.2.3 Research Question Three

One of the main aims of Chapter Four was to discern whether the inhibition of imitative responses is different from other types of inhibition – i.e. whether it is a special

domain-specific process. Chapter One introduced the current debate within the adult literature in which there seems to be a double dissociation between the inhibition of imitative responses and the inhibition of non-imitative responses (Brass et al., 2003). Brass and colleague's follow-up study implicated social brain areas such as the TPJ and the mPFC in the inhibition of imitative responses, which contradicted the previous assumption that all types of inhibition are underpinned by a designated domain-general inhibitory mechanism.

This contradiction was revisited by Darda and Ramsey in 2019 with their meta-analysis in which they sought to shed light on the debate of whether the inhibition of imitative responses is supported by a domain-specific neural mechanism associated with the social brain network. The results of their meta-analysis suggested that the TPJ was found to be activated during Imitation Inhibition studies but the mPFC was not. In addition, consistent bilateral activation of the dlPFC and the rIFG were found – which they regarded as part of a larger MD network (Darda & Ramsey, 2019). However, it should be noted that this meta-analysis concentrated only on studies which had used the Imitation Inhibition task – there was no comparison between activation on this task and activation on a non-imitative task, as was done in the current thesis.

Indeed, in Study Four we found evidence to suggest that *both* tasks elicited activation of the rIFG, rTPJ, the right mPFC and the right and left dlPFC when compared to the activation seen in the baseline condition. It is only when comparing the difference in activation *between* the two tasks that it is really possible to tell the differences in the neural mechanisms. By doing so, we discovered that the activation of

the rTPJ was slightly stronger in the Imitation Inhibition task (though not significantly). Our results are presented with some caution, given that greater activation was elicited by the Control conditions than the Inhibition conditions. One possible suggestion for the Control condition eliciting greater activation than the Inhibitory condition is that children may have found a way to reduce the WM demands of the Inhibition task by consolidating the task down to *one* rule: 'point to /do the opposite'. Such consolidation of the rules is not possible in the Control conditions since the stimuli and the required responses in this condition are not opposites. On the Control conditions then, children must still remember *two* rules: give response *a* for stimuli B and give response *b* for stimuli A.

Having said that, the behavioural results are highly suggestive that children found the Inhibitory conditions harder than the Control conditions (as evidenced by their higher performance on the controls). Generally, if a task is more taxing, the cognitive demand is higher and as such, it elicits greater levels of neural activation. Whilst it is possible that children both found the Inhibitory conditions hard because of the inhibitory demands, and the Control conditions hard because of the WM demands, it is very hard to interpret the current finding that the behavioural results seem to contradict the neural results. It is therefore possible that whilst the inhibitory demands were higher on the Inhibitory conditions than the Control conditions (as evidenced by children's poorer performance on the Inhibitory conditions), the WM demands were higher on the Control conditions than the Inhibitory conditions. Of course, the contradiction between the behavioural results and the neuroimaging results makes it very difficult to assess which of the conditions were more or less difficult for children,

or indeed whether this was even the reason for children's greater activation on the Control conditions. As such, further testing is required to see whether this finding replicates.

The finding that the right mPFC was activated during both tasks is also a little difficult to interpret. Indeed, whilst some evidence has suggested that the mPFC is *not* consistently activated during an Imitation Inhibition task (Darda & Ramsey, 2019) and other evidence suggests that it *is* activated during an Imitation Inhibition task but *not* during a non-imitative task (Brass et al., 2005), the current work presents yet another contradiction with the finding that it was recruited during *both* tasks. It is not clear whether this contradiction is associated with differences between adults and children, or differences between the Stroop task and the Grass-Snow task, or something else entirely. There is a possibility that the mPFC could play a role in WM (Lui et al., 2014; Smith et al., 2018). Given that children have poorer WM than adults it would therefore make sense that the mPFC might be recruited more in a developmental population. Another possibility is that the optode placement may have resulted in the measurement of another prefrontal area. Indeed, our array design meant that there were only two channels over the mPFC, and since we did not have individual neural scans from the children it was difficult be certain that the intended ROIs were being measured.

We also consider the findings of the rTPJ. Whilst the difference was not significant, there was a trend towards the Imitation Inhibition condition eliciting greater levels of activation than the Pointing Inhibition condition over this area. On the one hand, this finding seems to support the theory that the inhibition of imitative responses

is different from other responses and involves the rTPJ (Brass et al., 2003; 2005). On the other hand, the increase in oxyhaemoglobin (HbO_2) was also accompanied an increase in deoxyhaemoglobin (HHb) which is not a canonical response.

A canonical haemodynamic response is characterised by an increase in HbO_2 (since the increased blood flow brings additional oxygenated blood to the region) and a decrease in HHb (as this reflects the amount of oxygen which is absorbed by the brain tissue - Lachert et al., 2017). In this way, a synchronous increase in both HbO_2 and HHb should not be possible. Yet there have been other instances of this occurring in the literature with young children (e.g. Li et al., 2021). In a review of the infant literature (Cristia et al., 2013), almost 10% of studies were found to demonstrate an *increase* in HHb following stimulus presentation. Cristia et al. (2013) propose that because HHb concentrations are generally smaller in magnitude than HbO_2 concentrations, they are more likely to be affected by noise within the data. However, in Study Four, no significant motion artefacts were identified, after the applied corrections, suggesting that the data over this channel was not particularly noisy, so this explanation also seems unlikely.

We do acknowledge that there is some controversy about whether increase in total haemoglobin (HbT) an increase in HbO_2, or a decrease in HHb provides the best measure of 'activation' (Cristia et al., 2013; Obrig et al., 2010). But despite the suggestion that HHb concentrations are more susceptible to noise, there is also an argument that HHb signal provides a more sensitive measure of concentration change because it is less affected by physiological factors such as heartbeat and breathing than

HbO_2 (Obrig & Villringer, 2003). In the current study we determined activation as either an increase in HbO_2 or a decrease in HHb. This was in preference to using total haemoglobin as a measure of activation, since this seemed to be a less sensitive measure.

5.3 Limitations & recommendations for future research

Due to the COVID-19 pandemic, the course of this thesis was altered. One of the alterations made was to analyse an existing data set, which was necessitated due to the inability to collect any face-to-face data for a prolonged duration. Another alteration was presenting an inhibitory control task to young children in an online study rather than a face-to-face one. Both of these alterations were associated with several limitations which will now be discussed in further detail.

In Chapter Three, we presented an analysis of an existing data set. In this data set, 3-year-old children were tested on a battery of studies, which included an overimitation task, a GNG task and the ECITT. Given that one of the overarching aims of the current thesis was to investigate whether poorer inhibitory control in young children might be related to a greater tendency to copy other's actions, we had hoped that this data might provide some useful insights. Unfortunately, the sample sizes were smaller than would have been ideal, resulting in the correlational analyses being underpowered. The results of these analyses suggested that there was no relationship between children's scores on an overimitation task and their scores on either the GNG task or the ECITT. Furthermore, the median split analyses produced a significant effect for the GNG task but not the ECITT.

A potential contributing factor to the non-significant result was the methodological differences between the ECITT and the overimitation task. For instance, the ECITT measures a child's ability to respond to stimuli by switching from the prepotent location to the alternative location, thus providing a measure of spatial compatibility. Conversely, the overimitation task was a measure of children's tendency to copy the irrelevant action within a sequence of actions demonstrated by the experimenter. This required children to observe, remember and then recall the entire sequence of actions *except* for the irrelevant action. Since a *low* overimitation score reflected a *lack of imitation* (e.g. less occurrences of imitating the irrelevant action in the sequence), the assumption might be that these children are *successfully* inhibiting their imitative tendencies. However, it could instead be the case that children who overimitate *less* do so because they *lack* the WM capacity to remember the entire sequence of actions. In this way, we must be cautious about the way we interpret children's scores on the overimitation task in relation to their ability (or not) to inhibit their imitative tendencies.

Had we been able to collect our own data, it is unlikely that we would have chosen an overimitation task as a measure of children's imitative tendencies. With the benefit of hindsight, our suggestion was that a task that requires a more immediate suppression of one's imitative tendencies may be beneficial for investigating the inhibition of imitative tendencies. Indeed, inhibitory control may be more likely to be employed in situations in which children need to inhibit a faster response, for instance when inhibiting the tendency to copy someone else's actions in real time.

Based on the limitations in Chapter Three, the tasks used to investigate the inhibition of imitative and non-imitative response tendencies in Chapter Four were considered carefully. As a measure of non-imitative inhibitory responses, the Grass-Snow-like task presented in Chapter Two was used since this was found to have good efficacy even with children as young as 36 months. The measure of imitative inhibitory responses was an Imitation Inhibition task much like the Hand Game task described by Hughes (1998). Children's performance on these two tasks were then compared in an online study, which was necessitated due to the measures introduced to combat the COVID-19 pandemic. Because of this, we were only able to make accuracy comparisons between the two tasks.

Running an online task with young children presented some significant limitations. Firstly, the task set-up was complicated. For instance, the software would only run on a laptop or a pc, not a tablet or phone and required parents to install software to enable the task to run. It also required the experimenter to use Zoom's 'Remote Control' feature, in order to take control of the participants screen to be able to run the task. Secondly, the exclusion rates were very high compared with the face-to-face versions of the task (in Chapters Two and Four). In the online study, 14 children were excluded because they were unable to stay on-task for the duration of the four conditions, resulting in incomplete data sets. In addition, eight participants were excluded from the final sample because the video footage of the sessions were not sufficient to enable accuracy analysis due to internet connection and lagging. Given that there were no exclusions in the study presented in Chapter Two (which had an identical age range of 36 to 72 months), this indicates that the high rate of exclusions in Study

One was associated with the study being conducted via an online medium. The findings from the current thesis provide several avenues for future research. The task developed throughout this thesis has standardised the way in which SRC task instructions are given to children. Throughout this research, we have shown that our task is indeed a good measure of inhibitory control in young children. Future research can build on the work presented here by using this task to further investigate the inhibition of imitative and non-imitative responses in a developmental population. It is possible that this task can be used in its current form in the future without the need to administer the control condition. That being said, we highly recommend that when making any *changes* to the task methodology (e.g. stimuli or responses) the control condition be added to be sure that the task remains a valid measure of inhibitory control.

It would also be prudent to further investigate the role of the rTPJ in the inhibition of imitative responses in a larger sample size using the task introduced in Chapter Four. A larger sample size would allow for correlational analyses between the imitative and the non-imitative inhibitory conditions as well as between behavioural performance and neural responses. It may also be beneficial to use a NIRS system with a larger optode capacity, since having a system with only eight sources and eight detectors limits the number of available channels to test each region of interest (ROI) with. A digital optical localisation mapping tool may also provide a better accuracy of cap placement than visual inspection alone.

5.4 Conclusions

In this thesis, a new touchscreen SRC task (the TIC task) was introduced to measure inhibitory control in young children in which rule teaching was standardised. Additionally, a feedback condition was implemented to test whether the WM demands of the task could be reduced in an effort to improve young children's performance. The data have demonstrated that providing accuracy feedback was not beneficial, since children did not struggle to remember and apply the rules of the task. We have also shown that standardisation of the rule teaching was successful, opening up future avenues for the use of the TIC task in the study of inhibitory control in young children.

The work in this thesis has also investigated whether children with poor inhibitory control might have a tendency to demonstrate greater imitative tendencies. Our findings demonstrated the opposite – that children with poor inhibitory control seem to imitate *less*. Having considered that the tasks used to make these comparisons might have had substantially different WM demands, the subsequent work carried out in this thesis used better-matched tasks with which to compare young children's inhibition of imitative and non-imitative response tendencies.

In an online study we demonstrated that these tasks appeared to be a good measure of inhibitory control in young children. As such, they were used in an fNIRS study which found evidence of greater activation of the rTPJ during the inhibition of imitative responses than during the inhibition of non-imitative responses. Despite being more in line with the domain-specific account of imitation inhibition, future research is

needed to replicate these findings since an uncanonical activation of both oxygenated and deoxygenated haemoglobin was found.

To conclude, the work contained within this thesis has provided insights from behavioural and fNIRS research into the role of inhibitory control in resisting imitation in young children. Whilst we have only scratched the surface, we believe that the methodologies introduced in these studies hold great potential for further investigation into the inhibition of imitative and non-imitative response tendencies in young children during this salient period of brain maturation.

References

Allan, N. P., & Lonigan, C. J. (2014). Exploring dimensionality of effortful control using hot and cool tasks in a sample of preschool children. *Journal of experimental child psychology*, *122*, 33-47. DOI: 10.1037/a0023748

Aron, A. R., Robbins, T. W., & Poldrack, R. A. (2004). Inhibition and the right inferior frontal cortex. *Trends in Cognitive Sciences*, *8*(4), 170–177. DOI: 10.1016/j.tics.2004.02.010

Aron, A. R., Robbins, T. W., & Poldrack, R. A. (2014). Inhibition and the right inferior frontal cortex: One decade on. *Trends in Cognitive Sciences*, *18*(4), 177–185. DOI: 10.1016/j.tics.2013.12.003

Aslin, R. N., & Mehler, J. (2005). Near-infrared spectroscopy for functional studies of brain activity in human infants: Promise, prospects, and challenges. *Journal of Biomedical Optics*, *10*(1), 011009. DOI: 10.1117/1.1854672

Bailey, H. (2017). The OBS Project Contributors. Open Broadcasting Software. Retrieved from https://www.obsproject.org/

Bardi, L., Six, P., & Brass, M. (2017). Repetitive TMS of the temporo-parietal junction disrupts participant's expectations in a spontaneous Theory of Mind task. *Social Cognitive and Affective Neuroscience*, *12*(11), 1775–1782. DOI: 10.1093/scan/nsx109

Barth, M., & Poser, B. A. (2011). Advances in high-field BOLD fMRI. *Materials*, *4*(11), 1941-1955.

Bassett, H. H., Denham, S., Mincic, M., & Graling, K. (2012). The structure of preschoolers' emotion knowledge: Model equivalence and validity using a structural equation modeling approach. *Early Education & Development, 23,* 259-279. DOI: 10.1002/icd.1763

Baydar, N., Kağitçibaşi, Ç., Küntay, A. C., & Gökşen, F. (2008). Effects of an educational television program on preschoolers: Variability in benefits. *Journal of applied developmental psychology*, *29*(5), 349-360.

Bertenthal, B. I., Longo, M. R., & Kosobud, A. (2006). Imitative response tendencies following observation of intransitive actions. *Journal of Experimental Psychology: Human Perception and Performance*, *32*(2), 210–225. DOI: 10.1037/0096-1523.32.2.210Blair, C., & Razza, R. P. (2007). Relating Effortful Control, Executive Function, and False Belief Understanding to Emerging Math and Literacy Ability in Kindergarten. *Child Development, 78*(2), 647–663. DOI: 10.1111/j.1467-8624.2007.01019.x

Blakey, E., Visser, I., & Carroll, D. J. (2016). Different executive functions support different kinds of cognitive flexibility: Evidence from 2-, 3-, and 4-year-olds. *Child development, 87,* 513-526. DOI: 10.1111/cdev.12468

Brass, M., & Heyes, C. (2005). Imitation: Is cognitive neuroscience solving the correspondence problem? *Trends in Cognitive Sciences*, *9*(10), 489–495. DOI: 10.1016/j.tics.2005.08.007

Brass, M., Derrfuss, J., Matthes-von Cramon, G., & von Cramon, D. Y. (2003). Imitative response tendencies in patients with frontal brain lesions. *Neuropsychology*, *17*(2), 265–271. DOI: 10.1037/0894-4105.17.2.265

Brass, M., Derrfuss, J., & von Cramon, D. Y. (2005). The inhibition of imitative and overlearned responses: A functional double dissociation. *Neuropsychologia*, *43*(1), 89–98. DOI: 10.1016/j.neuropsychologia.2004.06.018

Brass, M., Ruby, P., & Spengler, S. (2009). Inhibition of imitative behaviour and social cognition. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 364(1528), 2359–2367. DOI: 10.1098/rstb.2009.0066

Brass, M., Zysset, S., & von Cramon, D. Y. (2001). The Inhibition of Imitative Response Tendencies. *NeuroImage*, *14*(6), 1416–1423. DOI: 10.1006/nimg.2001.0944

Brugger, A., Lariviere, L. A., Mumme, D. L., & Bushnell, E. W. (2007). Doing the Right Thing: Infants' Selection of Actions to Imitate From Observed Event Sequences. *Child Development*, *78*(3), 806–824. DOI: 10.1111/j.1467-8624.2007.01034.x

Bull, R., & Scerif, G. (2001). Executive Functioning as a Predictor of Children's Mathematics Ability: Inhibition, Switching, and Working Memory.

Developmental Neuropsychology, *19*(3), 273–293. DOI: 10.1207/S15326942DN1903_3

Bunge, S. A., Dudukovic, N. M., Thomason, M. E., Vaidya, C. J., & Gabrieli, J. D. (2002). Immature frontal lobe contributions to cognitive control in children: evidence from fMRI. *Neuron*, *33*(2), 301-311.

Burdett, E. R. R., McGuigan, N., Harrison, R., & Whiten, A. (2018). The interaction of social and perceivable causal factors in shaping 'over-imitation'. *Cognitive Development*, *47*, 8–18. DOI: 10.1016/j.cogdev.2018.02.001

Burle, B., Spieser, L., Roger, C., Casini, L., Hasbroucq, T., & Vidal, F. (2015). Spatial and temporal resolutions of EEG: Is it really black and white? A scalp current density view. *International Journal of Psychophysiology*, *97*(3), 210-220.

Camerota, M., Willoughby, M. T., Magnus, B. E., & Blair, C. B. (2020). Leveraging item accuracy and reaction time to improve measurement of child executive function ability. *Psychological assessment*, *32*, 1118. DOI: 10.1037/pas0000953

Carlson, S. M. (2005). Developmentally Sensitive Measures of Executive Function in Preschool Children. *Developmental Neuropsychology*, *28*, 595–616. DOI: 10.1207/s15326942dn2802

Carlson, S. M., & Moses, L. J. (2001). Individual Differences in Inhibitory Control and Children's Theory of Mind. *Child Development*, *72*(4), 1032–1053. DOI: 10.1111/1467-8624.00333

Carroll, D. J., Blakey, E., & Simpson, A. (2021). Can we boost preschoolers' inhibitory performance just by changing the way they respond? *Child Development, 92*, 2205-2212. DOI: 10.1111/cdev.13617

Casey, B. J., Trainor, R. J., Orendi, J. L., Schubert, A. B., Nystrom, L. E., Giedd, J. N., Castellanos, F. X., Haxby, J. V., Noll, D. C., Cohen, J. D., Forman, S. D., Dahl, R. E., & Rapoport, J. L. (1997). A Developmental Functional MRI Study of Prefrontal Activation during Performance of a Go-No-Go Task. *Journal of Cognitive Neuroscience*, *9*(6), 835–847. DOI: 10.1162/jocn.1997.9.6.835

Caspers, S., Zilles, K., Laird, A. R., & Eickhoff, S. B. (2010). ALE meta-analysis of action observation and imitation in the human brain. *NeuroImage*, *50*(3), 1148–1167. DOI: 10.1016/j.neuroimage.2009.12.112

Cassotti, M., Agogué, M., Camarda, A., Houdé, O., & Borst, G. (2016). Inhibitory control as a core process of creative problem solving and idea generation from childhood to adulthood. *New directions for child and adolescent development*, *2016*(151), 61-72. DOI: 10.1002/cad.20153

Chartrand, T. L., & Bargh, J. A., (1999). The chameleon effect: the perception–behavior link and social interaction. J. *Pers. Soc. Psychol. 76*, 893–910.

Chartrand, T. L., & Lakin, J. L. (2013). The Antecedents and Consequences of Human Behavioral Mimicry. *Annual Review of Psychology*, *64*(1), 285–308. DOI: 10.1146/annurev-psych-113011-143754

Clark, R. (1977). What's the use of imitation? *Journal of Child Language*, *4*(3), 341–358. DOI: 10.1017/S0305000900001732

Corbetta, M., Patel, G., & Shulman, G. L. (2008). The Reorienting System of the Human Brain: From Environment to Theory of Mind. *Neuron*, *58*(3), 306–324. DOI: 10.1016/j.neuron.2008.04.017

Cowan, N. (2014). Working memory underpins cognitive development, learning, and education. *Educational psychology review*, *26*, 197-223.

Crescentini, C., Mengotti, P., Grecucci, A., & Rumiati, R. I. (2011). The effect of observed biological and non biological movements on action imitation: An fMRI study. *Brain Research*, *1420*, 80–92. DOI: 10.1016/j.brainres.2011.08.077

Cristia, A., Dupoux, E., Hakuno, Y., Lloyd-Fox, S., Schuetze, M., Kivits, J., Bergvelt, T., Van Gelder, M., Filippin, L., Charron, S., & Minagawa-Kawai, Y. (2013). An online database of infant functional near infrared spectroscopy studies: a community-augmented systematic review. *PloS one*, *8*(3), e58906.

Cross, K. A., & Iacoboni, M. (2014). To imitate or not: Avoiding imitation involves preparatory inhibition of motor resonance. *NeuroImage*, *91*, 228–236. DOI: 10.1016/j.neuroimage.2014.01.027

Cross, K. A., Torrisi, S., Reynolds Losin, E. A., & Iacoboni, M. (2013). Controlling automatic imitative tendencies: Interactions between mirror neuron and

cognitive control systems. *NeuroImage, 83,* 493–504. DOI: 10.1016/j.neuroimage.2013.06.060

Cutini, S., & Brigadoi, S. (2014). Unleashing the future potential of functional near-infrared spectroscopy in brain sciences. *Journal of Neuroscience Methods, 232,* 152-156. DOI: 10.1016/j.jneumeth.2014.05.024

Dalenberg, J. R., Hoogeveen, H. R., & Lorist, M. M. (2018). Physiological measurements: EEG and fMRI. In *Methods in Consumer Research, Volume 2* (pp. 253-277). Woodhead Publishing.

Darda, K. M., & Ramsey, R. (2019). The inhibition of automatic imitation: A meta-analysis and synthesis of fMRI studies. *NeuroImage, 197,* 320-329.

Davidson, M. C., Amso, D., Anderson, L. C., & Diamond, A. (2006). Development of cognitive control and executive functions from 4 to 13 years: Evidence from manipulations of memory, inhibition, and task switching. *Neuropsychologia, 44*(11), 2037-2078.

di Pellegrino, G., Fadiga, L., Fogassi, L., Gallese, V., & Rizzolatti, G. (1992). Understanding motor events: a neurophysiological study. *Experimental brain research, 91,* 176-180.

de Klerk, C. C. J. M., Hamilton, A. F. de C., & Southgate, V. (2018). Eye contact modulates facial mimicry in 4-month-old infants: An EMG and fNIRS study. *Cortex, 106,* 93–103. DOI: 10.1016/j.cortex.2018.05.002

Decety, J. (1997). Brain activity during observation of actions. Influence of action content and subject's strategy. *Brain*, *120*(10), 1763–1777. DOI: 10.1093/brain/120.10.1763

Diamond, A. (2002). Normal Development of Prefrontal Cortex from Birth to Young Adulthood: Cognitive Functions, Anatomy, and Biochemistry. In D. T. Stuss & R. T. Knight (Eds.), Principles of Frontal Lobe Function (pp. 466–503). *Oxford University Press*. DOI: 10.1093/acprof:oso/9780195134971.003.0029

Diamond, A. (2013). Executive Functions. *Annual Review of Psychology, 64*(1), 135–168. DOI: 10.1146/annurev-psych-113011-143750

Diamond, A., Barnett, W. S., Thomas, J., & Munro, S. (2007). Preschool program improves cognitive control. *Science*, *318*, 1387-1388. DOI: 10.1126/science.1151148

Diamond, A., & Kirkham, N. (2005). Not quite as grown-up as we like to think: Parallels between cognition in childhood and adulthood. *Psychological Science*, *16*, 291-297. DOI: 10.1111/ j.0956-7976.2005.01530.x

Diamond, A., & Taylor, C. (1996). Development of an aspect of executive control: Development of the abilities to remember what I said and to "Do as I say, not as I do". *Developmental psychobiology*, *29*(4), 315-334.

Diamond, A., Kirkham, N., & Amso, D. (2002). Conditions under which young children can hold two rules in mind and inhibit a prepotent response. *Developmental Psychology, 38*, 352–362. DOI: 10.1037//0012-1649.38.3.352

Diamond, A., Prevor, M. B., Callender, G., & Druin, D. P. (1997). Prefrontal Cortex Cognitive Deficits in Children Treated Early and Continuously for PKU. *Monographs of the Society for Research in Child Development*, *62*(4), i–206. DOI: 10.2307/1166208

Dowsett, S. M., & Livesey, D. J. (2000). The development of inhibitory control in preschool children: Effects of "executive skills" training. *Developmental Psychobiology*, *36*(2), 161–174. DOI: 10.1002/(SICI)1098-2302(200003)36:2<161::AID-DEV7>3.0.CO;2-0

Duckworth, A. L., & Seligman, M. E. (2005). Self-discipline outdoes IQ in predicting academic performance of adolescents. *Psychological science*, *16*(12), 939-944. DOI: 10.1111/j.1467-9280.2005.01641.x

Durston, S., Davidson, M. C., Tottenham, N., Galvan, A., Spicer, J., Fossella, J. A., & Casey, B. J. (2006). A shift from diffuse to focal cortical activity with development. *Developmental Science*, *9*(1), 1–8. DOI: 10.1111/j.1467-7687.2005.00454.x

Durston, S., Thomas, K. M., Yang, Y., Uluğ, A. M., Zimmerman, R. D., & Casey, B. J. (2002). A neural basis for the development of inhibitory control. *Developmental Science*, *5*(4), F9–F16. DOI: 10.1111/1467-7687.00235

Duncan, J. (2010). The multiple-demand (MD) system of the primate brain: mental programs for intelligent behaviour. *Trends in cognitive sciences*, *14*(4), 172-179.

Faul, F., Erdfelder, E., Buchner, A., & Lang, A. G. (2009). Statistical power analyses using G*Power 3.1: Tests for correlation and regression analyses. *Behavior Research Methods*, *41*, 1149-1160.

Floyd, R. G., & Kirby, E. A. (2001). Psychometric properties of measures of behavioral inhibition with preschool-age children: Implications for assessment of children at risk for ADHD. *Journal of Attention Disorders*, *5*(2), 79-91.

Garon, N. (2016). A review of hot executive functions in preschoolers. *Journal of Self-Regulation and Regulation*, *2*, 57-80. DOI: 10.11588/josar.2016.2.34354

Garon, N., Bryson, S. E., & Smith, I. M. (2008). Executive function in preschoolers: A review using an integrative framework. *Psychological Bulletin*, *134*(1), 31–60. DOI: 10.1037/0033-2909.134.1.31

Garon, N., Smith, I. M., & Bryson, S. E. (2014). A novel executive function battery for preschoolers: Sensitivity to age differences. *Child Neuropsychology*, *20*(6), 713–736. DOI: 10.1080/09297049.2013.857650

Gerstadt, C. L., Hong, Y. J., & Diamond, A. (1994). The relationship between cognition and action: performance of children 3½ –7 years old on a stroop-like day-night test. *Cognition*, *53*, 129-153. DOI: 10.1111/1467-7687.00134

Grezes, J. (1998). Top down effect of strategy on the perception of human biological motion: a PET investigation. *Cognitive Neuropsychology*, *15*(6–8), 553–582. DOI: 10.1080/026432998381023

Haartsen, R., Jones, E. J., & Johnson, M. H. (2016). Human brain development over the early years. *Current Opinion in Behavioral Sciences*, *10*, 149–154. DOI: 10.1016/j.cobeha.2016.05.015

Hakim, U., Pinti, P., Noah, A. J., Zhang, X., Burgess, P., Hamilton, A., Hirsch, J., & Tachtsidis, I. (2022). Investigation of functional near-infrared spectroscopy signal quality and development of the hemodynamic phase correlation signal. *Neurophotonics*, *9*(02). DOI: 10.1117/1.NPh.9.2.025001

Hanlon, C. A., Canterberry, M., Taylor, J. J., DeVries, W., Li, X., Brown, T. R., & George, M. S. (2013). Probing the Frontostriatal Loops Involved in Executive and Limbic Processing via Interleaved TMS and Functional MRI at Two Prefrontal Locations: A Pilot Study. *PLoS ONE*, *8*(7), e67917. DOI: 10.1371/journal.pone.0067917

Heyes, C., & Ray, E. (2000). What is the significance of imitation in animals? *Advances in the Study of Behavior*, *29*, 215–245.

Hoehl, S., Zettersten, M., Schleihauf, H., Grätz, S., & Pauen, S. (2014). The role of social interaction and pedagogical cues for eliciting and reducing overimitation in preschoolers. *Journal of Experimental Child Psychology*, *122*, 122-133.

Hogeveen, J., Obhi, S. S., Banissy, M. J., Santiesteban, I., Press, C., Catmur, C., & Bird, G. (2015). Task-dependent and distinct roles of the temporoparietal junction and inferior frontal cortex in the control of imitation. *Social Cognitive and Affective Neuroscience*, *10*(7), 1003–1009. DOI: 10.1093/scan/nsu148

Holland, R., Leff, A. P., Josephs, O., Galea, J. M., Desikan, M., Price, C. J., Rothwell, J. C., & Crinion, J. (2011). Speech Facilitation by Left Inferior Frontal Cortex Stimulation. *Current Biology*, *21*(16), 1403–1407. DOI: 10.1016/j.cub.2011.07.021

Holmboe, K., Larkman, C., de Klerk, C., Simpson, A., Bell, M. A., Patton, L., Christodoulou, C., & Dvergsdal, H. (2021). The early childhood inhibitory touchscreen task: A new measure of response inhibition in toddlerhood and across the lifespan. *PLOS ONE*, *16*(12), e0260695. DOI: 10.1371/journal.pone.0260695

Horner, V., & Whiten, A. (2005). Causal knowledge and imitation/emulation switching in chimpanzees (Pan troglodytes) and children (Homo sapiens). *Animal Cognition*, 8(3), 164–181. DOI: 10.1007/s10071-004-0239-6

Hosomi, F., Yanagi, M., Kawakubo, Y., Tsujii, N., Ozaki, S., & Shirakawa, O. (2019). Capturing spontaneous activity in the medial prefrontal cortex using near-infrared spectroscopy and its application to schizophrenia. *Scientific Reports*, *9*(1), 5283. DOI: 10.1038/s41598-019-41739-4

Houdé, O. & Borst, G. (2015). Evidence for an inhibitory-control theory of the reasoning brain. *Frontiers in human neuroscience*, *9*, 148. DOI: 10.3389/fnhum.2015.00148

Howard, S. J., & Melhuish, E. (2017). An early years toolbox for assessing early executive function, language, self-regulation, and social development: Validity,

reliability, and preliminary norms. *Journal of Psychoeducational Assessment*, *35*(3), 255-275.

Howard, S. J., & Okely, A. D. (2015). Catching Fish and Avoiding Sharks: Investigating Factors That Influence Developmentally Appropriate Measurement of Preschoolers' Inhibitory Control. *Journal of Psychoeducational Assessment*, *33*(6), 585–596. DOI: 10.1177/0734282914562933

Hughes, C. (1998). Executive function in preschoolers: Links with theory of mind and verbal ability. *British Journal of Developmental Psychology*, *16*(2), 233–253. DOI: 10.1111/j.2044-835X.1998.tb00921.x

Huppert, T., Diamond, S., Franceschini, M., & Boas, D. (2009). HomER: a review of time-series analysis methods for near-infrared spectroscopy of the brain. *Applied optics*, 48(10). DOI: 10.1364/ao.48.00d280

Iacoboni, M., Woods, R. P., Brass, M., Bekkering, H., Mazziotta, J. C., & Rizzolatti, G. (1999). Cortical mechanisms of human imitation. *science*, *286*(5449), 2526-2528. DOI: 10.1126/science.286.5449.2526

Inquisit 5 [Computer software]. (2016). Retrieved from *https://www.millisecond.com*

Isquith, P. K., Gioia, G. A., & Espy, K. A. (2004). Executive function in preschool children: Examination through everyday behavior. *Developmental Neuropsychology*, *26*, 403 – 422

Jacobson, L., Koslowsky, M., & Lavidor, M. (2012). tDCS polarity effects in motor and cognitive domains: a meta-analytical review. *Experimental brain research*, *216*, 1-10.

Jeannerod, M. (2003). The mechanism of self-recognition in humans. *Behavioural Brain Research*, *142*(1–2), 1–15. DOI: 10.1016/S0166-4328(02)00384-4

Jobsis, F. F. (1977). Noninvasive, infrared monitoring of cerebral and myocardial oxygen sufficiency and circulatory parameters. *Science* 198, 1264–1267. DOI: 10.1126/science.929199

Johnson, M. H. (1999). Cortical plasticity in normal and abnormal cognitive development: Evidence and working hypotheses. *Development and Psychopathology*, *11*(3), 419-437.

Jones, L. B., Rothbart, M. K., & Posner, M. I. (2003). Development of executive attention in preschool children. *Developmental Science*, *6*(5), 498–504. DOI: 10.1111/1467-7687.00307

Jones, S. S. (2007). Imitation in infancy: The development of mimicry. *Psychological science*, *18*(7), 593-599.

Kenward, B., Karlsson, M., & Persson, J. (2011). Over-imitation is better explained by norm learning than by distorted causal learning. *Proceedings of the Royal Society B: Biological Sciences*, *278*(1709), 1239–1246. DOI: 10.1098/rspb.2010.1399

Keupp, S., Behne, T., & Rakoczy, H. (2013). Why do children overimitate? Normativity is crucial. *Journal of Experimental Child Psychology*, *116*(2), 392–406. DOI: 10.1016/j.jecp.2013.07.002

Kim, S., Nordling, J., Yoon, J., Boldt, L., & Kochanska, G. (2013). Effortful control in "hot" and "cool" tasks differentially predicts children's behavior problems and academic performance. *Journal of Abnormal Child Psychology, 41*, 43–56. DOI 10.1007/s10802-012-9661-4

Kochanska, G., Coy, K. C., & Murray, K. T. (2001). The development of self-regulation in the first four years of life. *Child development, 72*, 1091-1111. DOI: 10.1111/1467-8624.00336

Kochanska, G., Murray, K. T., & Harlan, E. T. (2000). Effortful control in early childhood: continuity and change, antecedents, and implications for social development. *Developmental psychology*, *36*(2), 220.

Kochanska, G., Murray, K., Jacques, T. Y., Koenig, A. L., & Vandegeest, K. A. (1996). Inhibitory control in young children and its role in emerging internalization. *Child development*, *67*(2), 490-507.

Kolk, S. M., & Rakic, P. (2022). Development of prefrontal cortex. *Neuropsychopharmacology*, *47*(1), 41-57.

Kostyrka-Allchorne, K., Cooper, N. R., Gossman, A. Banks, K. J., & Simpson, A. (2017). Differential effects of film on preschool children's behaviour dependent on editing pace. *Acta Paediatrica*, *106*, 831-836. DOI: 10.1111/apa.13770

Kostyrka-Allchorne, K., Holland, A., Marrow, R., Simpson, A., Cooper, N. R., & Ahamed, W. (2019a). What helps children learn difficult tasks: A teacher's presence may be worth more than a screen. *Trends in Neuroscience and Education, 17*. DOI: 10.1016/j.tine.2019.100114

Kostyrka-Allchorne, K., Cooper, N. R., & Simpson, A. (2019b). Disentangling the effects of video pace and story realism on children's attention and response inhibition. *Cognitive Development, 49*, 94-104. DOI: 10.1016/j.cogdev.2018.12.003

Krall, S. C., Rottschy, C., Oberwelland, E., Bzdok, D., Fox, P. T., Eickhoff, S. B., Fink, G. R., & Konrad, K. (2015). The role of the right temporoparietal junction in attention and social interaction as revealed by ALE meta-analysis. *Brain Structure and Function*, *220*(2), 587–604. DOI: 10.1007/s00429-014-0803-z

Krall, S. C., Volz, L. J., Oberwelland, E., Grefkes, C., Fink, G. R., & Konrad, K. (2016). The right temporoparietal junction in attention and social interaction: A transcranial magnetic stimulation study: RTPJ-TMS in Attention and Social Interaction. *Human Brain Mapping*, *37*(2), 796–807. DOI: 10.1002/hbm.23068

Lachert, P., Janusek, D., Pulawski, P., Liebert, A., Milej, D., & Blinowska, K. J. (2017). Coupling of Oxy-and Deoxyhemoglobin concentrations with EEG rhythms during motor task. *Scientific reports*, *7*(1), 15414.

Lee, S. M., & McCarthy, G. (2016). Functional Heterogeneity and Convergence in the Right Temporoparietal Junction. *Cerebral Cortex*, *26*(3), 1108–1116. DOI: 10.1093/cercor/bhu292

Levin, H. S., Culhane, K. A., Hartmann, J., Evankovich, K., Mattson, A. J., Harward, H., Ringholz, G., Ewing-Cobbs, L., & Fletcher, J. M. (1991). Developmental changes in performance on tests of purported frontal lobe functioning. *Developmental Neuropsychology*, *7*(3), 377–395. DOI: 10.1080/87565649109540499

Lew-Levy, S., van den Bos, W., Corriveau, K., Dutra, N., Flynn, E., O'Sullivan, E., Pope-Caldwell, S., Rawlings, B., Smolla, M., Xu, J., & Wood, L. (2023). Peer learning and cultural evolution. *Child Development Perspectives*, *17*, 97–105.

Li, H., Wu, D., Yang, J., Luo, J., Xie, S., & Chang, C. (2021). Tablet Use Affects Preschoolers' Executive Function: fNIRS Evidence from the Dimensional Change Card Sort Task. *Brain Sciences 11*(5) 567. DOI: 10.3390/brainsci11050567

Linebarger, D. L., Kosanic, A. Z., Greenwood, C. R., & Doku, N. S. (2004). Effects of Viewing the Television Program Between the Lions on the Emergent Literacy Skills of Young Children. *Journal of Educational Psychology*, *96*(2), 297.

Ling, D. S., Wong, C. D., & Diamond, A. (2016). Do children need reminders on the day–night task, or simply some way to prevent them from responding too

quickly? *Cognitive Development, 37*, 67–72. DOI: 10.1016/j.cogdev.2015.10.003

Liu, D., Gu, X., Zhu, J., Zhang, X., Han, Z., Yan, W., Cheng, Q., Hao, J., Fan, H., Hou, R. & Chen, Z., (2014). Medial prefrontal activity during delay period contributes to learning of a working memory task. *Science, 346*(6208), 458-463.

Livesey, D. J., & Morgan, G. A. (1991). The development of response inhibition in 4- and 5-year-old children. *Australian journal of Psychology*, *43*(3), 133-137.

Lloyd-Fox, S., Blasi, A., & Elwell, C. E. (2010). Illuminating the developing brain: The past, present and future of functional near infrared spectroscopy. *Neuroscience & Biobehavioral Reviews*, *34*(3), 269–284. DOI: 10.1016/j.neubiorev.2009.07.008

Luna, B., Garver, K. E., Urban, T. A., Lazar, N. A., & Sweeney, J. A. (2004). Maturation of cognitive processes from late childhood to adulthood. *Child development*, *75*(5), 1357-1372.

Luria, A. R. (1966) Higher Cortical Functions in Man. *Moscow University Press*

Lyons, D. E., Young, A. G., & Keil, F. C. (2007). The hidden structure of overimitation. *Proceedings of the National Academy of Sciences, 104*(50), 19751–19756. DOI: 10.1073/pnas.0704452104

Lyons, D. E., Damrosch, D. H., Lin, J. K., Macris, D. M., & Keil, F. C. (2011). The scope and limits of overimitation in the transmission of artefact culture.

Philosophical Transactions of the Royal Society B: Biological Sciences, *366*(1567), 115–1167. DOI: 10.1098/rstb.2010.0335

Magnus, B. E., Willoughby, M. T., Blair, C. B., & Kuhn, L. J. (2019). Integrating item accuracy and reaction time to improve the measurement of inhibitory control abilities in early childhood. *Assessment*, *26,* 1296-1306. DOI: 10.1177/1073191117740953

Marsh, L., Pearson, A., Ropar, D., & Hamilton, A. (2013). Children with autism do not overimitate. *Current Biology*, *23*(7), R266–R268. DOI: 10.1016/j.cub.2013.02.036

Marsh, L. E., Ropar, D., & Hamilton, A. F. de C. (2019). Are you watching me? The role of audience and object novelty in overimitation. *Journal of Experimental Child Psychology*, *180*, 123–130. DOI: 10.1016/j.jecp.2018.12.010

Marshall, P. J., & Drew, A. R. (2014). What makes Simon Says so difficult for young children? *Journal of Experimental Child Psychology*, *126*, 112–119. DOI: 10.1016/j.jecp.2014.03.011

The MathWorks Inc. (2017). MATLAB version: 9.3.0 (R2017b), Natick, Massachusetts: The MathWorks Inc. *https://www.mathworks.com*

McClelland, G. H., Lynch, J. G., Irwin, J. R., Spiller, S. A., & Fitzsimons, G. J. (2015). Median splits, Type II errors, and false–positive consumer psychology: Don't fight the power. *Journal of Consumer Psychology*, *25*(4), 679–689. DOI: 10.1016/j.jcps.2015.05.006

McGuigan, N., Whiten, A., Flynn, E., & Horner, V. (2007). Imitation of causally opaque versus causally transparent tool use by 3- and 5-year-old children. *Cognitive Development*, *22*(3), 353–364. DOI: 10.1016/j.cogdev.2007.01.001

McGuigan, N., Makinson, J., & Whiten, A. (2011). From over-imitation to super-copying: Adults imitate causally irrelevant aspects of tool use with higher fidelity than young children: From over-imitation to super-copying. *British Journal of Psychology*, *102*(1), 1–18. DOI: 10.1348/000712610X493115

Mehnert, J., Akhrif, A., Telkemeyer, S., Rossi, S., Schmitz, C. H., Steinbrink, J., Wartenburger, I., Obrig, H., & Neufang, S. (2013). Developmental changes in brain activation and functional connectivity during response inhibition in the early childhood brain. *Brain and Development*, *35*(10), 894–904. DOI: 10.1016/j.braindev.2012.11.006

Meltzoff, A. N. (1988). Infant imitation after a 1-week delay: Long-term memory for novel acts and multiple stimuli. *Developmental Psychology*, *24*(4), 470–476. DOI: 10.1037/0012-1649.24.4.470

Montgomery, D. E., & Fosco, W. (2012). The effect of delayed responding on Stroop-like task performance among preschoolers. *The Journal of Genetic Psychology, 173*, 142-157. DOI: 10.1080/00221325.2011.583699

Murray, K. T., & Kochanska, G. (2002). Effortful control: Factor structure and relation to externalizing and internalizing behaviors. *Journal of abnormal child psychology, 30*, 503-514.

Nair, D. G. (2005). About being BOLD. *Brain Research Reviews*, *50*(2), 229–243. DOI: 10.1016/j.brainresrev.2005.07.001

Nakamura, K., & Kawabata, H. (2015). Transcranial Direct Current Stimulation over the Medial Prefrontal Cortex and Left Primary Motor Cortex (mPFC-lPMC) Affects Subjective Beauty but Not Ugliness. *Frontiers in Human Neuroscience*, *9*. DOI: 10.3389/fnhum.2015.00654

Nejati, V., Salehinejad, M. A., & Nitsche, M. A. (2018). Interaction of the Left Dorsolateral Prefrontal Cortex (l-DLPFC) and Right Orbitofrontal Cortex (OFC) in Hot and Cold Executive Functions: Evidence from Transcranial Direct Current Stimulation (tDCS). *Neuroscience*, *369*, 109–123. DOI: 10.1016/j.neuroscience.2017.10.042

Nielsen, M. (2006). Copying actions and copying outcomes: Social learning through the second year. *Developmental Psychology*, *42*(3), 555–565. DOI: 10.1037/0012-1649.42.3.555

Nielsen, M., & Blank, C. (2011). Imitation in young children: When who gets copied is more important than what gets copied. *Developmental Psychology*, *47*(4), 1050–1053. DOI: 10.1037/a0023866

Nielsen, M., Simcock, G., & Jenkins, L. (2008). The effect of social engagement on 24-month-olds' imitation from live and televised models. *Developmental Science*, *11*(5), 722–731. DOI: 10.1111/j.1467-7687.2008.00722.x

Nishitani, N., & Hari, R. (2002). Viewing lip forms: cortical dynamics. *Neuron*, *36*(6), 1211-1220.

Nobusako, S., Nishi, Y., Nishi, Y., Shuto, T., Asano, D., Osumi, M., & Morioka, S. (2017). Transcranial Direct Current Stimulation of the Temporoparietal Junction and Inferior Frontal Cortex Improves Imitation-Inhibition and Perspective-Taking with no Effect on the Autism-Spectrum Quotient Score. *Frontiers in Behavioral Neuroscience*, *11*, 84. DOI: 10.3389/fnbeh.2017.00084

Obrig, H., & Villringer, A. (2003). Beyond the visible—imaging the human brain with light. *Journal of Cerebral Blood Flow & Metabolism*, *23*(1), 1-18.

Obrig, H., Rossi, S., Telkemeyer, S., & Wartenburger, I. (2010). From acoustic segmentation to language processing: evidence from optical imaging. *Frontiers in Neuroenergetics*, *2*, 1484.

O'Sullivan, E. P., Bijvoet-van Den Berg, S., & Caldwell, C. A. (2018). Automatic imitation effects are influenced by experience of synchronous action in children. *Journal of Experimental Child Psychology*, *171*, 113–130. DOI: 10.1016/j.jecp.2018.01.013

Oostenbroek, J., Suddendorf, T., Nielsen, M., Redshaw, J., Kennedy-Costantini, S., Davis, J., Clark, S., & Slaughter, V. (2016). Comprehensive longitudinal study challenges the existence of neonatal imitation in humans. *Current biology*, *26*(10), 1334-1338.

Over, H. & Carpenter, M. (2009). Priming third-party ostracism increases affiliative imitation in children. *Developmental Science*, *12*(3), F1–F8. DOI: 10.1111/j.1467-7687.2008.00820.x

Passler, M. A., Isaac, W., & Hynd, G. W. (1985). Neuropsychological development of behavior attributed to frontal lobe functioning in children. *Developmental Neuropsychology*, *1*(4), 349-370.

Pauli-Pott, U., Roller, A., Heinzel-Gutenbrunner, M., Mingebach, T., Dalir, S. & Becker, K. (2014). Inhibitory control and delay aversion in unaffected preschoolers with a positive family history of attention deficit hyperactivity disorder. *Journal of Child Psychology and Psychiatry*, *55*, 1117-1124. DOI: 10.1080/ 09297049.2013.778236

Petersen, I. T., Hoyniak, C. P., McQuillan, M. E., Bates, J. E., & Staples, A. D. (2016). Measuring the development of inhibitory control: The challenge of heterotypic continuity. *Developmental Review*, *40*, 25–71. DOI: 10.1016/j.dr.2016.02.001

Piaget, J. (1962). Play, dreams and imitation in childhood. *New York: Norton.*

Quaresima, V., & Ferrari, M. (2019). Functional near-infrared spectroscopy (fNIRS) for assessing cerebral cortex function during human behavior in natural/social situations: a concise review. *Organizational Research Methods*, 22(1), 46-68.

Quesque, F., & Brass, M. (2019). The Role of the Temporoparietal Junction in Self-Other Distinction. *Brain Topography*, *32*(6), 943–955. DOI: 10.1007/s10548-019-00737-5

Reed, M. A., Pien, D. L., & Rothbart, M. K. (1984). Inhibitory self-control in preschool children. *Merrill-Palmer Quarterly 30*(2), 131-147.

Reiß, F., Meyrose, A. K., Otto, C., Lampert, T., Klasen, F., & Ravens-Sieberer, U. (2019). Socioeconomic status, stressful life situations and mental health problems in children and adolescents: Results of the German BELLA cohort-study. *PloS one*, *14*(3), e0213700.

Rubia, K., Smith, A. B., Taylor, E. & Brammer, M. (2007). Linear age-correlated functional development of right inferior fronto-striato-cerebellar networks during response inhibition and anterior cingulate during error-related processes. *Human brain mapping*, 28(11), 1163-1177.

Santiesteban, I., Banissy, M. J., Catmur, C., & Bird, G. (2012). Enhancing Social Ability by Stimulating Right Temporoparietal Junction. *Current Biology*, *22*(23), 2274–2277. DOI: 10.1016/j.cub.2012.10.018

Santiesteban, I., Banissy, M. J., Catmur, C., & Bird, G. (2015). Functional lateralization of temporoparietal junction – imitation inhibition, visual perspective-taking and theory of mind. *European Journal of Neuroscience*, *42*(8), 2527–2533. DOI: 10.1111/ejn.13036

Schleihauf, H., Graetz, S., Pauen, S., & Hoehl, S. (2018). Contrasting Social and Cognitive Accounts on Overimitation: The Role of Causal Transparency and Prior Experiences. *Child Development*, *89*(3), 1039–1055. DOI: 10.1111/cdev.12780

Scholkmann, F., & Wolf, M. (2013). General equation for the differential pathlength factor of the frontal human head depending on wavelength and age. *Journal of Biomedical Optics*, *18*(10), 105004. DOI: 10.1117/1.JBO.18.10.105004

Schroeder, P. A., Seewald, A., & Svaldi, J. (2022). Spotlight on the left frontal cortex: no evidence for response inhibition from cathodal high-definition transcranial direct current stimulation over left inferior frontal gyrus or left dorsolateral prefrontal cortex. *Journal of Cognitive Neuroscience*, *34*(6), 1090-1102.

Schuwerk, T., Schurz, M., Müller, F., Rupprecht, R., & Sommer, M. (2017). The rTPJ's overarching cognitive function in networks for attention and theory of mind. *Social Cognitive and Affective Neuroscience*, *12*(1), 157–168. DOI: 10.1093/scan/nsw163

Senn, T. E., Espy, K. A., & Kaufmann, P. M., (2004) "Using path analysis to understand executive function organization in preschool children". *Developmental Neuropsychology, 26*(1), 445-464

Shimada, S., & Hiraki, K. (2006). Infant's brain responses to live and televised action. *NeuroImage*, *32*(2), 930–939. DOI: 10.1016/j.neuroimage.2006.03.044

Shrout, P. E., & Rodgers, J. L. (2018). Psychology, science, and knowledge construction: Broadening perspectives from the replication crisis. *Annual review of psychology*, *69*, 487-510.

Simpson, A., & Carroll, D. J. (2019). Understanding Early Inhibitory Development: Distinguishing Two Ways That Children Use Inhibitory Control. *Child Development*, *90*, 1459–1473. DOI: 10.1111/cdev.13283

Simpson, A., Cooper, N. R., Gillmeister, H., & Riggs, K. J. (2013). Seeing triggers acting, hearing does not trigger saying: Evidence from children's weak inhibition. *Cognition*, *128*(2), 103-112.

Simpson, A., Lipscombe, S., & Carroll, D. (2022). Why are some inhibitory tasks easy for preschool children, when most are difficult? Testing two hypotheses. *Journal of Experimental Child Psychology*, *220*, 105431.

Simpson, A., & Riggs, K. J. (2005a). Inhibitory and working memory demands of the day-night task in children. *British Journal of Developmental Psychology*, *23*, 471–486. DOI: 10.1348/ 026151005X28712

Simpson, A., & Riggs, K. J. (2005b). Factors responsible for performance on the day-night task: Response set or semantics? *Developmental Science*, *8*, 360–371. DOI: 10.1111/j.1467-7687.2005.00424.x

Simpson, A., & Riggs, K. J. (2006). Conditions under which children experience inhibitory difficulty with a "button-press" go/no-go task. *Journal of*

Experimental Child Psychology, *94*(1), 18–26. DOI: 10.1016/j.jecp.2005.10.003

Simpson, A. & Riggs, K. J. (2009). What makes responses prepotent for young children? Insights from the grass-snow task. *Infant and Child Development*, *18*, 21–35. DOI: 10.1002/icd.576

Simpson, A., & Riggs, K. J. (2011). Under what conditions do children have difficulty in inhibiting imitation? Evidence for the importance of planning specific responses. *Journal of Experimental Child Psychology*, *109*(4), 512–524. DOI: 10.1016/j.jecp.2011.02.015

Smith, E., Anderson, A., Thurm, A., Shaw, P., Maeda, M., Chowdhry, F., Chernomordik, V., & Gandjbakhche, A. (2017). Prefrontal Activation During Executive Tasks Emerges Over Early Childhood: Evidence From Functional Near Infrared Spectroscopy. *Developmental Neuropsychology*, *42*(4), 253–264. DOI: 10.1080/87565641.2017.1318391

Smith, R., Lane, R. D., Alkozei, A., Bao, J., Smith, C., Sanova, A., Nettles, M., & Killgore, W. D. (2018). The role of medial prefrontal cortex in the working memory maintenance of one's own emotional responses. *Scientific reports*, *8*(1), 3460.

Southgate, V., Johnson, M. H., Osborne, T., & Csibra, G. (2009). Predictive motor activation during action observation in human infants. *Biology Letters*, *5*(6), 769–772. DOI: 10.1098/rsbl.2009.0474

Sowden, S., Wright, G. R. T., Banissy, M. J., Catmur, C., & Bird, G. (2015). Transcranial Current Stimulation of the Temporoparietal Junction Improves Lie Detection. *Current Biology, 25*(18), 2447–2451. DOI: 10.1016/j.cub.2015.08.014

Strommen, E. A. (1973). Verbal self-regulation in a children's game: impulsive errors on "Simon Says". *Child Development*, 849-853.

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of experimental psychology, 18*(6), 643.

Tomasello, M., Carpenter, M., Call, J., Behne, T., & Moll, H. (2005). Understanding and sharing intentions: The origins of cultural cognition. *Behavioral and brain sciences*, 28(5), 675-691.

Tomasello, M., Kruger, A. C., & Ratner, H. H. (1993). Cultural learning. *Behavioral and brain sciences*, *16*(3), 495-511.

Uzefovsky, F., Allison, C., Smith, P., & Baron-Cohen, S. (2016). Brief Report: The Go/No-Go Task Online: Inhibitory Control Deficits in Autism in a Large Sample. *Journal of Autism and Developmental Disorders*, *46*(8), 2774–2779. DOI: 10.1007/s10803-016-2788-3

Uzgiris, I. C. (1981). Two functions of imitation during infancy. *International Journal of Behavioral Development*, *4*(1), 1-12.

Van Den Wildenberg, W. P. M., & Van Der Molen, M. W. (2004). Developmental trends in simple and selective inhibition of compatible and incompatible

responses. *Journal of Experimental Child Psychology*, *87*(3), 201–220. DOI: 10.1016/j.jecp.2003.11.003

Villringer, A., & Chance, B. (1997). Non-invasive optical spectroscopy and imaging of human brain function. *Trends in neurosciences*, *20*(10), 435-442. DOI: 10.1016/S0166-2236(97)01132-6

Vivanti, G., Hocking, D. R., Fanning, P., & Dissanayake, C. (2017). The social nature of overimitation: Insights from Autism and Williams syndrome. *Cognition*, *161*, 10–18. DOI: 10.1016/j.cognition.2017.01.008

Wada, J. A., & Davis, A. E. (1977). Fundamental nature of human infant's brain asymmetry. *Canadian Journal of Neurological Sciences*, *4*(3), 203-207.

Watson, A. J., & Bell, M. A. (2013). Individual Differences in Inhibitory Control Skills at Three Years of Age. *Developmental Neuropsychology*, *38*(1), 1–21. DOI: 10.1080/87565641.2012.718818

Wang, Y., & Hamilton, A. F. de C. (2012). Social top-down response modulation (STORM): a model of the control of mimicry in social interaction. *Frontiers in human neuroscience*, *6*, 153.

Wang, H., Ge, W., Zhu, C., Sun, Y., & Wei, S. (2022). How pom cheerleading improves the executive function of preschool children: the mediating role of speed and agility. *BMC psychology*, *10*(1), 1-11. DOI: 10.1186/s40359-022-00944-z

Want, S. C., & Harris, P. L. (2002). How do children ape? Applying concepts from the study of non-human primates to the developmental study of 'imitation' in children. *Developmental Science*, *5*(1), 1-14.

Whiten, A., & Custance, D. M. (1996). Studies of imitation in chimpanzees and children. In: Cecilia M. Heyes and Bennett G. Galef, eds. *Social learning in animals. The roots of culture.* San Diego, USA: Academic Press

Whiten, A., & Ham, R. (1992). On the nature and evolution of imitation in the animal kingdom: Reappraisal of a century of research. *Advances in the study of behavior*, *21*, 239-283.

Wiebe, S. A., Sheffield, T. D. & Espy, K. A. (2012). Separating the Fish from the Sharks: A Longitudinal Study of Preschool Response Inhibition: Development of Preschool Response Inhibition. *Child Development*, *83*(4), 1245–1261. DOI: 10.1111/j.1467-8624.2012.01765.x

Williams, B. R., Ponesse, J. S., Schachar, R. J., Logan, G. D., & Tannock, R. (1999). Development of inhibitory control across the life span. *Developmental psychology*, *35*(1), 205.

Willoughby, M. T., Kupersmidt, J. B., & Voegler-Lee, M. E. (2012). Is preschool executive function causally related to academic achievement? *Child Neuropsychology*, *18*(1), 79–91. DOI: 10.1080/09297049.2011.578572

Wolfe, C. D., & Bell, M. A. (2004). Working memory and inhibitory control in early childhood: Contributions from physiology, temperament, and language. *Developmental Psychobiology*, *44*(1), 68–83. DOI: 10.1002/dev.10152

Wolfe, C. D., & Bell, M. A. (2007). The integration of cognition and emotion during infancy and early childhood: Regulatory processes associated with the development of working memory. *Brain and Cognition*, *65*(1), 3-13.

Wood, L. A., Kendal, R. L., & Flynn, E. G. (2013). Whom do children copy? Model-based biases in social learning. *Developmental Review*, *33*(4), 341–356. DOI: 10.1016/j.dr.2013.08.002

Ye, H., Chen, S., Huang, D., Zheng, H., Jia, Y., & Luo, J. (2015). Modulation of neural activity in the temporoparietal junction with transcranial direct current stimulation changes the role of beliefs in moral judgment. *Frontiers in Human Neuroscience*, *9*, 659.

Zheng, H., Lu, X., & Huang, D. (2018). tDCS Over DLPFC Leads to Less Utilitarian Response in Moral-Personal Judgment. *Frontiers in Neuroscience*, *12*, 193. DOI: 10.3389/fnins.2018.00193

Yuan, E. (2024) *Zoom Video Communications* (version 5.17.11) [Computer software]. https://www.zoom.us