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Deconstructing Complex Cognition: The Development of Cognitive Flexibility in Early Childhood

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**Abstract**

The goal of this research was to gain a more comprehensive understanding of how cognitive flexibility (CF) develops in early childhood. Previous research on cognitive flexibility development has tended to focus solely on studying 3- to 4-year-olds on a single paradigm that involves children switching from one task to another while resolving response conflict. For example, children switch from sorting coloured shapes by a rule (e.g., colour) to sorting the same stimuli by a new rule (e.g., shape). This has led to the pervasive, but simplistic idea that children achieve CF when they overcome perseveration at age 4 (e.g., Munakata, 2012; Zelazo *et al*., 2003). Consequently, theoretical accounts of CF development have focused on explaining why 3-year-olds perseverate. Perseveration has been explained as either a failure of working memory *or* a failure of inhibitory control, and little progress has been made in testing between these two accounts.

Three approaches were combined in the current research to address this issue: 1) A new paradigm was used to study cognitive flexibility, capable of examining different types of flexible behaviour; 2) 2-year-olds were studied for the first time on measures of CF to learn about its emergence; and 3) both individual differences studies and randomised control training studies were used to examine how working memory and inhibitory control contribute to the development of CF. Together, the findings challenge the prevailing view that CF development begins with perseveration at age 3 and flexible behaviour at age 4 due to increases in working memory *or* inhibitory control by showing that: 1) overcoming response conflict is not the only way children can demonstrate flexible behaviour; 2) key developments in CF occur prior to age 3; and 3) both working memory and inhibitory control contribute to CF development depending on the task demands. Collectively, the findings provide a more comprehensive and nuanced account of cognitive flexibility development.

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**Declaration**

I hereby declare that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis. All experiments were designed and conducted by myself under the supervision of Dr Dan Carroll. The Latent Markov modelling analyses in Chapter two were done in collaboration with Dr Ingmar Visser. Ione Haddock assisted with data collection in Chapter one, and Hannah Biney assisted with data collection in Chapter five. Some of the studies presented in this thesis have been previously presented in the following journal articles and conference presentations detailed below.

Publications

Chapter two is based on the following paper:

Blakey, E., Visser, I., & Carroll, D. J. (2015) Different executive functions support different kinds of cognitive flexibility: Evidence from two-, three- and four-year-olds. *Child Development.* Advance online publication. DOI: 10.1111/cdev.12468

Chapter six is based on the following paper:

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Publications under review

Chapter three is based on a manuscript currently under review at *Child Development:*

Blakey, E., & Carroll, D. J. Not all distractions are the same: Investigating why preschoolers make distraction errors when switching.

Conference Presentations

Blakey, E.(November 2015) Can executive functions be improved in preschoolers? Invited talk at the Current Issues in Educational Neuroscience workshop, Birkbeck, University of London.

Blakey, E., & Carroll, D. J. (September 2015) Why do preschoolers make distraction errors on measures of cognitive flexibility? *British Psychological Society Social and Developmental Section conference* (Manchester).

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Blakey, E. (March 2015) An integrative approach to understanding working memory training: Insights from across typical and atypical development. *Convened paper symposium* at the *International Convention of Psychological Science,* (Amsterdam, the Netherlands).

Blakey, E., & Carroll, D. J. (September 2014) Executive function training improves preschool working memory.Paper presentation at the *British Psychological Society Developmental Section conference* (Amsterdam, the Netherlands).

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Blakey, E., & Carroll, D. J. (September 2013) Which better predicts cognitive flexibility in 2- to 4-year-olds: Working memory or inhibitory control? Poster presentation at the *BPS Cognitive and Developmental Section conference* (Reading).

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Chapter One

The Development of Cognitive Flexibility

This Chapter provides a review of the current literature on the development of Cognitive Flexibility (CF), and a discussion of its relation to two executive functions: working memory and inhibitory control. The introduction begins with an overview of executive functions, and then moves on more specifically to CF. CF is considered to be an emergent property of the cognitive system rather than a stand-alone executive function. An account of CF development from infancy to middle childhood is given, with a discussion of two influential theories of CF development. Three significant gaps are discussed that need to be addressed in order to gain a comprehensive account of CF development. First, researchers need to examine different ways in which flexible behaviour can be achieved in childhood; second, researchers need to address the development of CF in 2-year-olds so that its emergence can be understood; and third, there is an important need to clearly deconstruct how working memory and inhibitory control contribute to CF development

**1. Executive Functions**

Successful human behaviour requires the ability to maintain and flexibly update information, to suppress external distractions and to adjust our behaviour in a way most adaptive to our environment and our goals (Anderson & Reidy, 2012). The collection of skills that allow us to engage in such behaviour are known as executive functions: the set of interrelated, higher-order cognitive skills that enable us to control and co-ordinate our behaviour (Jurado & Rosselli, 2007; Miyake *et al*., 2000). Executive functions are a form of top-down control as they allow behaviour to be guided by internal rules and goals, such as the intention to complete a task or to take a particular mental or physical action (Altmann & Trafton, 2002). This is in contrast to bottom-up control whereby attention and behaviour are guided by the immediate environment (Awh, Belopolsky & Theeuwes, 2012). Executive functions are particularly important in novel situations when mappings between task-relevant stimuli and behaviour are weakly represented, and when automatically guided behaviour is likely to be inappropriate for the current goal. For example, executive functions are required in the classic Stroop task where participants have to name the ink colour of colour words presented in an incongruent ink colour (e.g. the word ‘blue’ written in red ink) (Stroop, 1935). Naming colours is a less practiced skill, and therefore is more weakly represented than reading words. Because of the automaticity of reading, participants must maintain the task goal and inhibit the strongly activated but task-irrelevant response of reading the word.

Executive functions in adults are thought to consist of three discrete higher order cognitive skills that are moderately correlated: working memory, inhibitory control and set-shifting (Miyake *et al*., 2000). Working memory allows us to maintain and process information, inhibitory control allows us to suppress inappropriate responses or suppress interference from task-irrelevant information, and set-shifting allows us to switch our behaviour multiple times according to different task rules (Miyake *et al.,* 2000).[[1]](#footnote-1) This three-factor structure of working memory, inhibitory control and set-shifting has been derived from influential work by Miyake and colleagues who examined adults’ performance on a battery of executive function tasks, and used Structural Equation Modelling to examine the latent variables that best explained the variance across tasks. However, this three-factor structure is thought to slowly emerge in development when executive functions differentiate due to increased specialisation among prefrontal cortex networks (Wiebe *et al*., 2011). Evidence for this comes from factor analysis studies in children which have found a one-factor structure in 4- to 6-year-olds after measuring working memory, inhibitory control and planning (Hughes, Ensor, Wilson & Graham, 2011). Other studies have found a two-factor structure of inhibitory control and working memory after measuring working memory, inhibitory control and CF in 3- to 5-year-olds (Miller, Giesbrecht, Müller, McInerney & Kerns, 2011) and 6-year-olds (van der Ven, Kroesbergen, Boom & Leseman, 2012). In the latter two studies, researchers proposed that CF was not a stand-alone executive function but rather an emergent skill arising from the successful interplay of working memory and inhibitory control.

Executive functions show rapid improvements during the preschool years (e.g., Carlson, Mandell & Williams, 2004; Garon, Bryson & Smith, 2008). These cognitive improvements have been linked to significant growth spurts in the prefrontal cortex during this time (Stuss & Benson, 1986; Miller & Cohen, 2001). The prefrontal cortex is thought to be responsible for regulating thought and behaviour by activating task-relevant information such as goals or internal rules and by inhibiting other neural areas (Knight & Stuss, 2002; Miller & Cohen, 2001). Developments in the prefrontal cortex between the ages of 3 and 5 years have been linked to a significant increase in preschoolers’ ability to control and regulate their behaviour (Anderson, Anderson, Northam, Jacobs & Carroppa, 2001; Fuster, 2000).

In line with these rapid developments, the preschool period has emerged as an important time for when individual differences in executive function begin to predict a range of developmental outcomes (see Diamond, 2013). For example, children’s executive function ability in nursery predicts language, literacy and social competence one year later when children start school (Bierman, Nix, Greenberg, Blair & Domitrovich, 2008) and academic attainment up to eight years later (Clark, Pritchard, Woodward, 2010; Duncan *et al.,* 2007). The relation between executive functions and academic skills holds after controlling for baseline academic skills, general cognitive ability and social skills (e.g., Clark *et al*., 2010). However, the relation between executive functions and mathematics is particularly robust – it remains even after controlling for language ability and IQ (Alloway & Alloway, 2010; Alloway & Passolunghi, 2011). Because preschool executive function skills play such an important role in future academic attainment, understanding the development of executive functions during this time is essential in understanding how to best support children’s academic skills.

1. **Cognitive Flexibility**

CF is a skill that allows us to switch our thoughts or behaviour in line with changes in our goals or the environment (e.g., Chevalier *et al.,* 2012). There is a growing consensus that rather than being a stand-alone executive function, CF should be regarded as the emergent property of successful cognition (Dajani & Uddin, 2015; Ionescu, 2012) or a skill arising from working memory and inhibitory control (Garon *et al*., 2008; Chevalier *et al*., 2012). Before one can switch flexibly between multiple tasks or representations, one must be able to hold in mind multiple rules in working memory and have the ability to inhibit other previously applied rules (Garon *et al*., 2008; Anderson & Reidy, 2012). Following this line of reasoning, the emergence of CF during the preschool years has been explained as arising from increased working memory and inhibitory control resources (Chevalier *et al*., 2012). However, the precise contribution of these skills is still unclear and CF remains poorly understood (see Chevalier *et al*., 2012).

There are a variety of paradigms used to measure CF across development, however common to all tasks is the requirement that participants perform a task according to a specific rule, and then switch their response so that the same task can be completed by a new rule (Clearfield & Niman, 2012). For example, on the Dimensional Change Card Sort task (DCCS; Zelazo *et al*., 2003) preschool children sort coloured picture cards into trays according to a matching rule (e.g., colour). After several trials, the rule changes and children must sort by a new rule (e.g., shape). The cards that children must sort contain both colour *and* shape information (e.g., a blue rabbit) therefore affording two responses depending on the rule of the task. Children therefore have to resolve response conflict when the rule changes (see section 3.3 for further detail). Response conflict[[2]](#footnote-2) arises during the post-switch phase when stimuli can be sorted either by the current rule or by the old, no longer relevant rule. Because of this response conflict, in order to sort correctly, children must (i) maintain the new rule – because the correct sorting rule cannot be determined from the cards – and (ii) attend to only the relevant dimension of the stimulus for that trial. This illustrates how CF requires the co-ordination of numerous distinct cognitive skills (Cragg & Chevalier, 2009) and therefore can be considered an emergent property of cognition. Across most CF tasks, children must maintain the current task-goal, switch attention to a new aspect of a stimulus and then selectively attend to the relevant aspect of a stimulus.

1. **The development of Cognitive Flexibility in childhood**

*3.1. Precursors to cognitive flexibility in the first two years of life*

It is during infancy that children’s behaviour becomes increasingly the product of controlled goal-oriented thought, and much less driven by reactions to stimuli in the environment (Wiebe, Lukowski & Bauer, 2010). Because infants have limited motor and verbal abilities, early CF is often measured using eye-movement paradigms or using reaching paradigms. In both of these types of paradigm, infants are tested on their ability to first build an association between a stimulus and a response, and then to flexibly update this association in line with changes in the task. It is around six months of age that infants become able to learn and then relearn a stimulus-response association.

Looking is one of the first controlled behaviours to develop in infants (Johnson, Dziurawiec, Ellis & Morton, 1991). It is around six months of age that infants begin to endogenously control their attention and selectively allocate their attention to information in their environment (Colombo, 2001). This is thought to be a precursor to later executive functions more broadly because it reflects infants’ growing ability to internally control their attention (Sheese, Rothbart, Posner, White & Fraundorf, 2008). Because of this development, precursors to CF can be measured by examining infants’ flexible stimulus-response mappings with eye-movement paradigms. For example, in one study, 7-month-old infants’ anticipatory looks were measured in response to a cue that predicted a visual or auditory reward at one side of a screen (Kovacs & Mehler, 2009). The critical measure of CF was the infants’ ability to then shift their anticipatory looks in response to a new cue that predicted a reward on the opposite side of the screen. This particular study aimed to test whether preverbal infants raised in bilingual households showed more flexible stimulus-response mappings because they may have more practice flexibly attending to and controlling input from two different languages. They found that bilingual 7- and 12–month-old infants were better able to reverse their stimulus-response mapping and increase their anticipatory looks to a new cue then the monolingual infants were. This suggests that repeated engagement of CF in the environment can lead infants to develop CF skills earlier in development.

At around six months of age, infants also become able to reach towards items that they want, allowing researchers to measure early CF using reaching paradigms. The A-not-B task examines infants’ ability to shift their reaching from one location to another. The task is thought to tap both working memory and inhibitory control in infants, and has therefore been regarded as an early measure of CF (Clearfield, Diedrich, Smith & Thelen, 2006; Clearfield & Niman, 2012). In the classic version of this task used with 8-month-olds (Diamond, 1985), an infant watches an experimenter hide a toy in one of two identical boxes placed in front of the child (the A location). After a two-second delay, infants are allowed to retrieve the toy. After several trials where the toy is hidden in location A, the toy is then hidden in the other box (the B location). As before, after a two-second delay, the child is allowed to retrieve the toy. Eight-month-old infants typically make the A-not-B perseverative error on B trials: they search at the A location where the toy has been previously hidden and not at the B location, therefore persisting with a no-longer-relevant behaviour. Similar results have been found when eye movements are used as the dependent measure rather than reaching (e.g. Bell & Adams, 1999). This suggests that infants’ perseveration cannot be explained by a failure of response inhibition to change reaching location. Perseveration has therefore been explained as a combination of memory difficulties such as forgetting where the toy has been hidden, and attentional inhibition as infants must overcome the habit of attending to the first location (Diamond, 1985).

Longitudinal studies examining infants’ performance on the A-not-B task have revealed an interesting developmental trajectory of early CF (Clearfield & Niman, 2012; Clearfield *et al*., 2006). In two separate studies, Clearfield and colleagues studied infants’ performance on the task longitudinally between five and 12 months of age. In this version of the task, instead of toys being hidden, the experimenter cued one of two objects to be reached for. The experimenter cued the object and left it in full view of the child alongside the non-cued object. For example, on A trials, the experimenter would cue the A-object by waving it and tapping it, and then after a three-second delay the infant was allowed to reach for the toys. On the B trials, the B object was cued. A striking developmental pattern of behaviour on the B trials was found: five-month-olds responded unsystematically, sometimes reaching for B and sometimes reaching toward A; 8-month-olds perseverated by repeatedly incorrectly reaching towards A; and 12-month-olds consistently reached correctly. Thus development on the A-not-B task appeared to follow a U-shaped curve, with perseveration increasing between 5 months and 8 months.

Clearfield, Dineva, Smith, Diedrich and Thelen (2009) proposed that this developmental pattern was driven by early working memory development (see Stedron, Sahni & Munakata, 2005, for a similar account). Between the ages of 5 and 12 months, infants are thought to become better able to maintain in working memory the current hiding location of the toy. Because 5-month-olds have a less well developed working memory, they are thought to maintain weak memories that are mainly for what is currently occurring in their immediate environment (known as active memories). This means that on the B trials of the A-not-B task, 5-month-olds are able to maintain the B location on some of the trials. As memory develops between 5 and 8 months, 8-month-olds begin to maintain stronger memories for stimuli that are not in their immediate environment. This means that on the B trials of the A-not-B task, 8-month-olds perseverate because they maintain the A location strongly, yet inappropriately (known as a latent memory). In contrast, 12-month-olds have the ability to flexibly balance active and latent memories depending on what is appropriate. Therefore, 12-month-olds show a more advanced form of flexible behaviour. From this account, perseveration is a sign of developmental progression, as infants move from holding active memories to latent memories therefore resulting in more incorrect, but more systematic behaviour.

By the second year of life, infants have developed the ability to resist interference from distractors that are not relevant to the task at hand (Wiebe *et al*., 2010). This is a crucial requirement for more advanced measures of CF. To study this in infancy, researchers have exploited infants’ tendency to imitate actions that they have observed. In one paradigm, Wiebe *et al.* (2010) used an imitation task with distractor items. In the task, infants first observed the experimenter carry out a three-step action sequence involving two toys. Afterwards, infants were given the same two toys in addition to the several distractor items that had not been used in the sequence by the experimenter and were encouraged to reproduce the same three-step sequence. The researchers found that between 12 and 20 months, infants became significantly better at accurately imitating the sequences using the same toys as the experimenter. In addition, infants’ tendency to use the distractor items decreased significantly with age. Wiebe and colleagues propose that this reflects infants growing ability to maintain information and resist distraction from task-irrelevant information which takes place during the second year of life.

* 1. *The development of Cognitive Flexibility in two-year-olds*

It is around 2 years of age that children become able to explicitly sort stimuli consistently by a simple rule. This is the crucial baseline ability necessary for the ability to switch between different rules. Two-year-olds are also able to switch their behaviour in line with explicit rules, as long as they do not need to switch their attention to focusing on a single aspect of a stimulus. For example, 2-year-olds can sort correctly on reversal shift tasks where no switch in selective attention is required. On reversal shift tasks, children simply have to go from categorising stimuli one way to categorising it the opposite way. For example, 2-year-olds can sort trucks with trucks and stars with stars, and then switch to sorting stars with trucks and trucks with stars (Brooks, Hanauer, Padowska, & Rosman, 2003). In addition, on the reverse categorisation task (Carlson *et al*., 2004), 2-year-olds can sort objects first according to one rule (such as placing big bricks into the ‘big brick’ box, and placing little bricks into the ‘little brick’ box), and then to sort the same objects according to the opposite rule (such as placing big bricks into the ‘little box’ and little bricks into the ‘big box’). This research demonstrates that 2-year-olds are able to reverse a stimulus-response mapping – an early example of simple flexible behaviour – providing that the selective attention demands are minimal. Specifically, 2-year-olds are able to flexibly follow a new rule when they do not need to selectively attend to one aspect of a stimulus.

The toddler years remain an understudied area in CF research (Garon *et al*., 2008) and consequently have been described as the ‘dark ages’ of cognitive development (Carlson *et al.,* 2004). However, there is evidence to suggest that this is an important time for executive function development, particularly in terms of predicting later developmental outcomes. For example, 2-year-olds’ performance on simple measures of working memory and inhibitory control predict Theory of Mind at age 3 (e.g., Carlson *et al.,* 2004) and age 4 (Hughes & Ensor, 2007), as well as predicting classroom engagement and academic skills at age 6 (Fitzpatrick & Pagani, 2012). However, the cognitive mechanisms underpinning these developments remain to be explained.

*3.3. The development of Cognitive Flexibility in three- to four-year-olds*

It is between the ages of 3 and 4 that children become able to switch flexibly from sorting stimuli by one dimension to sorting the same stimulus by another dimension. CF is typically assessed during the preschool years using dimension switching paradigms where children have to sort bi-dimensional stimuli first by one rule (e.g., colour) and then by a new rule (e.g., shape). On these tasks, including the DCCS (Zelazo *et al*., 2003; see Figure 1) and the Shape School (Espy, 1997) children have to selectively attend to one aspect of a bi-dimensional stimulus (i.e., a coloured shape) and following a rule change must then switch their attention to a new aspect of the same stimulus. By around 4 years of age, children become able to switch between sorting stimuli by one dimension to sorting them by another. Doing this successfully requires children to (i) maintain the relevant rule, and (ii) selectively attend to the right dimension.

The DCCS is the most widely used paradigm to measure CF in preschoolers (see Figure 1). On the DCCS, children have to switch from sorting bi-dimensional picture cards from one dimension rule (e.g., colour) to a different dimension rule (e.g., shape; see section two for a description). In order to sort correctly, children must resolve response conflict: when the rule changes, the stimuli can be sorted by both the new rule and the old rule, and so this conflict needs to be resolved if children are to sort flexibly. Children typically sort eight picture cards in the pre-switch phase and eight cards in the post-switch phase. The robust finding on this task is that 3-year-olds typically sort all of the cards incorrectly in the post-switch phase. Their behaviour is therefore generally described as perseveration (Zelazo *et al*., 2003). Four-year-olds, on the other hand, tend to sort correctly by the new post-switch rule. This so-called 3 to 4 shift from perseveration to switching is considered one of the most significant milestones in development (Munakata, Snyder & Chatham, 2012).

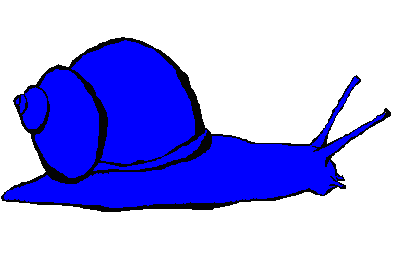
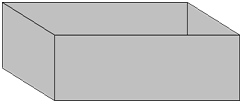
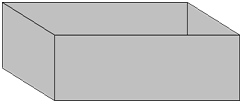
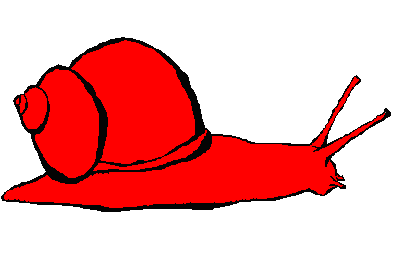
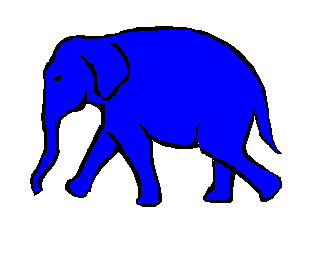


Figure 1. The Dimensional Change Card Sort task (DCCS). Children have to sort the test card (the blue snail) into one of the two trays with a target card attached, according to a given rule. In the pre-switch phase, children sort test cards by one rule (e.g., colour) for eight trials; in the post-switch phase, children sort test cards by a new rule (e.g., shape) for eight trials.

3.3.1. *Response conflict on preschool cognitive flexibility tasks*

One notable feature of all preschool CF paradigms is that children have to resolve response conflict when the rule changes. Response conflict arises on a task when a stimulus possesses properties that prompt both possible rules on a given task; in other words, it arises when it is possible to match a stimulus both by a new rule, and by the initial sorting rule. In this situation, both perceptual aspects of the stimulus (e.g. colour and shape) are relevant according to one of the two possible rules on the task. When this response conflict is reduced or removed, even 3-year-olds can succeed on the task. Several manipulations designed to reduce response conflict have been reported, all of which lead 3-year-olds to successfully switch rules. Manipulations have included: replacing the target cards with puppets who have a ‘preference’ for a dimension (Perner & Lang, 2005); separating the dimensions on the test cards (e.g., the colour becomes the background and therefore not part of a single stimulus) (Kloo & Perner, 2005); labelling the test card by the relevant dimension before it is sorted (Kirkham, Cruess & Diamond, 2003); and depicting only one dimension on the test cards (e.g, the outline of a shape) (Rennie, Bull & Diamond, 2004). These studies have led to a consensus that perseveration is caused by 3-year-olds’ difficulty in resolving the response conflict that arises during the post-switch phase.

3.3.2. *Do children only err by perseverating on cognitive flexibility tasks?*

Although the DCCS has advanced our understanding of preschool CF, one main methodological concern with the task is that is only tells us about one type of CF. The DCCS only tells us about how children resolve response conflict and therefore, how children overcome perseveration. However, errors may arise for other reasons. Children may make errors of distraction, or through a temporary failure to maintain the rule. In support of this, when switching tasks are used that allow for errors of distraction, children can and do make other types of error (Chevalier & Blaye, 2008). In this study, preschoolers had to match stimuli according to a given rule and could err by selecting the previously relevant dimension (thus making a perseverative error) or they could err by selecting a never relevant dimension (thus making a distraction error). Interestingly on this task, 3-year-olds made as many distraction errors as perseverative errors. However, using the DCCS, it is impossible to distinguish between different types of error that children can make. When the rule changes on the DCCS, only two response options are available to children: either they sort correctly or they continue to sort by the no longer relevant rule. This means that we cannot tell if children only make perseverative errors, since that is the only type of error children can make on the task (Cragg & Chevalier, 2009). This has led to a widespread assumption that the development of CF in preschoolers is complete when children overcome perseveration.

When researchers have used CF tasks that can assess different types of error, preschoolers show a more varied pattern of responding than is typically seen with the DCCS task. For example, on the Flexible Induction of Meaning (FIM) task (Deák, 2003; Deák & Wiseheart, 2015), children have to infer the meaning of novel words by attending to different novel properties of objects that do not have a common referent. In the FIM task, children are presented with five objects. One is the target object that matches three objects on either shape, material or because it has an identical part attached to the object. The fourth object is a distractor that does not match the target object on any property. Children are asked to find the matching object based on a predicate cue given by the experimenter. Specifically, the experimenter asks: “can you find the other object that looks like/is made of/has a…” Each one of these cues refers to shape, material or the affixed part respectively. Children complete several trials with different objects. The task requires CF, as children have to switch between attending to different properties of an object. Around 20-30% of children perseverated on this task. Notably 16% of children were what Deák described as ‘indiscriminate’ – in other words these children responded randomly, and did not respond systematically by perseverating or switching. These children were the younger preschoolers in the sample of children tested. A small group of children also made errors by selecting the non-relevant distractor that did not match the target object on any feature. This research shows that when tasks are used that can detect different types of error, clearly children show a more varied pattern of responding consistent with the idea that perseveration is not the only alternative to flexible behaviour.

Because of the widespread assumption that preschoolers can only perseverate or switch on CF tasks, this has meant that researchers have often *only* categorised performance in a binary way (children are ‘switchers’ or ‘perseverators’) (e.g., Rennie *et al*., 2004). However, when statistical modelling techniques are used that are able to examine how performance varies across the post-switch phase, a much more diverse profile of children’s performance has emerged in five and six-year-olds, raising the possibility that this is also the case in preschoolers (Dauvier, Chevalier & Blaye, 2012). In this study, Dauvier and colleagues used finite-mixture general linear models to test how many different performance types there were across the post-switch phase. They found that in addition to switchers and perseverators, many children could be classed as mixed responders (children who neither switch nor perseverate) or children who systematically change half way through from perseverating to switching. Together this research suggests that perseveration is not the only way that children can fail at switching, and that a full explanation of CF development would need to take this into account.

*3.3.3. The SwIFT: A measure of cognitive flexibility for 2- to 4-year-olds*

As discussed, very little research has assessed CF in 2-year-olds and to date, no research has compared 2-year-olds on the same CF task that can also be used with 3- and 4-year-olds. The DCCS cannot be used with 2-year-olds because it uses relatively complex verbal instructions, and requires two distinct cognitive skills: the ability to selectively attend to a single aspect of a bi-dimensional stimulus (e.g. focusing on only the shape of a red triangle), and the ability to update the current sorting rule after a rule-switch (e.g. overwriting the old rule of “sort objects by shape” with the new rule of “sort objects by colour”; Hanania & Smith, 2010). This suggests that 2-year-olds may be unable to sort complex stimuli correctly in the pre-switch phase. This means that any early competencies in CF in younger children may have been missed due to task demands.

The Switching, Inhibition and Flexibility task (SwIFT) has recently been developed as a task to measure CF in 2-year-olds, as well as 3- and 4-year-olds (Carroll, Cragg, Blakey, Onetiu & Weyh, in prep). The SwIFT is a rule-switching task in which children must decide which of two colourful shapes matches a prompt image on the relevant dimension for that trial (either colour or shape, with the rule changing half-way through the task). The SwIFT is administered on a touchscreen computer, so that responses are simple for even very young children. It also has a staggered pre-switch phase where stimuli gradually increase in complexity: from simple univalent stimuli (e.g., the outline of a shape) to more complex bi-dimensional stimuli. Verbal demands on the task are simple (using the prompt “Touch the one that’s the same [colour/shape]”) making it easy for young preschoolers to understand. On the task, children first see a prompt stimulus at the top of the screen, shortly followed by two stimuli that appear beneath it (the target stimulus, which matches the prompt on the current rule, and a distractor stimulus which does not match the prompt on the current rule). By manipulating the type of information in the distractor stimulus, it is possible to study either perseverative errors (i.e., cases where children may select the distractor when it matches on the no longer relevant dimension) or distraction errors (i.e., cases where children select the distractor when it does not match the prompt on the current rule or the no-longer-relevant rule).

*3.4. The development of cognitive flexibility in four- to six-year-olds*

By age 4, children’s performance on CF tasks that involve a single switch reaches ceiling. Therefore, to measure CF in 4- to 6-year-olds, researchers use paradigms that involve multiple switches back and forth between tasks – a skill known as set-shifting. Two additional aspects of CF paradigms for this age group become more complex, specifically the type of dimension that children need to attend to and categorise by, and the transparency of the rule that children need to sort by. In terms of the dimension that children need to sort by, this has included: size, number of items, and location on the screen (e.g., up or down) (e.g. Jacques & Zelazo, 2001; Huizinga, Dolan & van der Molen, 2006). In terms of rule transparency, this differs from preschool paradigms where children are explicitly given the rule to requiring children to identify matching stimuli themselves. For example on the Flexible Item Selection Task (FIST), children are first told to select stimuli that go together, and then told to select stimuli that go together ‘in a different way’ (Jacques & Zelazo, 2001). In addition, reaction time (RT) can be examined as well as children’s accuracy. This is because whereas preschoolers tend to respond quickly and inaccurately when a switch in required, 4- to 6-year-olds begin to respond more like adults: they respond accurately, but more slowly when a switch is required (e.g. Diamond & Kirkham, 2005).

Between 4 and 6 years of age, developments in CF are thought to be primarily driven by children’s goal setting ability: their ability to process task cues and translate them into verbal rules. Goal setting is a requirement on the Advanced DCCS for 4- to 6-year-olds (Hongwanishkul *et al*., 2005). In this task, children first complete a pre-switch and a post-switch phase exactly like the standard DCCS (in this version referred to as ‘simple blocks’). Children then complete a mixed block where they must switch back and forth between sorting bi-dimensional stimuli by shape and colour on the basis of an arbitrary visual cue (e.g., a thick border around the test cards means that the sorting rule is shape, whereas a thin border around the test cards means that the sorting rule is colour). Around half of five-year-olds fail to consistently switch on the mixed block of this task. Part of children’s difficulty is thought to be related to translating the task cue into a meaningful verbal rule. In contrast to the standard DCCS for preschoolers, in which the task rule is explicitly verbally given, on the advanced DCCS children are simply presented with a visual cue (e.g., a black border around the test card) that is associated with a particular rule (e.g., shape). In support of this, when transparent tasks cues are given on the test cards (such as a colour patch for the colour rule and the outline of a shape for the shape rule) five and six-year-olds are able to switch tasks (Chevalier & Blaye, 2009).

From age 5, CF developments are also thought reflect quantitative improvements in executive functions. When children reach the age of 6, CF can also be measured by examining changes in RT on CF tasks. Two dependent variables are often calculated: switch costs and mixing costs. Switch costs are calculated as the difference in mean RT between switch trials (for example, switching from sorting stimuli by colour to sorting stimuli by shape) and non-switch trials (for example, sorting by colour, and sorting by colour again). Both older children and adults’ performance is slower and less accurate when they switch to sorting stimuli by a new rule, compared to when they repeat the same sorting rule (e.g. Cepeda, Kramer, Gonzalez de Sather, 2001; Kray, Eber & Lindenburger, 2004; Cragg & Nation, 2009). Mixing costs are calculated as the difference in RT between non-switch trials in mixed block trials where participants perform two different tasks, compared to simple block trials where just one task is performed. Mixing costs capture the difficulty that both children and adults have in maintaining two tasks as opposed to one (e.g., Chevalier *et al*., 2012). The two different dependent variables are thought to reflect different underlying cognitive processes: switch costs reflect the demand of having to inhibit the previous task, and re-activate the new task; and mixing costs are thought to reflect the demand of having two tasks active in working memory (e.g. Chevalier *et al*., 2012). Both switch costs and mixing costs significantly reduce between 5 and 11 years of age (Cragg & Nation; Huizinga *et al*., 2006; Kray *et al*., 2004). This is thought to be driven by improvements in working memory which aid the ability to translate tasks cues and maintain the rule; and inhibitory control which help reduce both response-based and perceptual-based interference from the previous task (Cragg & Nation, 2009).

There is some evidence that the improvements in CF from age 5 onwards also reflect a qualitative shift in the use of strategies (Chevalier, Huber, Wiebe & Espy, 2013). In this study, participants were either given just task cues for the current rule (e.g., if the stimuli are wearing a hat the rule is colour) on a CF task or both task cues *and* auditory transition cues (e.g., participants heard the word “different” to indicate a switch in rule is required and the word “same” if the same rule was to be followed). The extra transition cues were helpful for 5-year-olds, resulting in greater accuracy. In contrast, the extra transition cues were detrimental to 10-year-olds performance and adults’ performance both in terms of lower accuracy and increased RT. The authors argue that this reflects a qualitative shift in children’s switch detection strategies. They propose that whereas children process task cues semantically (e.g., they see a particular cue and then use the cue to create a verbal label e.g., colour) adults process task cues using a perceptual mismatch strategy. Specifically, adults determine the current rule based on what the stimuli look like (e.g., whether the stimuli are wearing a hat or not). This quick and efficient strategy used by adults is slowed down and interfered with by having to process extra transition cues.

Between 5 and 8 years of age, there is also thought to be a significant shift in children’s ability to prepare in advance for when to engage top-down control. Chatham, Frank and Munakata (2009) discuss this in terms of a shift from reactive to proactive control. Proactive control is the ability to prepare in advance for events that are likely to occur, whereas reactive control is when control is engaged in the moment when it is needed. Using pupil dilation as an index of mental effort, the researchers compared 3-year-olds’ and 8-year-olds’ mental effort on a task requiring them to press a button only after a particular prime-probe combination (e.g., respond to X only when it appears after A). By studying pupil dilation on the appearance of both A and X letters this informs us about the extent to which children engage reactive and proactive control. Specifically, a large pupil dilation on the appearance of the letter A – and thus greater mental effort – would reflect advance preparation to engage a response given that A usually precedes the target X. The 3-year-olds only showed mental effort on the appearance of the target (the letter X), suggesting a more reactive form of control. In contrast, the 8-year-olds showed mental effort on the appearance of the prime (i.e., the letter A) demonstrating an advanced mental effort. Chatham and colleagues argue that before age 5, children primarily rely on reactive control. The shift from reactive to proactive control is thought to be driven by improvements in working memory which allow children to maintain information in mind over longer periods which supports task preparation.

1. **Theoretical accounts of the development of Cognitive Flexibility**

Two influential accounts have been proposed to explain how CF develops in childhood: the Attentional Inertia account and the Graded Representations account. These two accounts argue that a single executive function – inhibitory control or working memory, respectively – drives the developments in CF during the preschool years. These accounts originally sought to explain preschoolers’ performance on the DCCS task.

*4.1. The Attentional Inertia account*

The Attentional Inertia account proposes a central role for inhibitory control in the development of CF (e.g. Diamond, Carlson & Beck, 2005; Diamond & Kirkham, 2005; Kirkham *et al*., 2003; Rennie *et al*., 2004). This account argues that CF development between the ages of 3 and 4 years is driven by improvements in inhibitory control which allow children to redirect their attention to the new dimension when the rule changes. Therefore, when 3-year-olds perseverate, this is because they fail to inhibit their attention away from the pre-switch dimension. Repeatedly sorting cards in one way during the pre-switch phase is thought to lead children to solely focus on only that dimension. Therefore, when the rule changes, the pre-potent response will be for children to attend to the no longer relevant dimension. The account proposes that before children see the target cards in the DCCS, they are ready to respond correctly because they have been given the new rule by the experimenter. However, upon seeing the test cards, because the no longer relevant dimension is present means that children’s attention is directed towards that dimension. Children who have better inhibitory control are better able to overcome this pre-potency to instead focus on the new dimension.

This account offers a plausible explanatory framework for a range of findings. In particular, there is a lot of evidence that manipulations that aim to decrease the saliency of the pre-switch dimension and increase the saliency of the post-switch dimension lead 3-year-olds to switch rules. For example, labelling the value of the relevant dimension on the test cards leads more 3-year-olds to sort correctly in the post-switch phase of the DCCS. This is thought to help children to re-direct their attention to the current dimension (Kirkham *et al*., 2003). Similarly, manipulations that highlight the pre-switch dimension have been found to increase perseveration. For example, when children are instructed to sort the test cards face up during the pre-switch phase, this leads to more errors during the post-switch phase. This is because this way of sorting the test cards encourages attention to be more focused on the pre-switch dimension and this is then harder to pull away from (Kirkham *et al*., 2003). However, when researchers have tested the account in explaining perseveration on other tasks – like the FIM – researchers have found little evidence that it can explain perseverative errors. For example, Deák and Narasimham (2003) introduced a delay between blocks where children had to switch their attention to a new stimulus. Delays are thought to reduce inhibitory control demands on executive functions tasks by allowing time for prepotent responses to dissipate (e.g., Simpson *et al*., 2012). However, the delay had no effect on reducing rates of perseveration. It is noteworthy that perseverative errors have been observed in children up to a month following the initial pre-switch phase on the DCCS (Garcia & Dick, 2013) suggesting that the Attentional Inertia account may not be able to fully explain perseveration.

*4.2. The Graded Representations account*

The Graded Representations account proposes a central role for working memory in the development of CF (Munakata, 2001; Blackwell, Cepeda & Munakata, 2009; Cepeda & Munakata, 2007; Marcovitch, Boseovski, Knapp & Kane, 2010; Morton & Munakata, 2002; Towse, Lewis & Knowles, 2007; Yerys & Munakata, 2006). Working memory is thought to support CF because of its role in maintaining task goals (or rules). Goal maintenance is critical to success on CF tasks. In order to behave flexibly, the task rule must first be updated, so that the no-longer-relevant rule is replaced with the currently relevant rule. This new rule must then be maintained over the course of the post-switch phase. The current task rule must be kept in an active, easily accessible state in the face of interference from previous, no-longer-relevant rules. The ability to maintain information in the face of interference is one of the primary functions of working memory (Engle, 2002; Kane, Bleckley, Conway & Engle, 2001). The Graded Representations account argues that working memory is crucial when a rule changes, because it allows children to maintain this rule in the face of competition from the previous rule (e.g., Munakata, 2001). More specifically, according to this account, CF arises when the new rule guiding behaviour is maintained more strongly than the no longer relevant rule. To explain this, the researchers describe memory representations are being latent or active. Latent representations are longer lasting memories held primarily in long-term memory; active representations are the primary focus of attention in short-term memory (Brace, Morton & Munakata, 2006; Kharitonova & Munakata, 2011). On CF tasks, following a rule change, the pre-switch rule persists as a latent memory, even though it is no longer relevant. The new sorting rule is present as an active memory – though because it has been used much less than the previously relevant rule, it may be represented less strongly than the latent memory of the pre-switch rule. Therefore, to be flexible, the active memory for the new rule needs to be stronger than the latent memory in order to override the old rule and allow flexible behaviour. The account argues that 3-year-olds perseverate on measures of CF because they do not have a strong enough working memory to hold the new rule in an active state, and therefore the latent memory for the previous rule guides behaviour instead.

Support for the Graded Representations account comes from research showing that when task manipulations aim to decrease the strength of the pre-switch rule in working memory, children are more likely to switch rules. For example, in one study, the experimenter gave each child a test card on the DCCS and referred to it using an uninformative label that did not refer to a dimension (e.g., “these go in this box”) during the pre-switch phase. This manipulation increased switching on the DCCS (Yerys & Munakata, 2006). In the same study, researchers also found that when pre-switch stimuli were used that depicted unfamiliar colours and shapes (e.g., a purple-grey cloud shape) children performed significantly better in the post-switch phase. Yerys and Munakata argued that using (i) an uninformative label and (ii) novel stimuli led to a weaker rule representation in working memory that was therefore easier to switch away from. In support of this account, in a separate study, researchers found that children who were faster at verbally recalling the current rule on a non-switching task where children sorted simple univalent stimuli (e.g., the outline of a shape), could switch better on the DCCS (Blackwell *et al*., 2009; Cepeda & Munakata, 2007). Children’s speed of responding to the rule was more predictive of successful switching than either age or processing speed. The researchers argue that these children have stronger working memories, therefore making the current sorting rule more accessible due to greater top-down support.

One limitation of the Graded Representations account is that is does not clearly specify how working memory supports CF. Given the multi-faceted nature of working memory, greater clarity is needed in specifying what mechanism in working memory supports rule maintenance in its role in flexible behaviour. The account proposes that working memory is the primary mechanism supporting CF, but it defines active and latent representations in terms of their storage in short-term and long-term memory. Short-term memory, long-term memory and working memory are typically considered separable memory systems (Baddeley, 2003; Cowan, 2008; Gathercole & Alloway, 2006; Hornung, Brunner, Reuter & Martin, 2011). Therefore, despite working memory being used as a key term in the Graded Representations account (e.g., Cepeda & Munakata, 2007), it is not clear whether CF can be explained as arising from more basic short-term memory processes or whether working memory is involved because it coordinates short-term memory and long-term memory (e.g., Baddeley, 2003). This is never explicitly discussed in the Graded Representations account. Memory systems could support CF via short-term memory processes that support the maintenance of information over time; via working memory that supports children’s ability to maintain *and* process information or through the successful coordination of short-term and long-term memory storage systems; or via updating – children’s ability to revise information in working memory – which may be important when the rule first changes

1. **Testing between the Graded Representations Account and the Attentional Inertia Account**

Distinguishing between the Attentional Inertia account and the Graded Representations account is difficult using standard CF paradigms, because both accounts make similar predictions for how preschoolers will perform on the DCCS (Yerys & Munakata, 2006). Perseveration in 3-year-olds can be explained either as a failure to inhibit attention to the previous dimension, or as a failure to maintain the new rule in the face of a competing memory of the old rule. Therefore, some researchers have suggested that an individual difference perspective may be needed to pull apart the two theories (Yerys & Munakata, 2006; Cepeda & Munakta, 2007; Chevalier *et al*., 2012).

*5.1 Testing between the two accounts using correlational designs*

There have been very few attempts to use an individual difference approach to explicitly test between the Attentional Inertia account and the Graded Representations account. However, there is some research which has looked at how performance on separate measures of working memory, inhibitory control or both relate to performance on CF paradigms. Marcovitch *et al.* (2010) aimed to test how working memory supports CF in children by experimentally varying how much the CF tasks require children to actively maintain the task goal. Four- and 5-year-olds completed one of two versions of the DCCS. In the Mostly Redundant version, 80% of the test cards matched the target cards exactly. The remaining 20% were standard DCCS conflicting cards which matched one target card on one dimension and the other target card on the other dimension. Because the redundant cards are identical to one of the target cards, and can therefore be sorted without reference to the rule, the researchers argued that the Mostly Redundant version encourages less active rule maintenance. In the Mostly Conflict version, 80% of the test cards were conflict cards and the remaining 20% were redundant cards. Because the rule cannot be determined from the conflict cards, the Mostly Conflict version involves more active rule maintenance. Children also completed a separate measure of working memory. In line with their hypothesis, they found that the Mostly Redundant version led children to make more errors when sorting the conflict cards, because children were less inclined to maintain the rule. They found that for 5-year-olds, working memory was only associated with the Mostly Redundant version, supporting the idea that this version involves more rule maintenance and therefore more working memory. However, for 4-year-olds, they found that working memory was associated with accuracy on both versions. This suggests that for younger children – for whom CF is just beginning to develop – rule maintenance in working memory is an essential part of all CF tasks which involve response conflict.

Research has also examined both working memory and inhibitory control and their contributions to CF in terms of set shifting – making multiple switches back and forth between tasks. Chevalier *et al*. (2012) had 3- to 5-year-olds complete a CF task in which they had to make multiple switches back and forth between two different rules. Their performance was examined in terms of their switch cost and mixing costs. Children with better working memory and inhibitory control had lower mixing costs (i.e., the cost of repeating a rule in a *mixed* block, in comparison to a pure block). The researchers proposed that working memory supports the maintenance of two rules and inhibitory control reduces the interference between them. There was no effect of working memory or inhibitory control on local costs (i.e., the cost of switching rules between trials). Similar results were also found by Brocki and Tillman (2014) in a broader age range and using a different task: the hearts and flowers task. On this task, 5- to 14-year-olds completed three blocks of trials: a congruent block, an incongruent block and then a switch block. In the congruent block, participants responded to the appearance of a heart stimulus by pressing a key congruent with the spatial location of the heart stimulus (e.g., if it appeared on the right of the screen participants pressed a key on the right of the keyboard). In the incongruent block, participants responded to the appearance of a flower stimulus by pressing a key incongruent with the spatial location of the stimulus. Finally, in the mixed block, participants alternate between responding to the congruent side when a heart appears and the incongruent side when a flower appears. The researchers found that children’s working memory was related to accuracy in the incongruent block and was also associated with faster responses during the mixed block suggesting that working memory facilitates rule maintenance under conditions of response conflict. Inhibitory control was associated with slower, but more accurate responses during the mixed block. As Chevalier *et al* (2012) found, both working memory and inhibitory control were most strongly associated with mixing costs, and not switch costs. To date, this individual difference approach has not been used to test between the two accounts of two CF development, or applied to understanding preschoolers’ performance on CF paradigms.

*5.2. Testing between the two accounts using training study designs*

Evidence so far suggests that working memory and inhibitory control may be related to CF by supporting different task demands that arises on CF tasks: working memory appears to be important under conditions where rule maintenance is needed because response conflict is present and inhibitory control appears to be important when there is interference from the no longer relevant rule. However the evidence so far is correlational, making it difficult to ascertain whether working memory and inhibitory control causally underpin CF. One way to test the causal relation between these skills would be to use cognitive training study designs. Cognitive training typically involves children completing tasks tapping working memory or inhibitory control over several sessions. These tasks increase in difficulty as a function of children’s performance on the task, such that if children perform well, the task gets harder. For example, many researchers have focused on working memory training and have given children a battery of working memory tasks that require children to maintain and process information (e.g., Karbach, Strobach & Schubert, 2014). As children’s performance improves over training, the tasks get harder and require children to maintain and process increasing amounts of information. The idea is that by giving children these tasks over several sessions (usually between four and 25 sessions), this will lead to improvements in these skills via improvements in the capacity or efficiency of working memory. A gold-standard training study tests whether training improves performance on different, non-trained tasks that are thought to be related to the training tasks (known as ‘transfer’) compared to an active control group.

Although the precise mechanism by which cognitive training improves performance is unclear (Shipstead, Redick & Engle, 2012), there is evidence that training does lead to improvements on non-trained measures of executive function. Improvements following cognitive training have been found in infants (Wass, Porayska-Pomsta & Johnson, 2011), older preschoolers (Thorell, Lindqvist, Bergman, Bohlin & Klingberg, 2008), and in middle childhood (e.g., Dunning, Holmes & Gathercole, 2013; Karbach *et al*., 2014). Notably, a handful of recent studies have also found transfer of executive function training to academic skills in school-age children (Goldin *et al*., 2014; Sӧderqvist & Bergman Nutley, 2015). This supports previous correlational studies that show executive functions and academic skills are related, and provides evidence that there may be a causal relation between the two. Although there is a paucity of training studies in the preschool years, meta-analyses have suggested that training may be more effective in leading to transfer the younger the participants are (Melby-Lervåg & Hulme, 2013). Supporting this, significant negative correlations have been found between the age of the participants and the transfer observed (Wass, Scerif & Johnson, 2012). This makes preschool executive function training a particularly promising approach for elucidating how working memory and inhibitory control causally contribute to CF. For example, if working memory training improves performance on CF tasks and inhibitory control training does not, it suggests a causal link between working memory and flexibility.

*6. Outstanding Questions*

Overall, the review has highlighted how the preschool period is a crucial time for CF development both due to the rapid developments in CF during this time, and because this is when individual differences in preschool executive functions predict later developmental outcomes. However, there is still a lot we do not know about CF development during this time. Based on this review of the literature, there are three outstanding questions that need to be addressed in order to have a comprehensive understanding of CF development. Firstly, there is a need to study preschoolers’ CF using paradigms that allow for different types of error and using paradigms that can examine CF with different task demands. Most of our understanding of preschool CF has been derived from studying children’s performance (i) on tasks that only allow for perseverative errors, and (ii) on tasks where children have to resolve response conflict when the rule changes. This has led to a widespread consensus in the literature that CF develops when children can resolve response conflict, which in turn has led theoretical accounts to solely focus on explaining how preschool children overcome perseveration. It will be important, therefore, to examine different kinds of errors that preschoolers can make with different task demands, specifically under conditions with and without response conflict.

Second, there is a need to go beyond the focus on 3- to 4-year-olds. There is a notable absence of CF research in 2-year-olds. Because there is such little research with 2-year-olds, it is not clear whether competencies in 2-year-olds have been missed due to a lack of paradigms that can be used with this age group. Therefore, we still do not know whether rule-governed CF does only begin to emerge at age 3 in the form of perseveration and whether the most rapid developments in CF occur between the ages poof 3 and 4 years. By broadening our study of preschool CF to include 2-year-olds, this will help us to have some answers to these questions and will allow us to understand the emergence of CF.

Third and finally, it is important to find ways to test between the two accounts of CF development so that we have a better understanding of how CF develops. Currently, very little research has been successful in directly testing between the two accounts since both accounts make similar predictions for how 3 and 4-year-olds will perform on measures of CF. Two approaches will be helpful in going forward with this: individual difference methods and training study designs. Individual difference designs will inform us how preschoolers’ CF performance on separate measures of working memory and inhibitory control are associated with CF performance. Training study designs will allow us to test causal relations among CF, working memory and inhibitory control.

All three of these outstanding questions will be directly addressed in the following experimental Chapters.

Chapter Two

Different executive functions support different kinds of cognitive flexibility: Evidence from 2-year-olds, 3-year-olds and

4-year-olds

The study reported in this Chapter is based on the published paper: Blakey, E., Visser, I., & Carroll, D. J. (2015). Different executive functions support different kinds of cognitive flexibility: Evidence from two-, three- and four-year-olds. Advance online publication. *Child Development.* This study directly addressed the three outstanding questions presented at the end of the Introduction. First, it examined children’s CF performance under two different conditions: one where children switched rules in the presence of response conflict; and one where children switched rules in the presence of distracting information. Second, it broadened the investigation of preschool CF to include 2-year-olds to learn about its emergence. Third and finally, it tested between the two theories of CF development by including separate measures of working memory and inhibitory control and examining how they were associated with CF under different task demands. One hundred and twenty 2-year-olds, 3-year-olds and 4-year-olds completed the two rule switching tasks. Switching in the presence of response conflict improved rapidly between the ages of 3 and 3.5 years, and was associated with better working memory. Conversely, switching in the presence of distraction developed significantly between the ages of 2 and 3 years, and was associated with better inhibitory control.

**1. Introduction**

CF describes the ability to adapt our thoughts and behaviour in response to changes in our goals or our environment. It is commonly conceptualised as a complex, later-developing ability that is made possible by improvements in inhibitory control and working memory (Chevalier *et al*., 2012; Cragg & Chevalier, 2009; Garon*et al.,* 2008). However, while there is increasing evidence that there are important associations between CF and inhibitory control and working memory, the nature of these associations remains poorly specified.

Developmental studies have been highly informative about CF, particularly when focusing on the preschool years (e.g. Diamond *et al.,* 2005; Müller, Dick, Gela, Overton & Zelazo, 2006). During the preschool period children first demonstrate the ability to guide and to change their actions in line with explicit rules – a fundamental milestone in engaging in systematic goal-directed behaviour. The crucial enabling development of the preschool years has often been characterized as the emergence of the ability to overcome behaviour based on an initial rule, in order to produce behaviour guided by a new rule (e.g., Zelazo, 2006). For example, on a range of preschool CF measures – including the DCCS (Zelazo, 2006) and Shape School (Espy, 1997) – 3-year-olds are able to sort coloured shapes by a single rule (e.g., colour) during the pre-switch phase. However, when the rule changes in the post-switch phase (e.g., to sorting by shape), 3-year-olds are unable to reliably switch to the new rule. In contrast, 4-year-olds are able to sort correctly when the rule changes (Zelazo, 2006). This 3- to 4-year shift – often characterised as a change from perseverative responding to flexible responding – has been presented as a crucial development in early cognition (Munakata *et al.*, 2012).

Explanatory accounts of the emergence of CF have tended to exclusively focus either on increases in inhibitory control, or on increases in working memory. All accounts have sought to explain why 3-year-olds perseverate on measures of CF and 4-year-olds do not. For example, the Attentional Inertia account (Diamond *et al*., 2005; Kirkham & Diamond, 2005) explains 3-year-olds’ failure to switch rules as arising from poor inhibitory control. This account argues that following a rule change, 3-year-olds are unable to inhibit their attention to the no-longer relevant dimension. In contrast, working memory accounts explain the same difficulty as arising from immature working memory. For example, the Graded Representations account explains 3-year-olds’ failure to switch rules as arising from an inability to maintain the current rule in the face of competition from the previously relevant rule (Kharitonova & Munakata, 2011; Munakata, 2001). This account argues that because children fail to maintain the current rule strongly in their working memory, the previous, no-longer relevant rule is selected instead as the basis for behaviour.

There are, therefore, two plausible but fundamentally different explanations offered to explain CF during the preschool period. Distinguishing between the two accounts is difficult, since both working memory and inhibitory control accounts make similar predictions for how 3- and 4-year-old children will perform on most current measures of CF. Nor is the focus on perseverative errors particularly helpful. Perseveration can be explained either as children failing to inhibit their attention to the previously relevant dimension, or as children failing to maintain in working memory the new task rule. Resolving the impasse between these different accounts is a primary concern for CF research, and indeed continues to be a question of great importance in the current literature (e.g., Chevalier *et al.,* 2012; Dick, 2014; Ionescu, 2012). However, research using existing paradigms has been unable to make much progress in this regard. It is this issue that the present paper addresses. We now set out three specific steps that will allow us to better understand the emergence of CF.

First, it is essential to be more precise about what is meant by “CF”. Within the preschool literature, CF is typically operationalized as the ability to sort a series of stimuli first by one rule, and then by another. However, alongside this basic demand, many paradigms also include the additional requirement for children to resolve within-stimulus conflict. Response conflict arises when a stimulus possesses properties that prompt both possible rules on a given task; in other words, when it is possible to match a stimulus both by a new rule, and by the initial sorting rule. In this situation, both perceptual aspects of the stimulus (e.g. colour and shape) are relevant according to one of the two possible rules on the task (see Figure 2 for an illustration). Most CF tasks therefore – whether deliberately or inadvertently – make *two* demands of children: they must change their sorting behaviour from using one rule to using another rule, and they must resolve the within-stimulus conflict between the previous dimension and the new dimension. These tasks might inadvertently create the impression that resolving conflict is the only way to learn about the development of CF. However, even in the absence of response conflict, switching rules is far from a trivial demand for young children (Brooks *et al.,* 2003; Chevalier & Blaye, 2008). Keeping these distinct task demands separate is essential if we are to fully understand the developmental trajectory of CF. As such, in the current study we separate these two demands by examining children’s ability to switch rules in the presence of (i) *conflicting* information and (ii) *distracting* information.

Figure 2: The SwIFT

**The pre-switch phase of the SwIFT**: “Touch the one that’s the same colour”

Univalent Stimuli:

The stimuli only contain information

relevant to the current rule.



Distracting Stimuli:

The stimuli contain colour and shape

information, but the wrong answer does

not match the prompt on the non-relevant

dimension (shape).

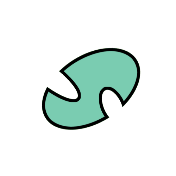
Conflicting Stimuli:

The stimuli contain colour and shape

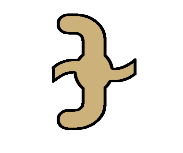
information, and the wrong answer

matches the prompt on the non-relevant

dimension (shape).

**The Post-switch phase:** “Touch the one that’s the same shape”





Conflicting SwIFT: The distractor matches Distracting SwIFT: The distractor the prompt on the previously relevant dimension does not match the prompt on the

relevant dimension. previously relevant dimension, but

contains potentially distracting

irrelevant information.

A further advantage of this dichotomy is that it allows us to distinguish between two distinct kinds of CF errors that would otherwise be conflated: perseverative errors, where children inappropriately persist with a previous rule, and distraction errors, where children fail to maintain their current sorting rule. Although standard measures of CF do not allow these types of error to be measured independently, there is clear evidence to suggest that this distinction is a crucial one. For example, Chevalier and Blaye (2008) assessed switching in preschoolers using the PAST-3, a paradigm requiring an intra-dimensional switch (e.g. from sorting blue pictures to yellow pictures). The task allowed perseverative errors and distraction errors to be distinguished. They found that in 3-year-olds, distraction errors were as common as perseverative errors. This remains a promising yet under-used approach to further understanding CF.

Second, it is important to study development prior to the 3- to 4-year period. Examining switching in 2-year-olds is likely to be particularly informative, since the relative paucity of research with this age group means that little is known about the early emergence of CF. Two-year-olds have been tested on very simple measures of inhibitory control (Carlson *et al.,* 2004) and working memory (Hughes & Ensor, 2007). However, most CF paradigms are too complex to use with children younger than 3 years. A paradigm with reduced incidental demands that would allow the study of CF from an earlier age would be particularly useful.

Third, looking at individual differences in inhibitory control and working memory will allow us to better understand their role in the development of CF. While previous attempts to use this approach have been limited in number, they have nevertheless been extremely promising. For example, Marcovitch *et al*. (2010) examined how preschoolers’ performance on a battery of working memory tasks predicted their ability to switch rules. They found that 4-year-olds with better working memory were better able to switch rules than children with poorer working memory. Chevalier *et al*. (2012) examined the separate contributions of both working memory and inhibitory control to local costs and mixing costs on the Shape School. Three- to 5-year-olds completed a mixed block of trials, requiring them to make multiple switches between two rules. Children with better working memory and inhibitory control had lower mixing costs (i.e., the cost of repeating a rule in a *mixed* block, rather than a pure block). There was no effect of working memory or inhibitory control on local costs (i.e., the cost of switching rules between trials). To our knowledge, these are the only studies to have taken an individual differences approach to examine the development of CF, so a further extension of this approach is likely to be informative.

The current study combined all three of these approaches to examine how individual differences in working memory and inhibitory control relate to different kinds of CF in 2- to 4-year-olds. Children were tested on separate measures of working memory and inhibitory control, as well as on two variants of a CF task. To examine CF, the Switching, Inhibition and Flexibility task, or SwIFT was used (Carroll *et al.,* in prep). This is a simple rule-switching task in which children must decide which of two colourful shapes matches a prompt image on the relevant dimension for that trial (either colour or shape, with the rule changing half-way through the task). The SwIFT is administered on a touchscreen computer, so that responses are simple for even very young children. To ensure that the task was appropriate for 2-year-old children, it included a staggered pre-switch phase where stimuli gradually increased in complexity: from simple univalent stimuli, to distracting stimuli, to conflicting stimuli (see Figure 1). The SwIFT has simple verbal demands (using the prompt “Touch the one that’s the same [colour/shape]”). In addition, in order to be able to identify subtle developmental changes, our age-related analyses used six-month age bands (c.f. Gerstadt, Hong & Diamond, 1994), to examine 2.5-year-olds, 3-year-olds, 3.5-year-olds, and 4-year-olds.

In order to study both the ability to switch rules in the presence of conflicting information and the ability to switch rules in the presence of distracting information, two different variants of the SwIFT task were used, differing only in the stimuli used. We systematically varied the type of stimuli children sorted in the post-switch phase to examine the development of switching (i) in the presence of response conflict (the Conflicting SwIFT) and (ii) in the presence of distracting information (the Distracting SwIFT; shown in Figure 1). In the Conflicting SwIFT, children had to switch rules while sorting stimuli with response conflict. In the post-switch phase of this task – as in tasks such as the Shape School or DCCS – it was possible for children to continue to sort by the previous, no-longer relevant dimension (in other words, it was possible for them to perseverate). In contrast, in the Distracting SwIFT, children had to switch rules while sorting stimuli with distracting, task-irrelevant information. In this version, children must still update their sorting behaviour. However, they cannot continue to match by the previously relevant dimension, since no post-switch stimuli match on that dimension. In other words, it was not possible for children to perseverate. Any errors children make in the post-switch phase of this condition reflect distraction errors. In addition, while it is often informative to categorise children based on their performance because there are often clearly homogenous groups (such as switchers and perseverators), it is important to confirm such potentially arbitrary categories using statistical techniques. Therefore, in the current study, latent Markov models were fitted to the data; this allowed us to discriminate between different types of errors that vary as a function of task and children’s age (Visser, 2011).

**2. Method**

*Participants*

One hundred and twenty children took part in the study (58 males and 62 females). Data from a further seven children were excluded: one child was later diagnosed with Specific Language Impairment, three failed to understand the task instructions, and three did not complete a full set of test trials. The remaining sample was split into four age groups: 26 2.5-year-olds (*M* age: 2 years 8 months; range: 2 years 4 months – 2 years 11 months), 42 3-year-olds (*M* age: 3 years 3 months; range: 3 years – 3 years 6 months), 21 3.5-year-olds (*M* age: 3 years 9 months; range: 3 years 7 months – 3 years 11 months), and 31 4-year-olds (*M* age: 4 years 3 months, range: 4 years – 4 years 6 months). Children were recruited either from a database of local families who had expressed an interest in participating in research, or from local nursery schools. All children were monolingual, were from homes or schools in working-class and middle-class areas of the UK and were predominantly white British. Participating families received a small gift as a token of appreciation for taking part. Informed consent was obtained from parents before testing began. Ethical approval was obtained from the department’s ethics sub-committee (see Appendix 1).

*Procedure*

Children were tested in a single session, either in the University Developmental Lab with their caregiver present, or in a quiet area of their nursery. Children first played a short warm-up game, which also served to make sure that they understood the words ‘colour’, ‘shape’, and ‘same’. They then completed four tasks in a fixed order: one variant of the SwIFT, the inhibitory control task, the working memory task, and finally the second variant of the SwIFT. To minimise the chance of data loss on the most developmentally appropriate switching task, the version of the SwIFT that children completed first differed according to age: 2.5-year-olds and 3-year-olds completed the Distracting SwIFT first, whereas 3.5-year-olds 4-year-olds completed the Conflicting SwIFT first. In addition, since there is no single age-appropriate inhibitory control task that can be used from 2 to 4 years of age, younger and older children completed different measures of inhibitory control.

*Assessing Cognitive Flexibility*

*The SwIFT:* This was a rule-switching task presented on a touchscreen computer, in which children had to decide which of two colourful shapes matched a prompt image on the relevant dimension for that trial (either colour or shape). The task was presented on an Iiyama ProLite touchscreen connected to a standard PC running E-Prime software (PST, Pittsburgh, PA). The task first began with three practice trials, followed by a pre-switch phase of 12 trials using one matching rule, and finally a post-switch phase of 8 trials using a different matching rule.

Each trial began with a prompt stimulus appearing at the top of the screen. After a delay of 1000ms, two response stimuli appeared in the lower corners of the screen. One stimulus was the target (the correct response, as it matched the prompt on the currently relevant dimension), and the other was a distractor (the incorrect response). The distractor and target were equally likely to appear on the left or right. Children were prompted to respond with the recorded instruction “Touch the one that’s the same [colour / shape]”. Children responded by touching their chosen image. When children selected the correct response, a musical cartoon animation appeared in place of the stimulus selected. When children selected the incorrect response, the display disappeared, no animation was played, and the next trial began. If the child did not make a response, the experimenter repeated the prompt. Rule order was fully counterbalanced. Two different versions of the SwIFT were used, differing only in the type of stimuli children sorted by in the post-switch phase.

*Conflicting SwIFT:* In this variant of the SwIFT, the post-switch stimuli had response conflict: the incorrect response option matched the prompt image on the no-longer-relevant dimension (and would thus appear to be the correct response if children failed to select the appropriate sorting rule).

*Distracting SwIFT:* In this variant of the SwIFT, the post-switch stimuli did not have response conflict, since the incorrect response option did not match the prompt image on the no-longer-relevant dimension. Instead, the distractor stimuli contained distracting, task-irrelevant shape or colour information.

*Assessing Inhibitory Control*

*Reverse Categorisation task*: 2.5-year-olds and 3-year-olds completed the Reverse Categorisation task, a measure of inhibitory control appropriate for younger preschoolers (Carlson *et al*.,2004). The task used two boxes (one yellow and one blue) and 12 cubes (6 yellow and 6 blue). In the introductory phase, children were told to place cubes into the box of the same colour. In the testing phase, children were told to place the cubes into the box of the other colour. A rule reminder was provided on every trial. The dependent variable was the number of cubes correctly sorted in the testing phase of the task.

*Day/Night Stroop task*: 3.5-year-olds and 4-year-olds completed the Day/Night Stroop task, a measure of inhibitory control in older preschoolers (Simpson & Riggs, 2005). The task used a pair of picture cards, one depicting a book and the other depicting a car. The experimenter explained that when she said “book”, children should point to the car picture, and when she said “car”, they should point to the book picture. Children then completed four practice trials, with feedback. The testing phase had twelve trials, without feedback, where “book” and “car” were said aloud in a fixed order with no more than three consecutive repetitions of one of the words. The dependent variable was the number of correct responses.

*Assessing Working Memory*

*The Spin the Pots task*: All children completed the Spin the Pots task (Hughes & Ensor, 2007). Eight visually distinct pots with lids were arranged on a rotating tray. Children watched the experimenter put colourful stickers in six of the pots, and the two empty pots were pointed out before testing began. Each search trial began with the experimenter covering the tray with a cloth and then rotating the tray for a few seconds. If the children found a sticker in the pot they selected, they kept it. After each search attempt, the tray was again covered and rotated, and a new search trial began. The task ended either once children had found all six stickers, or after 16 trials. The dependent variable was reverse coded for ease of interpretation and so calculated as 16 minus the total number of trials taken.

**3. Results**

*Preliminary analyses:* A series of one-way ANOVAs found no significant effect of gender on working memory; on inhibitory control; or on CF (all *ps* > . 05). A two-way ANOVA found no significant effect of rule order on accuracy on either SwIFT variant, and no interaction (all *ps* > .05). One-sample t-tests conducted separately for each age group found that all age groups sorted at above-chance levels in the pre-switch phase of the SwIFT (all *ps* < .001), and thus could perform well on the basic task. To look first at how SwIFT accuracy varied by age, one-way ANOVAs were conducted to examine the effect of age group on overall accuracy on each SwIFT task. There was no significant effect of age group on Conflicting SwIFT accuracy (*F* (3,111) = 1.93, *p* > .10; see below for why this may be the case). There was a significant effect of age group on Distracting SwIFT accuracy *F*(3,114) = 13.65, *p* < .001). Bonferroni *post-hoc* tests found that this was due to improvements in the ability to switch in the presence of distracting information between the ages of 2.5 years (*M* = 5.31, *SD* = 1.64) and 3 years (*M* = 6.36, *SD* = 1.59), *p* = .02.

*Identifying SwIFT Performance types using Latent Markov Models:* Prior research with preschool switching tasks has identified large individual differences that are categorical in nature (e.g., Dauvier*,* Chevalier & Blaye, 2012; van Bers, Visser, van Schijndel, Mandell & Raijmakers, 2011). For example, children may respond either by switching correctly; by perseverating with the initial rule; or by fluctuating between the two rules. It is difficult to measure these differences using techniques such as ANOVA that depend on measuring central tendency. To illustrate: if half the children in a sample perseverated, and half switched successfully, the overall sample mean of four out of eight might appear to indicate that the entire sample was performing at chance. The systematic, within-group difference in performance would be lost. Hence, in order to better identify individual differences in children’s post-switch performance, latent Markov models were used (Visser, 2011). Latent Markov models were used to analyse the trial-by-trial sequences of children’s performance during the post-switch phase using the depmixS4 package (Visser & Speekenbrink, 2010), an add-on package for the statistical analysis software R (R Core Team, 2014). A similar approach to van Bers *et al*., (2011) and van Bers, Visser and Raijmakers (2014) was followed in order to identify discrete categories of performance type during the post-switch phase (referred to in the model as ‘strategies’). The word strategy is used here solely in the sense that children perform consistently across a number of trials (see Rickard, 2004). In addition, latent Markov models can also identify any transitions between these strategies over the course of the post-switch phase.

To differentiate between the different types of errors that children made in the Conflicting SwIFT and the Distracting SwIFT, latent Markov models were used to model trial-by-trial accuracy in the post-switch phase of each task. Latent Markov models with 1-4 states were fitted on the Conflicting and Distracting SwIFT data separately. The first step was to determine the optimal number of states of the latent Markov models. Models with a larger number of states are better at capturing the data (as evidenced by a higher log-likelihood), but at the cost of adding more parameters. Model selection statistics such as the Akaike's Information Criterion (AIC; Akaike, 1973) and the Bayesian Information Criterion (BIC; Schwarz, 1978) are used to find the right balance between better capturing the data while retaining a parsimonious model. Here, the small sample corrected version of the BIC was used (Nylund*,* Asparouhov & Muthen,2007; Sclove, 1987). As our main interest was to determine whether different participants used different initial strategies, models were also tested in which the initial probability of starting in one particular strategy depended upon the age of the participants.

*Model-based analyses: Conflicting SwIFT*

The modelling analyses revealed that for the Conflicting SwIFT, the ‘3-state+age’ model had the best (i.e. lowest) BIC value and hence we proceeded with interpretation of that model. Table 1 shows the goodness-of-fit statistics of the fitted latent Markov models with 1-4 states.

Table 1: Goodness-of-fit statistics for the latent Markov models of the Conflicting Switching Inhibition and Flexibility task (SwIFT).

Model LL npar AIC BIC BICw

1 state -619.57 1 1241.15 1242.80 .00

Regression (Age) -608.44 2 1220.80 1224.19 .00

2-state -517.68 5 1045.36 1053.60 .00

2-state+age -515.55 6 1043.10 1052.99 .00

3-state -508.17 9 1034.34 1049.18 .00

3-state+age -500.85 9 1019.70 1034.54 .94

4-state -505.51 10 1031.02 1047.51 .00

4-state+age -494.62 14 1017.24 1040.32 .05

Note: npar denotes the number of parameters; it is corrected for parameters estimated at their boundary values (0 or 1); the small sample version of the BIC is reported here, and finally BICw denotes the BIC weights.

Table 2: Parameter estimates of each model in the Conflicting Switching Inhibition and Flexibility task (SwIFT) demonstrating the transition matrix values (i.e. the probability of transitioning from one strategy to another during the post-switch phase).

Model Switchers Mixed Responders Perseverators

Switchers (.93) 1.0 .00 .00

Mixed Responders (.52) .00 .98 .03

Perseverators (.07) .09 .00 .91

Note: Initial state probabilities of switching are given in parentheses.

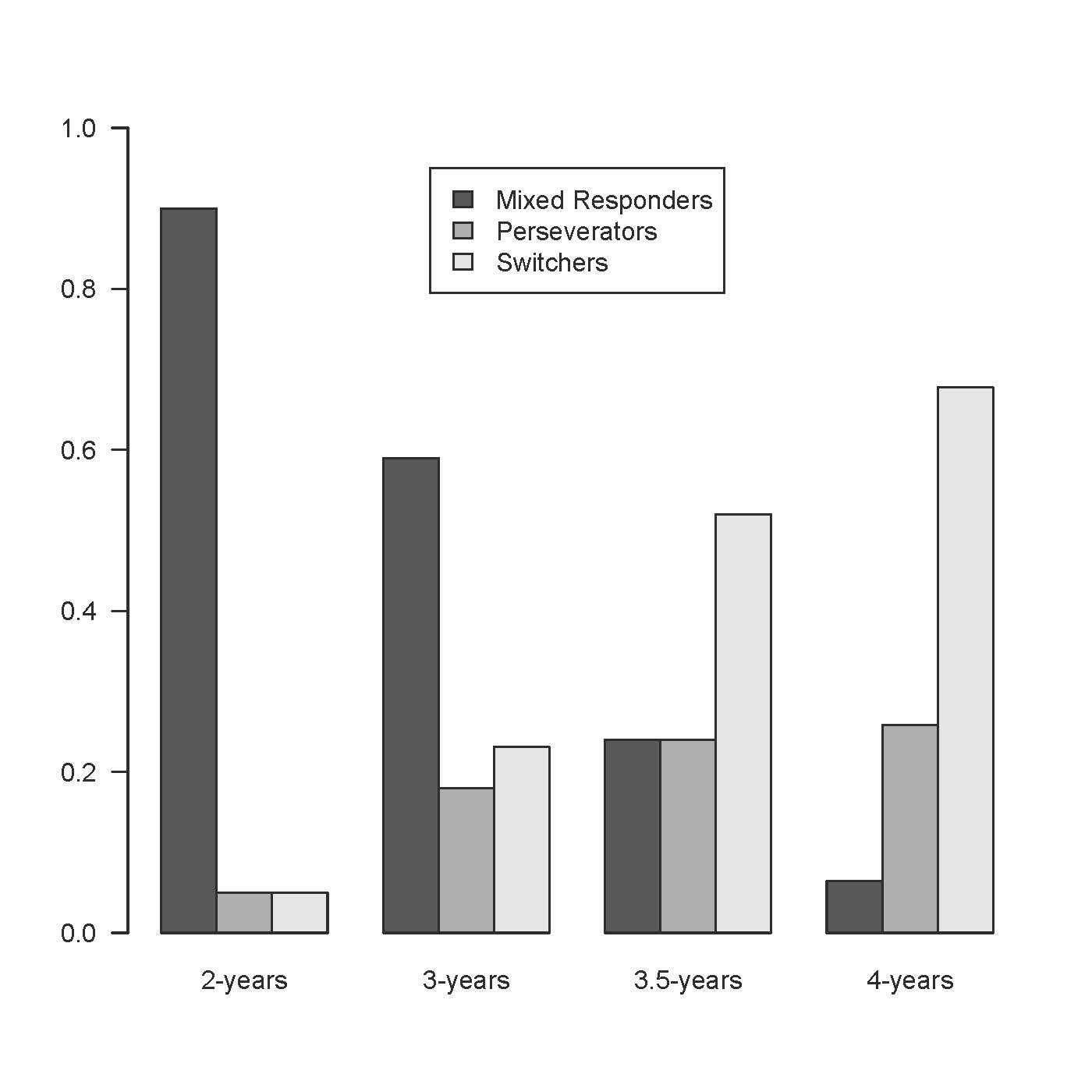
There are three noteworthy findings in the parameter estimates given in Table 2. First, the three states of the model had clearly identifiable strategies. The first state has a post-switch probability correct of around .52, approximately chance level. We refer to this as the “mixed responding” state. The second state has a probability correct of .07, that is, an almost complete absence of switching. We refer to this as the “perseveration” state. Finally, the third state has a probability correct of .93, corresponding to almost completely accurate responding. We refer to this as the “switch” state. Note that on tasks such as the DCCS, typically only two types of performance are recognised (perseveration and switching).

Second, the probability of remaining in the switch state, once entered, is 1.0. In other words, once participants adopt this optimal strategy, they do not revert to other strategies after that – there is no *un*learning once the correct strategy has been adopted. Furthermore, the only positive transitions were (i) from mixed responding to perseveration, and (ii) from perseveration to switch. This suggests that participants who start in the mixed responding state transition to the perseveration state *first*, and only then to the switch state. Crucially, there is no *direct* transition from the mixed responding state to the switch state. Perseveration therefore appears to represent an intermediate stage in the development of successful switching.

Third, the initial probabilities model parameters are informative about the developmental pathway suggested by these data. Figure 3 displays the proportion of participants starting in each strategy as a function of age group. Figure 3 was created by first assigning participants to strategies for each observation using posterior state sequences (Visser, 2010), and then computing the proportion of assigned strategies within age groups. An interesting developmental pattern is revealed: Most 2-year-olds show a mixed responding strategy, which decreases with age. The perseveration strategy slowly increases with age, albeit in a relatively small group of children. Finally, the proportion of children initially using the correct switch strategy clearly increases with age.

To test the hypothesis that working memory predicts which strategy children use on the Conflicting SwIFT, two models were compared. In one, age was included as a covariate on children’s initial strategy choice; in the other, working memory was used as a covariate. The BIC values were 1002.81 and 995.46 for the 'age' model and the 'working memory' model respectively. These values indicated that the 'working memory' model provided a better fit to the data, and thus that working memory predicts initial strategy better than age. (Note that these BIC values are not comparable to the ones in Table 2 because for these models five children were dropped due to missing working memory data.) Model-based analyses with inhibitory control as a covariate were not computed because children completed a different inhibitory control task depending on their age.

Figure 3. The proportion of children starting in each strategy on the Conflicting SwIFT as a function of age group.



*Model-based analyses: Distracting SwIFT*

The modelling approach for the Distracting SwIFT is analogous to that for the Conflicting SwIFT. Table 3 shows the goodness-of-fit statistics of the fitted latent Markov models with 1-3 states. The ‘2-state+age’ model has the best (i.e. lowest) BIC value, and hence we proceeded with interpretation of that model. The parameter estimates are given in the Table 4. The two states of the model have clearly identifiable strategies. The first state has a probability correct on post-switch trials of around .63, corresponding to a “mixed responding” state. The second state has a probability correct of .96, corresponding to a “switch state.” The results show that the 2-state model is optimal, demonstrating that children show two different patterns of responding on this task (switching and mixed responding). Figure 4 displays the proportion of children starting in each strategy as a function of age group: the mixed responding strategy gradually reduces between 2 and 4 years of age.

Table 3: Goodness-of-fit statistics for the latent Markov models of the Distracting Switching Inhibition and Flexibility task (SwIFT).

Model LL npar AIC BIC BICw

1 state -448.13 1 898.27 899.94 .00

Regression (Age) -415.56 2 835.13 838.48 .01

2-state -421.80 4 851.61 858.30 .00

2-state+age -403.71 6 819.42 829.46 .96

3-state -419.92 5 849.84 858.21 .00

3-state+age -398.53 11 819.05 837.47 .02

Note: npar denotes the number of parameters; it is corrected for parameters estimated at their boundary values (0 or 1); the small sample version of the BIC is reported here, and finally BICw denotes the BIC weights.

Table 4: Parameter estimates of each model in the Distracting Switching Inhibition and Flexibility task (SwIFT) demonstrating the transition matrix values.

Model Switchers Mixed Responders

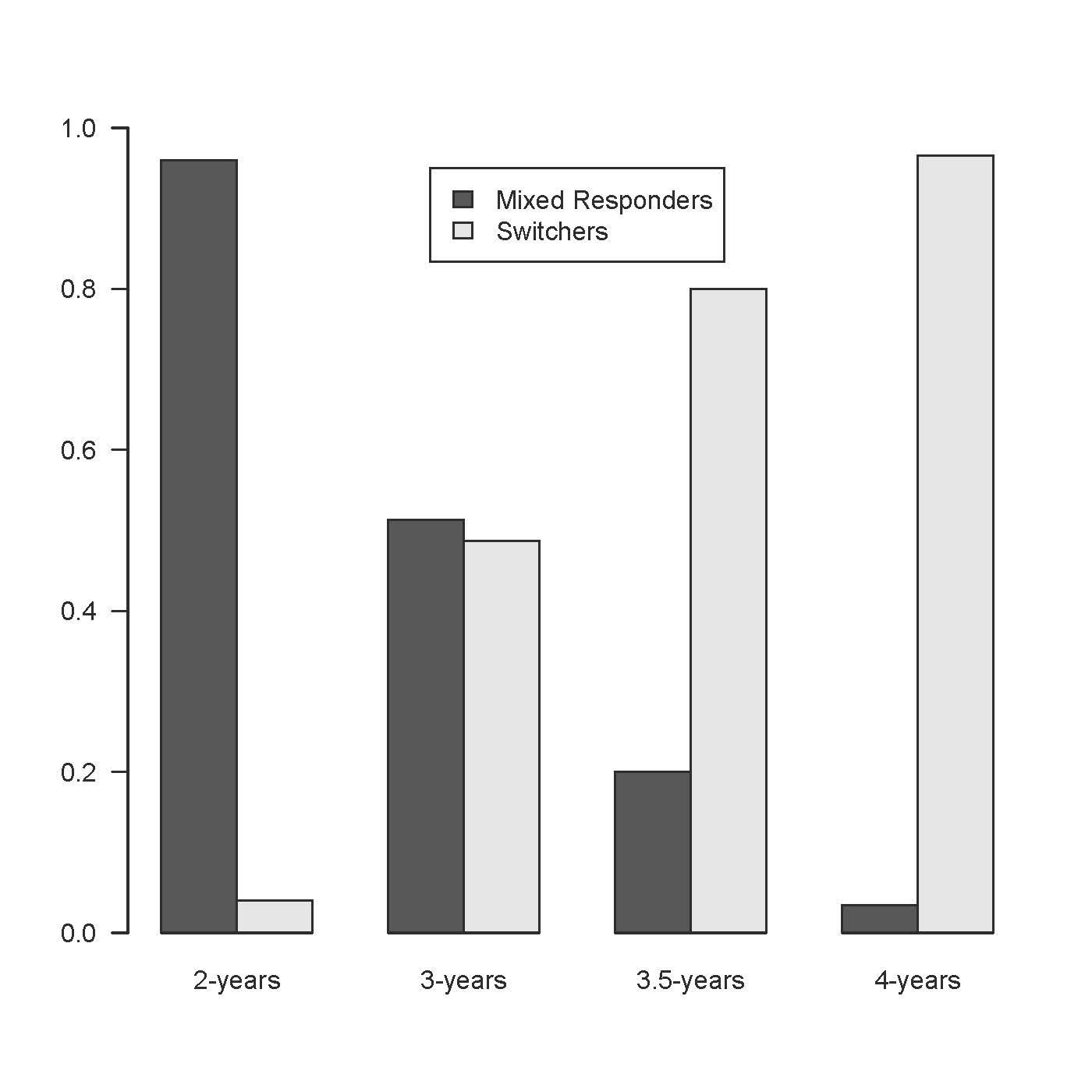
Switchers (.96) 1.00 .00

Mixed Responders (.63) .05 .96

Note: Initial state probabilities of switching are given in parentheses.

To test whether working memory predicted which strategy children used on the Distracting SwIFT, two models were compared: one in which age was included as a covariate on initial strategy choice, and one in which working memory was a covariate. The BIC values were 788.45 and 810.90 for the 'age' model and the 'working memory' model respectively. These values indicate that the ‘age’ model provides a better fit to the data, and hence that age better predicts initial strategy on the Distracting SwIFT than working memory.

Figure 4. The proportion of children starting in each strategy on the Distracting SwIFT as a function of age group.



*Individual differences analyses*

Adopting the categories of switching performance established by the modelling analyses, children were grouped on the basis of their SwIFT performance into one of three categories: ‘switchers’ (children who sorted 6-8 correct trials out of 8), ‘mixed responders’ (3-5 correct trials), or ‘perseverators’ (0-2 correct trials). These categories were used to further examine relations with working memory and inhibitory control.

*Contributions of working memory to cognitive flexibility:* The modelling analyses indicated that some numerically higher scores on the Conflicting SwIFT (mixed responding, i.e. a score of around 4 out of eight) reflect poorer CF than perseveration (i.e. a score of zero). Correlations were thus inappropriate for analysing Conflicting SwIFT data. Therefore, the following analyses examine how children’s performance type on the Conflicting SwIFT (perseveration, mixed responding, switching) and age predict working memory performance on the Spin the Pots task.

A two-way ANOVA was conducted to investigate whether age group and performance type on the SwIFT predicted children’s performance on the Spin the Pots task. (Children were categorised as ‘perseverators’ if they scored between 0-2 on the post-switch phase (*n =* 27); as ‘mixed responders’ if they scored 3-5 (*n* = 34); and as ‘switchers’ if they scored 6-8 (*n* = 54).) With regard to the ability to switch rules in the presence of response conflict, there was a significant main effect of age (*F*(3, 100) = 2.92, *p* = .038, η 2 = .06), and a significant main effect of Conflicting SwIFT performance type on Spin the Pots score (*F*(2, 100) = 5.23, *p* = .007, η 2 = .08). There was no interaction between age and performance type (*F*(6, 100) = .90, *p* = .50). Bonferroni *post-hoc* tests were used to follow up the significant main effect of SwIFT performance type. These showed the effect was driven by mixed responders (*M* = 6.64, *SD* = 2.63) performing worse on the Spin the Pots task than switchers (*M* = 8.71, *SD* = 1.39), with lower scores denoting better performance) (*p* = .010). Perseverators (*M* = 7.70, *SD* = 2.51), did not perform significantly different to switchers (*p* > .10).

With regard to the ability to switch in the presence of distracting information, both performance-type analyses and correlational analyses were conducted (as on the Distracting SwIFT, higher scores reliably correspond to better performance). Children were categorised as either switchers (*n* = 31) or mixed responders (*n* = 85). Two children categorised as perseverating were excluded, since it is not possible to match stimuli by the pre-switch rule on this task, and their performance likely indicates a failure to understand the task. A two-way ANOVA with age and performance type as factors found a significant effect of age on Spin the Pots score (*F*(3,103)= 3.17, *p* = .03, η 2 = .17). There was no significant effect of Distracting SwIFT performance type on Spin the Pots performance (*F*(2,103) = .73, *p* = .48), and no interaction (*F*(4,103) = 1.48, *p* = .21). In addition, Pearson’s correlations found no significant correlation between switching in the presence of distraction and working memory in 2-year-olds (*r*(23) = -.08, *p* > .10), 3-year-olds (*r*(40) = .19, *p* > .10), 3.5-year-olds (*r*(21) = .04, *p* > .10) or 4-year-olds (*r*(29) = .27, *p* > .10).

*Contributions of inhibitory control to cognitive flexibility:* To investigate the relation between CF and inhibitory control, a series of one-way ANOVAs were conducted for each age group (because children completed a different measure of inhibitory control depending on their age). With regard to switching in the presence of conflict, a one-way ANOVA was conducted to look at whether performance type on the Conflicting SwIFT predicted Reverse Categorisation scores in 2-year-olds. There was no significant effect of performance type on 2-year-olds’ inhibitory control (*F*(2,17) = .08, *p* > .10). As 3-year-olds performed near ceiling on the Reverse Categorisation task, it was not possible to look at the relation between their inhibitory control and CF. For 3.5-year-olds and 4-year-olds, a two-way ANOVA with age and performance type on the Conflicting SwIFT was run on Stroop accuracy. There was no significant effect of age (*F*(1,43) = .01, *p* > .10), nor of performance type (*F*(2,43) = .84, *p* > .10).

With regards to switching rules in the presence of distracting information, similar ANOVAs were run as above. Pearson’s correlations were also conducted for each age group. For 2-year-olds, there was a borderline-significant effect of Distracting SwIFT performance type on Reverse Categorisation scores (*F* (1,22) = 4.03, *p =* .057, η 2 = .15). Two-year-olds categorised as mixed responders (*N* = 13; *M* = 4.15, *SD* = 4.28) performed worse on the Reverse Categorisation task than those categorised as switchers (*N* = 11; *M* = 8.18, *SD* = 5.55). In addition, there was a positive correlation between accuracy on the Distracting SwIFT and Reverse Categorisation performance (*r*(25) = .43, *p* = .03). As 87% of 3.5-year-olds and 97% of 4-year-olds were able to switch on the Distracting SwIFT meaning there was little variance within performance types in the older children, only correlations were run between Stroop accuracy and total accuracy on the Distracting SwIFT. For 3.5-year-olds there was a positive correlation between accuracy on the Distracting SwIFT and Stroop accuracy (*r*(19) = .48, *p* = .038). For 4-year-olds, there was no significant correlation between accuracy on the Distracting SwIFT and Stroop accuracy (*r*(30) = .10, *p* > .10).

In summary, inhibitory control was related to the ability to switch in the presence of distracting information for both 2.5-year-olds and 3.5-year-olds. Conversely, children who showed mixed responding when switching in the presence of response conflict had poorer working memory than children who were able to switch rules successfully.

**4. Discussion**

The aim of this study was to investigate the emergence of CF during early childhood by combining an individual differences approach with a wider, younger age range, and using finer-grained definitions of CF. Three findings in particular shed new light on this topic. First, when asked to switch rules, 2.5-year-olds’ and 3-year-olds’ post-switch performance was most typically characterised by mixed responding (that is, not sorting consistently by either available sorting rule), rather than by perseveration. Second, the different kinds of CF showed distinct developmental trajectories. Switching in the presence of response conflict (as measured by the Conflicting SwIFT) showed an increase in perseveration and a decrease in mixed performance during the preschool period. In contrast, switching in the presence of distracting information (as measured by the Distracting SwIFT) improved significantly between the ages of 2.5 and 3 years. Third, inhibitory control and working memory were both associated with CF, but importantly, each was associated with a distinct kind of CF. Taken together, these results substantially advance our understanding by identifying distinct developmental trajectories of two kinds of CF, and, further, by offering evidence that these trajectories are underpinned separately by inhibitory control and working memory. We now consider these findings in further detail.

For 2.5-year-olds and 3-year-olds, sorting during the pre-switch phase was simple. Their chief difficulty on both kinds of switching task was in maintaining systematic rule-governed behaviour when the sorting rule changed – as evidenced by their mixed responding both in the Distracting SwIFT and Conflicting SwIFT. Mixed responding in the presence of response conflict was common in 2.5-year-olds and 3-year-olds, but decreased substantially in 3.5-year-olds. Two-and-a-half-year-olds and 3-year-olds also frequently showed mixed responding when switching in the presence of distracting information. This improved significantly between the ages of 2 and 3 years. This shows that significant developments in CF occur at around three years of age, highlighting the importance of examining CF development in younger children. The model-based analyses confirmed that for the Conflicting SwIFT, children show one of three performance types (switching, mixed responding or perseverating), whereas for the Distracting SwIFT, children can be categorised in one of two ways (switching or mixed responding). This is noteworthy, since comparable model-based analyses examining 3- to 5-year-olds’ performance on the DCCS found only two performance types (switching or perseverating) with a transitional group of children that shift from perseveration to switching (van Bers *et al*., 2011). The model-based analyses in the present study justify the classification of children as 'mixed' performers, and indicate that perseveration is likely to be an intermediate state between mixed performing and successful switching.

The low incidence of perseveration in the present study stands in contrast to some previous research that reports high rates of perseveration (e.g., Zelazo *et al*., 2003). While the lack of perseveration when switching in the presence of distraction is unsurprising – since it is not possible to continue to sort by the previously relevant rule – it is noteworthy that there was so little perseveration from children switching in the presence of response conflict. Under these conditions, perseverative errors are perfectly possible (and according to some accounts of CF, to be expected). However, rates of perseveration were generally quite low. This is a finding of particular interest, since it includes data from an age group younger than the 3- to 4-year range typically studied. Results from the modelling analyses showed that perseveration was confined to only a small group of children, and interestingly, that this type of error gradually increased between the ages of 2 and 4 years (in contrast to mixed responding, which decreased with age). We note that the SwIFT and the DCCS both share the requirement that children categorise stimuli first by one rule, then by another. However, the SwIFT has reduced incidental demands. This may indicate that the low incidence of perseveration in the current study is because perseverative errors arise partly as a function of task demands incidental to switching.

Errors that are not perseverative in nature have received little attention in the literature, in part because many developmental paradigms are unable to detect them. Nevertheless, these types of errors have been documented in preschoolers, both on variants of the DCCS (Brooks *et al*., 2003; Chevalier & Blaye, 2008; Fisher, 2011; van Bers *et al*., 2011) and on other measures of preschool executive function (e.g., Dauvier *et al*., 2012; Towse *et al*., 2007). For example, Chevalier and Blaye (2008) found that when 3-year-olds could make either perseverative or distraction errors on a CF task, they were equally likely to make each kind of error. Our results offer further support to the idea that the ability to maintain the relevant task rule is a crucial demand on CF tasks – and to the suggestion that the importance of perseverative errors has been overestimated in prior work (Chevalier & Blaye, 2008).

Although mixed responding was a common pattern of performance on both the Conflicting SwIFT and Distracting SwIFT, it is likely that this pattern of performance arises for different reasons on each task. On the Conflicting SwIFT, when children are faced with competition from the previous rule, mixed responding was related to children’s working memory. In addition, the modelling analyses revealed that working memory was a better predictor of performance type than age on the Conflicting SwIFT. This is a surprising finding, though it is consistent with previous research suggesting a link between working memory and switching in older children (Marcovitch *et al*., 2010), and reduced mixing costs in young children (Chevalier *et al*., 2012). The present results suggest a specific link between working memory and mixed responding errors. Interestingly, this supports previous research by Dauvier *et al.*, (2012) who found that 5 and 6-year-olds’ mixed responding on an alternating-runs version of the DCCS was related to performance on a separate measure of working memory. Together, these results demonstrate that this pattern of performance is qualitatively different from perseveration. They highlight too the importance of working memory for not only updating rules (as in the alternating-runs version of the DCCS) but also for maintaining systematic rule-governed behaviour (as on the SwIFT). The relation between working memory and mixed responding errors may be because children do not maintain the pre-switch rule very strongly (as they do not perseverate), but nor do they adopt the post-switch rule (as they do not sort correctly).The present data are consistent with working memory and goal neglect accounts of CF development that are based on children’s performance on tasks with response conflict. These accounts posit that working memory supports CF by allowing children to maintain new task rules and use these to guide their behaviour – particularly under conditions where there is conflict between previously relevant task rules and new task rules (Blackwell *et al*., 2009; Marcovitch *et al*., 2010).

On the Distracting SwIFT, children cannot continue to match by the pre-switch rule, and so their errors must reflect distractibility rather than perseveration. This is an important observation: even when the previously relevant dimension is entirely removed, it is still challenging for preschool children to switch to a new rule – and their attempts to switch can be disrupted by their difficulty in inhibiting distracting information. The cost incurred by non-task-relevant information has been documented in only two previous studies we are aware of (Brooks *et al*., 2003; Chevalier & Blaye, 2008). Broader explanations of the emergence of CF have tended either to ignore this cost, or to conflate it with the ability to resolve within-stimulus conflict. The present study demonstrates clearly that these costs are separable, and should be treated as such in future research.

The results also allow us to refine our view of how inhibitory control supports CF. We found no association between inhibitory control and performance on the Conflicting SwIFT. Importantly, this stands in contrast to previous suggestions about the role of inhibitory control in CF. Specifically, the Attentional Inertia account suggests that young children perform poorly on switching tasks because they fail to inhibit attention to the no-longer relevant dimension when presented with response conflict (Diamond *et al*.,2003). However our results indicate that inhibitory control serves a different function in early CF. It appears to play a role in helping children to suppress distraction from task-irrelevant information when sorting by a new rule. Specifically, two-and-a-half-year-olds and 3.5-year-olds with stronger inhibitory control were better able to switch on the Distracting SwIFT than children with weaker inhibitory control. The results are consistent with previous research that reports inhibitory control to be related to aspects of switching that do not involve inhibiting attention to the previously relevant rule. Chevalier *et al*. (2012) found that 3- to 5-year-old children’s inhibitory control was not related to switching (measured using local costs), but was related to their mixing costs on a switching task. The authors argue that inhibitory control may help children to resist distraction from non-relevant features present in the stimuli. The current study shows that this observation extends to even younger children, and offers support for the idea that inhibitory control helps children to ignore task-irrelevant information when they are required to switch or update task sets.

Two age-related observations about inhibitory control must be addressed. First, inhibitory control in 4-year-olds was found to be unrelated to performance on the Distracting SwIFT. We suggest that this lack of association arises because 4-year-olds do not need to deploy inhibitory control in order to suppress their attention to distracting information, as by the age of 4, this demand is trivially easy for them. In support of this view, 97% of 4-year-olds could sort correctly in the presence of distracting information, suggesting that 4-year-olds are well able to switch rules while ignoring distractions. Second, 3-year-olds performed at near-ceiling levels on the Reverse Categorization task, meaning we cannot make any definitive claims about inhibitory control at this age. It seems parsimonious and plausible to hypothesise that 3-year-olds would show a broadly comparable pattern of performance to the 2.5- and 3.5-year-olds. Unfortunately, to our knowledge there is no single age-appropriate inhibitory control task that can be used from 2 to 4 years of age. The Reverse Categorisation task was chosen because it has been used successfully with children aged 39 months, the mean age of our 3-year-olds group (e.g., Carlson *et al*., 2004). We also note that an alternative inhibitory task, the Day/Night Stroop task has high attrition rates when used with younger 3-year-olds (Simpson & Riggs 2005). For that reason, the task would be unlikely to provide sufficient variance for an individual differences approach. Developing a measure of inhibitory control that can be used across a younger and broader age range remains a priority for future research.

When seeking to constrain theoretical accounts of the emergence of CF, it is important to note that working memory was *not* associated with the ability to switch rules in the presence of distracting information. In the absence of this observation, a rudimentary task analysis might suggest that holding in mind a strong representation of the current rule would be sufficient to allow children to ignore distractions efficiently. However, data from the present study do not support this view. Instead, they suggest that working memory is not integral to switching in the presence of distraction – likely because the lack of response conflict means there is no competition between the pre-switch rule and the new post-switch rule to resolve. This helps to refine theoretical accounts that posit a role for working memory in CF development. Specifically, the results show that working memory is integral to switching only when there is a response conflict to resolve.

The present study offers a finer-grained description of CF development, and shows how both working memory and inhibitory control contribute uniquely and distinctly to the emergence of CF in 2- to 4-year-olds. First, the present findings suggest that the role of perseveration has been overestimated in previous work, and that it is not best seen as the starting point in the development of CF. Rather, before they perseverate, young children tend to respond with unsystematic mixed responding. Perseveration appears to be an error that increases over the preschool years, as mixed responding decreases. Second, the present results go beyond theoretical accounts positing that CF arises either from working memory or inhibitory control, to show that the specific contributions of working memory and inhibitory control vary as a function of differing task demands. Working memory is crucial for flexible behaviour in the presence of response conflict. When faced with such response conflict in the present study, younger children tended to show mixed performance rather than perseveration, consistent with a failure to maintain the current task rule in working memory when updating behaviour. These results also show that preschool children can be distracted by task-irrelevant information when switching rules, even when response conflict is entirely absent. These difficulties were specifically related to individual differences in inhibitory control. Rather than inhibitory control helping children to suppress their attention to the previously relevant dimension, the current study suggests that it helps children to filter out task-irrelevant information when switching. Together, these two distinct processes develop and combine to allow the emergence of complex and flexible rule-driven behaviour.

Chapter Three

Not all distractions are the same: Investigating why preschoolers make distraction errors when switching

The study reported in this Chapter is based on a manuscript currently under review: Blakey, E., & Carroll, D. J. (2015). Not all distractions are the same: Investigating why preschoolers make distraction errors when switching. It directly follows on from the experiment reported in Chapter two which showed that when switching between tasks, preschoolers frequently make distraction errors – as distinct from perseverative errors. This study followed up this finding to examine why preschoolers make these errors. One hundred and sixty-four 2- and 3-year-olds completed one of four different conditions on a rule-switching task where children sorted stimuli according to one rule and then switched to a new rule. Conditions varied according to the type of information that children needed to ignore when switching. Children made significantly more distraction errors when the to-be-ignored information was related to the previous rule. When the to-be-ignored information was not related to a previous rule, even young preschoolers could disregard this information. This demonstrates that distraction errors are caused by children’s initial goal-representations that continue to affect later performance.

**1. Introduction**

Across various measures of preschool CF, 3-year-olds frequently make errors when switching from sorting stimuli by colour to sorting them by shape (e.g., Deák, 2003; Espy, 1997; Zelazo, 2006). These errors can be split into two distinct types: perseverative errors (where children make errors by continuing to sort stimuli by an old rule), and distraction errors (where children make errors that are neither compatible with the old rule nor the new rule). Perseverative errors have been the predominant focus of the literature, since many paradigms are set up to be able to detect errors of perseveration only (Chevalier & Blaye, 2008; Cragg & Chevalier, 2009). For this reason, theoretical accounts of CF development have tended to focus on the apparent shift from perseverative responding to flexible responding (Diamond *et al.,* 2005; Perner & Lang, 2002; Munakata *et al.*, 2012; Zelazo *et al.,* 2003). However, both in Chapter one and in recent research, there is evidence that errors of distraction can be just as common as perseverative errors, particularly in younger preschoolers (e.g., Chevalier & Blaye, 2008). Therefore, focusing solely on one type of switching only is to mischaracterise the development of CF. Nevertheless, there is a paucity of research examining why preschoolers make distraction errors. The present paper seeks to address this by systematically examining the nature of distraction errors in young preschoolers.

Resisting distraction from information unrelated to the current task at hand is an essential aspect of all goal-directed behaviour. Notably, both preschool children (Brooks *et al.,* 2003; Chevalier & Blaye, 2008; Deák & Wiseheart, 2015) and adolescents (Crone, Ridderinkhof, Worm, Somsen & van der Molen, 2004) make distraction errors on measures of CF. Distraction errors have been reported in young preschoolers when switching from one task to another, as is seen in research using the Preschool Attention Switching Task-3 (PAST-3: Chevalier & Blaye, 2008). Preschoolers were required to switch from sorting by one rule (“select only *yellow* stimuli”) to sorting by another rule (“select only *blue* stimuli”). On each trial, there were three possible response options, such that when the rule changed, preschoolers could make one of three possible responses. They could switch rule successfully – that is, switch from selecting yellow stimuli to selecting blue stimuli; they could perseverate with the initial rule – that is, continue selecting yellow stimuli; or they could make a distraction error by selecting a response from a never-relevant dimension – that is, switch from selecting yellow stimuli to selecting green stimuli. On this task, 3-year-olds were equally likely to make distraction errors as perseverative errors. This demonstrates that following a switch, it is not the case that preschool children will necessarily *either* switch successfully *or* perseverate with the initial rule. Their behaviour is more variable than this. For this reason, to focus only on errors of perseveration is to fail to account for a significant proportion of children’s behaviour on switching tasks.

It should be noted that preschoolers’ distraction errors have not been limited to a single paradigm. In Chapter two of this thesis, children initially matched stimuli according to a given rule (e.g., colour) and then had to switch to matching by a new rule (e.g., shape). There were two contrasting conditions, labelled the Conflicting condition and the Distracting condition. Both conditions required children to switch from sorting by one rule to sorting by a new rule. However, they differed crucially in terms of the stimuli presented in the post-switch phase. In the Conflicting condition, post-switch stimuli couldbe matched according to the pre-switch rule (that is, it was possible for children to perseverate). In the Distracting condition, post-switch stimuli *could not* be matched according to the pre-switch rule (that is, it was not possible for children to perseverate – so that any errors they made would necessarily be distraction errors). In the Conflicting condition, children could only sort correctly if they managed to resolve response conflict; in other words, since the stimuli they were sorting could be matched both by the old rule *and* by the new rule, children had to resolve this within-stimulus conflict in order to be able to sort correctly. Conversely, in the Distracting condition, children did not have to resolve response conflict to sort correctly; the stimuli they had to sort could not be matched by the old rule, so the principal challenge they had to meet was to ignore irrelevant information. Both 2-year-olds and 3-year-olds made similar numbers of errors in each condition, showing that when preschoolers fail to switch, they make both perseverative errors and distraction errors. Together, these studies demonstrate that distraction errors – errors that are neither compatible with the previous rule nor with the current rule – are common occurrences when children try to switch rules. However, because these errors have received so little attention in previous research, the cause of these distraction errors is unknown.

Distraction errors are intriguing because, as Chapter two found, they occur even when response conflict is entirely removed. This observation might at first seem surprising, given that the conditions that lead to perseveration are entirely absent, and as such, it is not possible for children to persist with the initial rule. They must simply match stimuli while ignoring irrelevant information. However, as the data show, for young preschoolers, this is not a trivial task demand. Nevertheless, to our knowledge, there has been no research examining the cause of children’s distraction errors. To state the problem simply: removing response conflict from measures of CF still leaves significant demands, but very little is known about what these demands are. The prevailing theoretical accounts of CF development offer little to explain how distraction errors arise, nor how children eventually overcome them. The principal aim of this Chapter is to directly address this gap in the literature. This will be done in two ways: firstly, and chiefly, by using a switching task to look at distraction errors, and systematically varying the conditions under which children must switch rules. This allows a direct test of competing hypotheses to explain the source of children’s distraction errors. Secondly, measures of working memory and inhibitory control will be administered to try to identify the contribution of core constituent processes known to underpin CF.

We propose three hypotheses to explain why distraction errors arise; the present study will test all three directly. Each hypothesis focuses on a specific task demand that may be problematic for young children when they switch rules. Distraction errors may arise (i) because of children’s difficulty with ignoring any kind of distracting information (what we refer to as the Selective Attention hypothesis); (ii) because of children’s difficulty ignoring information that used to be relevant (what we refer to as the Rule Maintenance hypothesis); or (iii) because of children’s difficulty re-engaging with information that was previously ignored (what we refer to as the Negative Priming hypothesis). Common to all three hypotheses is the idea that children’s distraction errors are driven by the information that they are trying to ignore. However, the nature of this to-be-ignored information is crucially different in each case.

The Selective Attention hypothesis suggests that distraction errors arise due to young children having a general difficulty in ignoring distracting information; and that when required to focus on a single aspect of a stimulus (such as its shape), they are unable to focus their attention sufficiently. In other words, *any* kind of to-be-ignored information is sufficient to disrupt young children’s switching behaviour. This hypothesis posits that children’s errors occur as a consequence of general distractibility. In contrast, the Rule Maintenance hypothesis suggests that distraction errors arise due to children continuing to attend to information *relevant to the previous goal*. In other words, children are well able to ignore most irrelevant information; however, if the to-be-ignored information relates to a rule children had been previously following, then their behaviour is liable to be disrupted. Thus, this hypothesis posits that children’s errors arise due to a persistence of the pre-switch goal. The Negative Priming hypothesis suggests that distraction errors arise due to children’s difficulties in re-engaging attention towards a dimension that has previously been ignored. It is a common feature of many CF tasks that when the rule changes, children have to redirect their attention back towards a dimension that they have actively suppressed during the pre-switch phase. Following a rule change, the suppressed dimension now becomes relevant, thus requiring children to re-engage their attention to something they had actively suppressed. This phenomenon is referred to as negative priming, and is known to incur additional processing costs. The Negative Priming hypothesis posits that distraction errors are more likely when children must redirect their attention to previously ignored information. Note that this possibility is not mutually exclusive with the Rule Maintenance hypothesis – both processes may have a significant effect on children’s switching behaviour.

If the Selective Attention hypothesis is correct, and children make distraction errors in the presence of any kind of task-irrelevant information, this would suggest that distraction errors arise due to a general deficit in young children’s selective attention. Selective attention is the process that enables us to focus only on a specific aspect of a stimulus (e.g. its colour), while *not* attending to other aspects of the same stimulus (e.g. its shape). Previous research indicates it is a very plausible candidate process to explain how distraction errors arise. Selective attention has been proposed as one explanation for why 3-year-olds fail to switch from sorting by one dimension to another (Brooks *et al.,* 2003; Hanania & Smith, 2010). For example, Brooks *et al*., (2003) demonstrated that 3-year-olds could successfully switch stimuli on the basis of shape, when those to-be-sorted stimuli were monochrome. However, when irrelevant colour information was added to the stimuli, 3-year-olds failed to switch rules (even though this irrelevant information was never referred to). The authors suggested that the irrelevant colour information made it more difficult for children to selectively attend to the relevant dimension. Further research has shown that when the need to selectively attend is removed, such as during reversal-shift tasks (where the switch requires children to attend to the same dimension as before the switch, but to make a different response) children’s difficulties with switching disappear (Brooks *et al*., 2003; Perner & Lang, 2002; Zelazo *et al*., 2003). The ability to ‘tune out’ irrelevant task features is considered a crucial aspect of selective attention (Neill & Westberry, 1987; Tipper, Bourque, Anderson, & Brehaut, 1989); deficits in selective attention may therefore explain why children make distraction errors on CF tasks.

If the Rule Maintenance hypothesis is correct, and children only make distraction errors in the presence of no-longer-relevant information (i.e., information that was relevant to a previous rule but which should now be ignored), this would suggest that distraction errors are due to the continued influence of the rule that was established during the pre-switch phase. Persistent influence from an outdated rule could plausibly be attributed to either poor inhibitory control or poor updating of working memory – and in either case, errors of this kind would best be considered as arising from immature executive function. Prior research offers strong evidence to support this hypothesis, not least as inhibitory control and working memory accounts have been influential in explaining perseverative errors on CF tasks. For example, inhibitory control accounts have argued that children make perseverative errors because they fail to disengage their attention to the no-longer relevant dimension when the rule changes (Diamond *et al.,* 2005; Diamond & Kirkham 2005). Working memory accounts have argued that children make perseverative errors because they cannot maintain the new rule in the face of competition from the previous rule (Cepeda & Munakata, 2007; Munakata, 2001). Both of these accounts can plausibly explain perseverative errors, and could also conceivably explain distraction errors too. For example, if children are unable to inhibit their attention to the *dimension* sorted by in the pre-switch phase, distraction errors could arise from poor inhibitory control, which would lead to inappropriate continued attention to this dimension in the post-switch phase. Alternatively – or in addition – poor working memory could lead to distraction errors if children were unable to establish and maintain the new rule in the face of distracting information. Although children cannot continue to match by the previous rule, the task-irrelevant information still contains perceptual information related to the previous rule. Without a new rule established to clearly guide their behaviour, children may be prone to unsystematic responding, or to having their behaviour disrupted by interference from previously relevant information. While the specifics of the processes underpinning this hypothesis remain to be determined, immature executive function would be a likely explanation if distraction errors arose chiefly in the presence of information related to a previously relevant rule.

If the Negative Priming hypothesis is correct, and children make more distraction errors when they have to sort by a new dimension that was previously ignored in the pre-switch phase, this suggests that distraction errors arise as a consequence of a process of active suppression – one where non-relevant information in the pre-switch phase is suppressed. Negative priming is a common demand on many switching tasks, because, following a rule change, children must re-engage their attention to a dimension that they have previously ignored in the pre-switch phase (Chevalier & Blaye, 2008; Müller *et al.,* 2006; Zelazo *et al.,* 2003). This additional demand has been shown to increase perseverative errors on CF tasks that involve response conflict. For example, Zelazo *et al*., (2003) and Müller *et al*., (2006) reported that when children had to attend to stimulus values that they had previously ignored during the pre-switch phase, they made significantly more errors when switching than in a condition where this demand was removed. These data demonstrate that negative priming contributes to preschoolers’ perseverative errors on CF tasks. It is plausible, therefore, to suggest that negative priming may also contribute to distraction errors.

In sum, there are three potential explanations for children’s distractions errors. The Selective Attention hypothesis suggests that distraction errors arise as a consequence of children’s poor selective attention, since they struggle to ignore *all* kinds of irrelevant information. The Rule Maintenance hypothesis suggests that distraction errors reflect persistent attention toward a previously relevant dimension from the pre-switch phase, arising due to immature executive function. And the Negative Priming hypothesis suggests that distraction errors arise from children’s difficulty in re-engaging their attention to a dimension they have previously suppressed. The present study aimed to test these three different hypotheses for explaining distraction errors in both two- and 3-year-olds. This is a particularly important period in development because it is during this time that the ability to switch behaviour in line with explicit rules first emerges (Blakey *et al.,* 2015; Carlson *et al.,* 2004). As stated in the introduction to this thesis, because of the widespread use of tasks that can only detect perseverative errors, this age range has received little attention. Gaining further direct insights into how flexible behaviour emerges during this time is essential in gaining a comprehensive understanding of CF.

To test these three hypotheses, preschoolers’ performance was compared across four different versions of the SwIFT designed to separate out these different demands. The stimuli used on the SwIFT are made up of different combinations of nine different colours, nine different shapes and nine different patterns. This use of a large and diverse stimulus set is particularly desirable when studying early CF, as it greatly reduces the likelihood of stimulus-related errors, which can arise when children repeatedly sort a small set of distinctive stimuli (see FitzGibbon, Cragg & Carroll, 2014). As the aim of the present study was to examine distraction errors, and not perseveration errors, there was no response conflict in any condition (i.e., after a switch, children could not continue to match by the previous rule, and therefore could not perseverate). Instead, in both the pre- and the post-switch phase, children had to match stimuli while ignoring irrelevant information.

There were four conditions: the Goal-Unrelated condition, the Goal-Related condition, the Goal-Related Negative Priming condition, and the Baseline non-switching condition. Each condition comprised 16 trials, presented across two phases. The dependent variable of interest was post-switch performance (that is, performance on the final eight trials). The crucial difference between conditions was the nature of the information that children had to ignore during the post-switch phase (see Figure 5). To ensure that basic task difficulty across conditions was equivalent, in all four conditions, children sorted *exactly* the same stimuli by *exactly* the same rule during these final eight trials that constitute the post-switch phase. Any between-condition differences cannot be attributed to incidental differences in the post-switch sorting rule or stimuli, since there are none. The only difference between conditions is in the type of information that children attend to initially during the first eight trials of the pre-switch phase, and which they must then ignore while sorting during the last eight trials of the post-switch phase. Therefore, it is this pre-switch phase that determines whether the information children must ignore in the post-switch phase was relevant to the pre-switch rule, or involved negative priming.

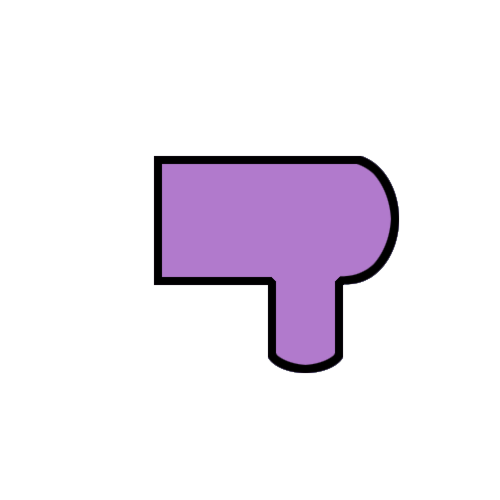
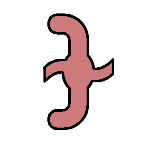
In the Goal-Unrelated condition, children initially sort stimuli by pattern in the pre-switch phase. For the post-switch phase, they switch to sorting by colour, while ignoring shape. The to-be-ignored information in the post-switch phase (shape) is therefore not related to the previous sorting rule. If the Selective Attention hypothesis is correct, and distraction errors are caused by children’s difficulties in selectively attending to a new dimension in the presence of any task-irrelevant information, then children should find this condition difficult, and should make distraction errors. In the Goal-Related condition, children initially sort by shape in the pre-switch phase. For the post-switch phase, they switch to sorting by colour, while ignoring shape. The to-be-ignored information in the post-switch phase (shape) is therefore relevant to the previous sorting rule. If the Rule Maintenance hypothesis is correct, and distraction errors are caused by inappropriate persistent attention toward to previously relevant rule, then children should find this condition difficult – and *more* difficult than the Goal-Unrelated condition. In the Goal-Related Negative Priming condition, children initially sort by shape in the pre-switch phase. For the post-switch phase, they switch to sorting by colour. The to-be-ignored information in the post-switch phase (shape) is therefore related to the previous sorting rule. In addition, the sorting dimension in the post-switch phase (colour) was also the task-irrelevant dimension in the pre-switch phase. If the Negative Priming hypothesis is correct, and active suppression of irrelevant information in the pre-switch phase causes additional difficulties that lead to distraction errors, children should make more errors in this condition relative to the Goal-Related condition. In the Baseline non-switching condition, children sorted by the same rule across all experimental trials, without switching rules at any point – in other words, the “pre-switch” and “post-switch” phases are the same, as there is no change of rule. As in the other three conditions, children finish by sorting bivalent stimuli by one rule (colour) while ignoring another rule (shape). This condition offers an index of baseline performance to show how children sort these stimuli in the absence of any need to switch. In addition to the switching task, all children completed measures of working memory (the Spin the Pots task) and inhibitory control (the Fruit Stroop task).

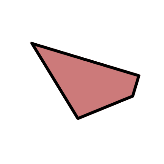
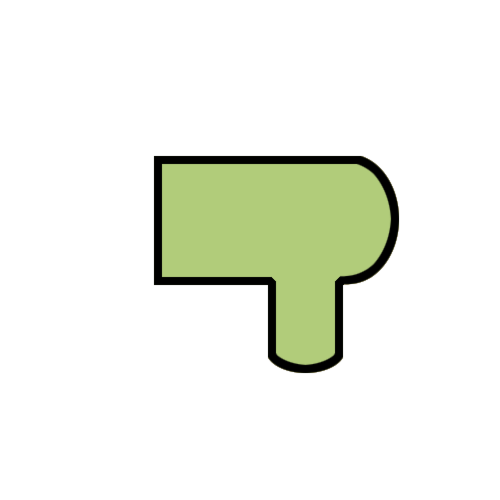
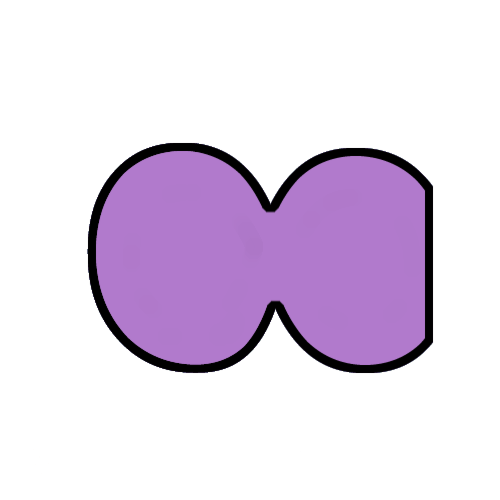
Figure 5 Each condition of the Distracting SwIFT

Baseline non-switching SwIFT:

Pre-switch: “Touch the one that’s Post-switch: “Touch the one that’s

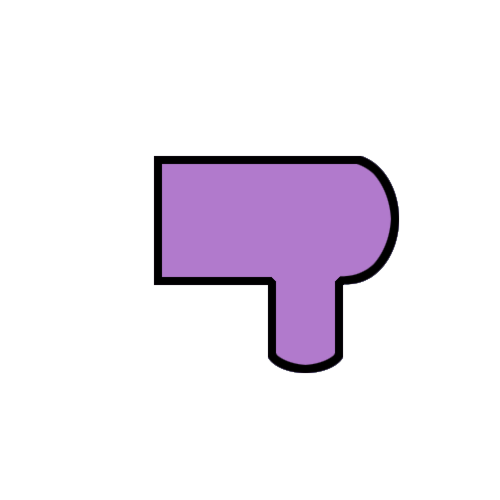
the same *colour*” the same *colour*”



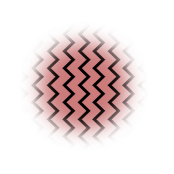
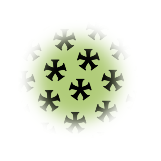


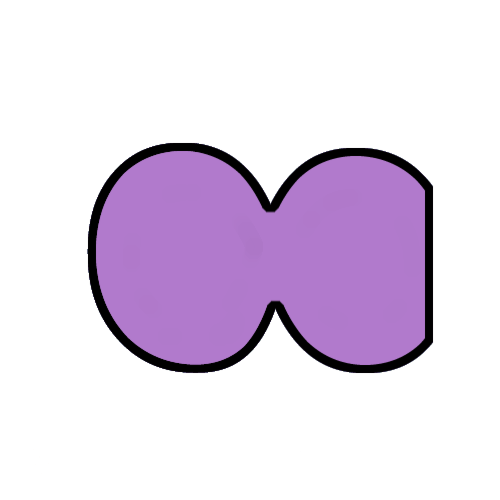
Goal-Unrelated SwIFT:

Pre-switch: “Touch the one that’s Post-switch: “Touch the one that’s

the same *pattern*” the same *colour*”



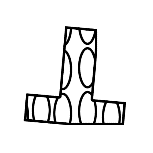
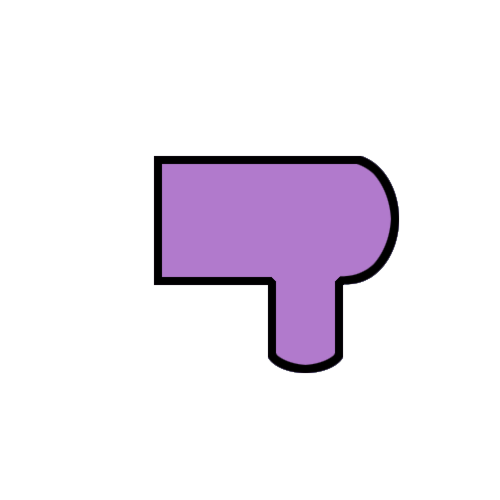


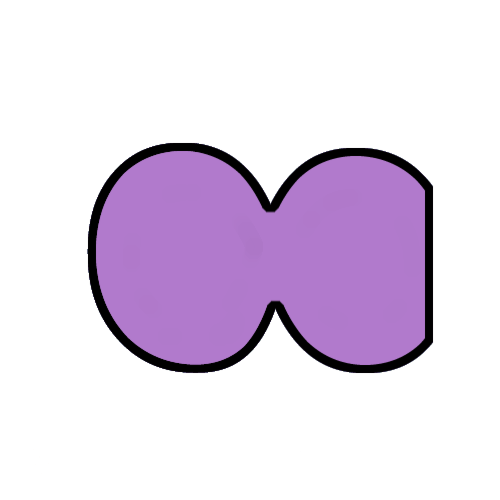
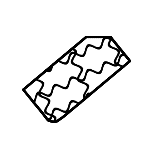
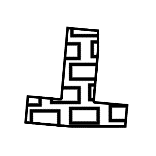


Goal-Related SwIFT:

Pre-switch: “Touch the one that’s Post-switch: “Touch the one that’s

the same *shape*” the same *colour*”

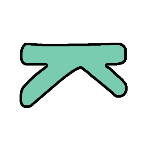


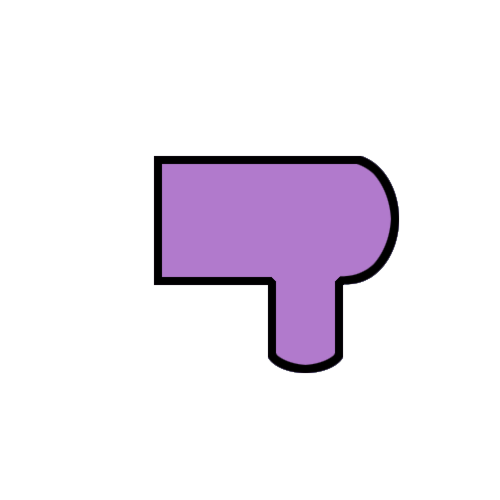


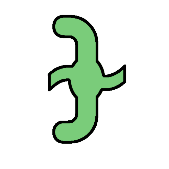
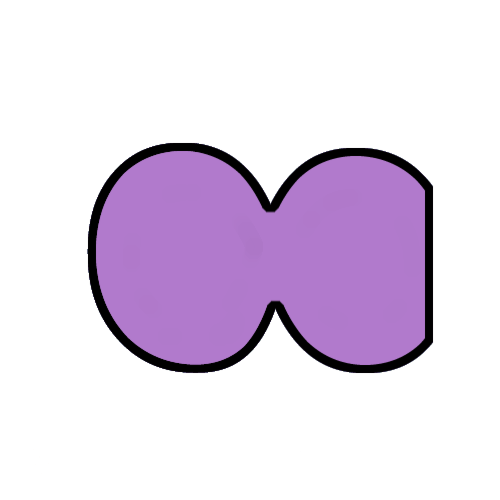
Goal-Related Negative Priming SwIFT:

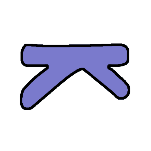
Pre-switch: “Touch the one that’s Post-switch: “Touch the one that’s

the same *shape*” the same *colour*”









**2. Method**

*Participants and design*

One hundred and sixty-four two- and 3-year-olds took part in the study (87 males and 77 females). Data from a further three children were excluded: two children were later diagnosed with specific language impairment, and one child did not understand the task instructions. The remaining sample was split into two age groups spanning six-month bands: 89 2-year-olds (*M* age: 2;9 years; range: 2;6 years – 2;11 years) and 75 3-year-olds (*M* age: 3;3 years; range: 3;0 years – 3;6 years). Children were randomly allocated to one of four conditions: Baseline (21 2-year-olds and 19 3-year-olds), Goal-Unrelated (23 2-year-olds and 18 3-year-olds), Goal-Related (21 2-year-olds and 20 3-year-olds), or Goal-Related Negative Priming (24 2-year-olds and 18 3-year-olds). Children were recruited either from a database of local families who had expressed an interest in participating in research, or from local preschools. All children were monolingual and were from working-class and middle-class areas of the UK. Informed consent was obtained from parents before testing began. Ethical approval was obtained from the department’s ethics sub-committee (see Appendix 1). Participating families received a small gift as a token of appreciation for taking part.

*Procedure*

Children were tested in a single session, either in the University Developmental Lab with their caregiver present, or in a quiet area of their nursery. Children completed three tasks in a fixed order: the SwIFT, the Fruit Stroop (a measure of inhibitory control), and the Spin the Pots task (a measure of working memory).

*The SwIFT:* Children completed one of four conditions of the SwIFT. In this version, the task began with four practice trials, followed by a pre-switch phase of 8 trials using one matching rule, and then a post-switch phase of 8 trials using a different rule. All four conditions used the same stimuli and sorting rule for the eight trials of the post-switch phase. On this task, all response conflict is removed: following the change of rule, children cannot continue to match by the previously relevant rule. Four different versions of the SwIFT were used, differing only in terms of the pre-switch phase (the first eight trials); the post-switch phase (or the final eight trials) was identical in all conditions: children sorted by colour and ignored shape in the post-switch phase. (See Figure 5 for an illustration.)

*Baseline SwIFT:* In this non-switching variant of the SwIFT, children sorted by colour and ignored shape throughout the task.

*Goal-Unrelated SwIFT:* In the pre-switch phase, children sorted by pattern and ignored colour; in the post-switch phase children sorted by colour and ignored shape. Therefore, the to-be-ignored information in the post-switch phase had never been relevant: it was not related to the pre-switch rule.

*Goal-Related SwIFT:* In the pre-switch phase, children sorted by shape and ignored pattern; in the post-switch phase children sorted by colour and ignored shape. Therefore, the to-be-ignored information in the post-switch phase was the information attended to in the pre-switch phase.

*Goal-Related Negative Priming SwIFT:* In the pre-switch phase, children sorted by shape and ignored colour; in the post-switch phase children sorted by colour and ignored shape. Therefore, the to-be-ignored information in the post-switch phase was the information attended to in the pre-switch phase – *and* children had to sort by a dimension in the post-switch phase that had previously been ignored in the pre-switch phase.

*The Fruit Stroop task:* The Fruit Stroop was used to measure inhibitory control (Kochanska, Murray & Harlan, 2000). In this task, children must inhibit pointing to a more salient, larger stimulus in order to respond to a less salient, smaller stimulus. Children were first shown three big pictures and three small pictures of the same fruits (banana, apple and orange). The experimenter named each big fruit and little fruit in turn. The small fruit pictures were then removed, and children were asked to point to each of the three big fruit pictures. This was to check that children knew the names of each fruit (all children did this successfully). In the experimental phase, children were presented with three pictures, each depicting a small fruit embedded in a different large fruit (e.g. a small banana embedded in a large apple). Children were then asked to point to each of the little fruits ("show me the *little* banana"). Children received a score of 0 if they pointed to the large fruit, a score of 1 if they pointed to the large fruit but self-corrected, and a score of 2 if they pointed to the little fruit. The dependent variable was the summed score from the three experimental trials.

*The Spin the Pots task*: The Spin the Pots task was used to measure working memory (Hughes & Ensor, 2007). See Chapter two for a description of the procedure. Spin the Pots task scores are reverse coded for ease of interpretation (16 minus number of attempts).

**3. Results**

Exploratory analyses indicated that data for all tasks were significantly negatively skewed, as indicated by significant Kolmogorov-Smirnov and Shapiro-Wilk tests (ps < .001). Therefore, raw scores were transformed using a logarithmic base 10 transformation (log10) to better approximate normality, and the transformed data were used in all subsequent analyses. For ease of interpretation, raw scores are reported in descriptive data.

First, preliminary analyses were run to check whether age differed by condition, and whether there was an effect of sex on any of the tasks. A one-way ANOVA showed that age did not vary by condition for the 2-year-olds (*p* = .56) or the 3-year-olds (*p* = .54). There was no significant effect of sex on Fruit Stroop (*p* = .26) or Spin the Pots performance (*p* = .47). There was a small but significant effect of sex on SwIFT performance (*F*(1,162) = 4.58, *p* = .032, *d* = .30) with females (*M* = 6.52, *SD* = 1.64) more accurate than males overall (*M* = 5.93, *SD* = 1.86). However, when accounting for condition, this effect disappeared (*p* > .05). Therefore, data were collapsed across sex for subsequent analyses. One-sample t-tests conducted separately for each age group found that both age groups sorted at above-chance levels on all conditions during the pre-switch phase of the SwIFT (*p*s < .001), and were able to perform the basic task well. To test whether working memory and inhibitory control performance improved with age, independent-samples t-tests compared working memory and inhibitory control scores by age group. Two 2.5-year-olds and one 3-year-old did not complete the Spin the Pots task, so analyses were run on the remaining 161 children; five 2.5-year-olds and two 3-year-olds did not complete the Fruit Stroop task, so analyses were run on the remaining 157 children. Levene’s test for equality of variance was significant for both the Spin the Pots task (F = 9.72, p = .002) and the Fruit Stroop task (*F* = 5.15, *p* = .03), so the corrected test not assuming equal variance between groups is reported. There was a significant improvement in working memory between 2.5 years (*M* = 7.45, *SD* = 2.58) and 3 years (*M* = 8.53, *SD* = 1.80), *t* (125) = - 3.05, *p* = .003. There was a marginal improvement in inhibitory control between the ages of 2.5 years (*M* = 4.37, *SD* = 2.02) and 3 years (*M* = 4.92, *SD* = 1.67), *t* (154) = - 1.82, *p* = .07. Finally, neither working memory scores nor inhibitory control scores were significantly correlated in 2.5-year-olds, *r*(82) = .11 , *p* = .10, nor in 3-year-olds, *r*(72) = .08, *p* = .44.

To test whether there was an effect of condition on post-switch accuracy a 4 x 2 ANOVA was run with condition and age group on post-switch accuracy, while controlling for pre-switch performance, which was a significant covariate (*F* (1,155) = 17.46, *p*  < .001, η2*partial* = .10. There was a significant main effect of condition on post-switch accuracy (*F* (3,155) = 6. 94, *p* <.001, η2*partial* = .12) (see Figure 2). Bonferroni *post-hoc* tests showed that this was specific to the Goal-Unrelated and Goal-Related conditions. Children in both conditions needed to switch rule while ignoring irrelevant information. However, when the to-be-ignored information was related to the pre-switch rule (as in the Goal-Related condition), children made significantly more errors than when the to-be-ignored information was not related to the pre-switch rule (as in the Goal-Unrelated condition) (*p* = .02). There was no significant difference between the Goal-Related Reactivation condition compared to the Goal-Related condition (*p* = 1.0), indicating that there was no additional cost due to having to reactivate a previously ignored dimension. In addition, there was no significant difference between the non-switching Baseline condition and the Goal-Unrelated condition: when children had to switch rules in the presence of task-irrelevant information not related to the previously relevant rule, their performance was no different to not having to switch rules at all (*p* = 1.0). There was a significant main effect of age on post-switch accuracy, with 3-year-olds (*M* = 6.76, *SD* = 1.61) significantly more accurate than 2.5-year-olds overall (*M* = 5.74, *SD* = 1.79), (*F* (1,155) = 4.78, *p* = .03, η2*partial* = . 03). Finally, the effect of condition did not differ as a function of age: there was no significant interaction between age and condition (*F* (3,155) = 0.25, *p* = .86).

Figure 6 Mean post-switch accuracy (0-8) by condition and age including standard error bars.

*p* = .01

To investigate how individual differences in inhibitory control and working memory related to switching while ignoring different types of irrelevant information, Pearson’s correlations were run for each age group. Because the Goal-Related and Goal-Related Reactivation conditions were not significantly different to one another they were combined to increase power. Similarly, because the Baseline Non-switching condition and the Goal-Unrelated were not significantly different, these two conditions were also combined. Seven children did not complete the inhibitory control tasks and three children did not complete the working memory task, so analyses were run on the remaining children. For 2.5-year-olds, neither inhibitory control nor working memory were related to switching accuracy in any of the conditions (all *ps =*  .40 - .96). For 3-year-olds, inhibitory control was significantly related to switching accuracy, but interestingly *only* in the conditions where the to-be-ignored information was previously relevant – the two Goal-Related switching conditions (*r*(38) = .31, *p* = .05). Inhibitory control was not related to switching accuracy when the to-be-ignored information was not previously relevant, as in the Baseline and Goal-Unrelated conditions (*r*(35)= .14, *p* ­= .66). Three-year-olds’ working memory was not associated with switching on any of the conditions (all *ps* = .54 - .60). A linear regression model confirmed that for 3-year-olds, Fruit Stroop score was a unique and significant predictor of accuracy in the Goal-Related condition and the Goal-Related Reactivation conditions, explaining 10% of the variance (*p* = .05) (see Table 1).

Table 5 Regression model fitting three-year-old inhibitory control scores (Fruit Stroop) to post-switch accuracy on the Goal-Related and Goal-Related Negative Priming switching conditions.

*B t p*

Inhibitory Control .39 2.42 .02

*R*2 = .15, *F* (1,36) = 6.17, *p* = .036.

**4. Discussion**

The present study aimed to determine what causes distraction errors in preschool children’s switching. It was found that children were able to switch rules when they had to ignore distracting information – provided that the information was unrelated to the rule they had previously sorted by. However, children made significantly more distraction errors when the information they had to ignore was related to a previous sorting rule. Notably, their performance was no worse when negative priming was also present (in other words, when children needed to re-engage with information that they had previously ignored). These results show that distraction errors are not due to general difficulties with selective attention, and that most kinds of non-relevant information can be ignored with relative ease, even by young preschoolers. Instead, distraction errors reflect persistent attention towards a previously relevant rule. This suggests that when children establish a sorting rule during the pre-switch phase, this rule continues to influence behaviour over time. What is striking is that this influence continues even when it is impossible for children to continue to match by the previously relevant rule – in other words, even when the rule itself no longer has any utility, it continues to influence children’s behaviour. Taken as a whole, the present results show that children’s distraction errors are specifically goal-related in nature, and arise from children continuing to preferentially attend to information consistent with a rule they previously used. This develops significantly between the ages of 2 and 3 suggesting that the ability to systematically maintain goal-directed behaviour in the face of distractions is a crucial milestone in the development of flexible cognition.

These data offer no support for the Selective Attention hypothesis. In the Goal-Unrelated condition, children performed extremely well, and were able to sort correctly by a new post-switch rule. Performance was so good as to be indistinguishable from the baseline condition, in which children did not switch rules at all. This supports the view that ignoring distracting information in general is trivially easy, for even young preschool children. The data also offer no support for the Negative Priming hypothesis. There is no evidence that Negative Priming causes distraction errors in preschool children, as performance in the Goal-Related Negative Priming condition was no different to the Goal-Related condition, in which there was no negative priming. It may be that children are highly efficient at re-engaging with previously ignored information, or more plausibly, that negative priming did not occur in the switching tasks reported here (a point that will be discussed further later). Conversely, the data offer clear support for the Rule Maintenance hypothesis: children made significantly more distraction errors when the information they had to ignore was related to a rule that was previously relevant. This strongly supports the idea that the rule established during the pre-switch phase continues to exert an influence on children’s subsequent behaviour. The next point to be addressed is how executive functions support switching in the presence of distracting information.

Switching performance in 3-year-old children was significantly predicted by inhibitory control, but not by working memory. Importantly, this was only the case in conditions where the to-be-ignored information was related to a previously relevant rule. This suggests that for 3-year-olds, the persistent attention to the no-longer-relevant rule stems from immature inhibitory control. These findings are consistent with the findings from Chapter two which showed that preschoolers’ inhibitory control was related to their ability to switch in the presence of task-irrelevant information. The present findings go further, to suggest that inhibitory control is only important when the to-be-ignored information is salient due to its relation to a previously relevant task. Switching performance in both 2- and 3-year-olds was unrelated to their working memory. This indicates that good working memory does not shield children from information that is distracting due to its association with a previous task.

No relation was found between switching and inhibitory control in 2-year-olds. This is somewhat surprising, since it contrasts both with the data from 3-year-olds, and with Chapter two of this thesis which report a positive relation between inhibitory control and switching in the presence of distractions in 2-year-olds. The reason for this discrepancy between present results and previous results is unclear. It may be due to unidentified between-sample differences, or it may arise from differences in the way that inhibitory control was measured across the two studies (with the Fruit Stroop task in the present study, and with the Reverse Categorisation task in the previous study). Given that there are strong theoretical grounds to think that inhibitory control helps preschoolers to resist distractions when switching, and given the consistent finding that 3-year-olds’ inhibitory control supports their switching behaviour, it is reasonable to speculate that inhibitory control is likely to play a role in 2-year-olds’ switching. The lack of a positive finding in the present study may indicate that the Reverse Categorisation task is a more sensitive measure of inhibitory control in 2-year-olds than the Fruit Stroop.

The present data further contribute to our understanding of the influence of negative priming on CF. Interestingly, the current study found no evidence that negative priming contributed to distraction errors. Children’s difficulty in ignoring information related to the initial sorting rule was no worse when children also had to re-engage with information they had previously ignored. There are two possible explanations for this effect, which are not mutually exclusive, but which remain to be disentangled. The first explanation is that negative priming may only occur at the values of the dimension (e.g. “blue”), not the dimension itself (e.g. “colour”). Therefore, negative priming may be more likely to occur on CF tasks with a particularly small set size (where children sort two colours and two shapes) compared to CF tasks with a larger set size, as in the current study, possibly because the more frequently that specific distracting information appears, the more it will be the target of active suppression. The second explanation is that negative priming may only occur in the presence of response conflict. In the current study, children never have to resolve response conflict; the absence of conflict during the pre-switch phase means that there is little need for children to actively suppress their attention to the non-relevant information. This is consistent with previous findings that negative priming is reduced in older preschoolers when response conflict is removed during the pre-switch phase (Müller *et al.,* 2006). The present results suggest that this may also be the case for 2-year-olds.

One striking result was that when the to-be-ignored information was unrelated to the previous task, children’s performance was very good – and indeed, no different to when they did not have to switch rules at all. This demonstrates that young preschoolers do not have problems with selective attention *per se*, and therefore already possess a necessary precursor ability for the development of advanced CF (Hanania & Smith, 2010). This is the first study to report that 2-year-olds can both selectively attend to a single dimension of a bivalent stimulus, and successfully switch their sorting behaviour from one rule to another (providing that the need to suppress attention to previously relevant information is minimised). It is worth noting in the present study that the stimuli children sorted did not involve any response conflict. There are grounds for thinking that selective attention is particularly important when children must switch tasks in the presence of response conflict, and that under such circumstances, otherwise easily ignored information can disrupt behaviour (e.g., Brooks *et al.,* 2003). However, the present data demonstrate that when response conflict is absent, even young preschoolers are able to switch from sorting by one rule to sorting by another.

The key finding from the present study is that children did not make distraction errors when the to-be-ignored information was not relevant during the pre-switch phase. However, there is an interesting comparison to be drawn between the present findings and those of the only other study to look at distraction errors in preschoolers. Chevalier and Blaye (2008) reported that children *did* make distraction errors when the to-be-ignored information was not relevant during the pre-switch phase (on a task where children switched between different colours, rather than between colour and shape). To reconcile this apparent difference, it is proposed that a distinction should be drawn between *inter*-dimensional switching and *intra*-dimensional switching. In Chevalier and Blaye’s study, children made an *intra*-dimensional switch; that is, they sorted by colour in both the pre-switch phase and post-switch phase, and switched between sorting pictures by different colour values (yellow to blue). The to-be-ignored information was a specific colour *value* that stayed constant throughout the task (green). Therefore the to-be-ignored information was relevant to the rule from the pre-switch phase (i.e. colour). In the present study, children made an *inter*-dimensional switch; that is, they sorted by one dimension in the pre-switch phase and a different dimension in the post-switch phase. Crucially, distraction errors only arose when the to-be-ignored information was relevant to the rule from the pre-switch phase. Together, these results suggest that distraction errors are likely to occur in the presence of information consistent with a previously relevant dimension, and are less likely to occur in the presence of information not consistent with a previously relevant dimension. Specifically, for 2 and 3-year-olds, distraction errors are mostly likely to occur if the to-be-ignored information contains *any* perceptual information related to the previously relevant rule.

The present study offers valuable insights into the nature of distraction errors in CF, and provides the first evidence to explain how these errors arise. This approach provides a new and essential complement to the substantial body of evidence looking at perseverative errors, and begins to shed light on the task demands that remain in CF even after the need to avoid perseveration is removed. It is now clear that young preschoolers’ switching performance is not inevitably disrupted by any kind of distracting information. Instead, the distraction errors they make are goal-related in nature: they arise from continued attention towards the dimension children previously sorted by. Furthermore, this influence persists even when it is not possible to continue to match by the previously relevant rule. The study suggests that the ability to maintain the relevant task rule in the face of distracting information is underpinned by inhibitory control. Together, these results suggest not only that key developments occur between the ages of 2 and 3 years, but also that systematically maintaining goal-directed behaviour in the face of distractions is a fundamental milestone in the development of flexible cognition.

Chapter Four

Flexible preschoolers have a better working memory, and neglect goals less often, than inflexible preschoolers

Chapter two reported a relation between preschoolers’ working memory and their ability to resolve response conflict when switching. The present study follows up this finding to more specifically address how working memory may support CF. Sixty-six 3-year-olds completed measures of CF, working memory and tasks of prospective memory which tap rule maintenance. Across both younger 3-year-olds and older 3-year-olds, switchers had stronger working memory and prospective memory. In contrast, mixed responders had poorer working memory and prospective memory. In particular, mixed responders were more likely to neglect goals both on an experimental task and a naturalistic prospective memory task. These results suggest that success on CF tasks that require children to resolve conflict draws upon children’s ability to strongly maintain rules.

**1. Introduction**

In Chapter two of this thesis, an association was found between working memory and children’s ability to switch rules in the presence of response conflict. Children aged 2 to 4 who responded unsystematically when the rule changed (so called ‘mixed responders’) had significantly poorer working memory than switchers. The working memory task used in Chapter two – Spin the Pots – is a classic measure of working memory, as it requires the combined maintenance, processing and updating of information. This study aims to broaden our investigation of this association to examine prospective memory – which is thought to specifically tap children’s ability to maintain goals – to better understand why children show mixed responding on the Conflicting SwIFT. The focus of this study is on 3 and 3.5-year-olds, the age at which response conflict switching most rapidly develops.

One influential account of CF development – the Graded Representations account – proposes that working memory plays the central role in supporting children’s CF (e.g., Munakata, 2001). The account argues that working memory supports CF by allowing children to maintain task rules. Maintaining task rules is particularly important during the post-switch phase, when children have to discard the old rule and update their behaviour in line with the new rule. While there is increasing evidence in support of this account, it remains notably vague in describing the precise mechanisms of how working memory supports CF. Working memory is a multi-faceted cognitive skill involving both short-term memory processes involved in the maintenance and retrieval of information and high-level processes that include maintaining information in the face of interference, and processing and updating information held in working memory (e.g., Garon *et al*., 2008; Gathercole *et al.,* 2008; Kane & Engle, 2003; Miyake & Shah, 1999). Therefore, it is important to determine precisely *how* working memory supports CF.

Links between CF and working memory in older preschoolers have been found on a variety of tasks tapping different components of working memory, including both complex maintenance and processing tasks and simple short-term memory retrieval tasks. For example, Marcovitch *et al*., (2008) found that 4- and 5-year-olds’ performance on standard measures of working memory that required both maintenance and processing of information – the backward word span and the backward digit span – was associated with their ability to switch rules on the DCCS. They found that this was particularly the case on a version which required more rule maintenance: the ‘Mostly Redundant DCCS.’ The experiment reported in Chapter two of this thesis found that performance on a task requiring the combined maintenance and updating of information related to children’s CF, but only on a version where children had to resolve response conflict. Together, this research suggests that working memory – including the maintenance, processing and updating of information – is important on CF tasks, particularly in cases when children have to resolve response conflict.

Associations have also been found between CF and basic rule retrieval tasks that simply require children to retrieve task rules from short-term memory. Blackwell *et al*., (2009) found that 5- to 6-year-olds who could switch rules on the DCCS responded to simple questions about what the current rule was on a separate pattern matching task more quickly and accurately than perseverators. The researchers argued that switchers have a better working memory and this enables them to maintain rules more strongly, as evidenced by their ability to retrieve these rules more quickly than perseverators. Working memory may therefore support CF through more basic rule maintenance processes that allow children to actively maintain information in short-term memory – as opposed to supporting CF through better working memory capacity – the amount of items that children can remember – or via the more complex ability to process and update information (e.g., Chevalier *et al*., 2012).

One relatively understudied aspect of memory that may be crucial to CF is prospective memory. Prospective memory research has proceeded separately from research on CF, however it may help elucidate whether working memory supports CF via basic rule maintenance and retrieval or via the processing and updating of information. This is because prospective memory predominantly relies upon rule maintenance and retrieval skills. Prospective memory is the ability to remember to carry out an intended action at an appropriate time in the future while being actively engaged in an unrelated activity. This type of memory directly relates to many everyday situations, for example planning to buy a pint of milk after work, or planning to say happy birthday to a friend. Prospective memory tasks are thought to involve three phases: the encoding of the intention or task rule, the maintenance of this rule, and the execution of the rule when the appropriate cue appears (e.g., Causey & Bjorklund, 2014). Errors of prospective memory are considered an example of goal neglect – a failure to act according to a rule or intention, despite understanding task requirements (Roberts & Anderson, 2014). These errors are thought to reflect a failure of rule maintenance in working memory. Importantly, CF may draw upon the same rule maintenance processes required on prospective memory tasks – though very little research to date has examined these hypothesised links empirically (see Mahy & Munakata, 2015 for a discussion). It is worth noting that there are striking similarities between the Graded Representations account of CF development and the Task Model account proposed to explain goal neglect in adults (Duncan *et al*., 2008). In the Task Model account, goal neglect is thought to occur when task goals are weakly represented in working memory. This account can explain why adults are more likely to neglect goals on prospective memory tasks when they have to follow more than two instructions, or when the instructions are more complex and have greater detail to process. The more information that needs to be represented, the greater the competition in working memory for space, and so the poorer the maintenance of goals.

Prospective memory is first demonstrated at around age 3. In one of the first prospective memory studies in preschoolers, Kleigel and Jäger (2007) had 2- to 6-year-olds name picture cards of everyday objects. The key instruction was that when children saw an apple card, they were to place it in a box behind them. Two-year-olds failed at this task (their performance was not statistically different from zero). Four- to 6-year-olds performed significantly better than 3-year-olds, suggesting that prospective memory can first be measured at age 3. Since then, research on prospective memory has tended to focus on understanding its development in 4- to 6-year-olds. For example, Mahy, Moses and Kleigel (2014) had 4- and 5-year-olds play a game where they helped a family move house. To do this, children had to put pictures of big or little household items into matching big or little boxes (the ongoing part of the task). Children were told that the family were also looking for their pet animals. If children saw a pet animal, they were instructed to ring a bell placed behind them, and not to put the pet into the box (the prospective memory part of the task). To place greater demands on maintenance and retrieval, Mahy and colleagues had children then complete a three-minute distractor task before the prospective memory task began. This task may be a purer measure of prospective memory compared to Kleigel and Jäger’s task because the pet animals looked distinct to the household items pictures, and they were neither big nor small so they do not require children to inhibit responding in the same way as the non-targets. Mahy *et al*., (2014b) found significant improvements on this task between the ages of 4 and 5. This research shows that prospective memory can be measured in preschoolers, and that like standard executive functions, it rapidly develops over the preschool period.

The present study aimed to get a more comprehensive understanding of why 3-year-olds fail to switch in the presence of response conflict, and how this relates to their memory skills. In this study, working memory is considered an umbrella skill which involves several different specific functions: (i) rule maintenance and retrieval and (ii) processing and updating of information. Prospective memory is considered to primarily tap the former two functions: maintenance and retrieval; whereas standard working memory tasks primarily tap the latter two functions: processing and updating of information. In order to more clearly specify how these functions support children’s ability to switch in the presence of response conflict, children are tested on different measures of prospective memory - that draw upon children’s rule maintenance and retrieval skills – and tested on standard measures of working memory that draw upon children’s processing and updating skills.

In this study, 3-year-olds completed the Conflicting SwIFT and two measures that require the processing and updating of information (i.e., standard working memory tasks): the Spin the Pots task and the Self-Ordered Pointing task. The Spin the Pots task was included to test whether the results in Chapter two would be replicated. The Self-Ordered Pointing task was included as an additional test of the relationship between CF and working memory. The Self-Ordered Pointing involves presenting children with the same set of stimuli, and each time children have to point to a different stimulus that they have not pointed to before. The task was chosen because it has been shown to be largely independent of children’s verbal ability (Cragg & Nation, 2007). Both of these working memory tasks require children to not only maintain information but also process and update that information. For example, on Spin the Pots, children have to process and update information on where the stickers are every time that they find a sticker, in order to not search in an empty box. On the Self-Ordered Pointing task, children have to maintain and process increasing amounts of information and revise the contents of their working memory each time they select stimuli so children know not to select the same stimulus. To test whether there was a relation between CF and prospective memory, children completed two measures of prospective memory – both an experimental task-based measure of prospective memory (called “Find the Pets”) and a naturalistic task (called “Remember the Stickers”). Both of these tasks involves maintaining information over a period of time and retrieving that information when it is needed. Because there are so few studies that have examined prospective memory in 3-year-olds, the task used in this study was adapted from the task used by Mahy *et al*., (2014b). Pilot testing with 3-year-olds was conducted beforehand to ensure that the task was age appropriate. Based on the pilot testing, some changes were made to the task, including: reducing the number of cards that children had to categorise from 96 to 32; removing the three-minute distractor task; and placing the bell that children had to ring upon seeing a target card in front of the child (not behind them like in Mahy *et al*). For the naturalistic prospective memory task, because motivation has been found to be a key factor in supporting young children’s success on these tasks (Ślusarczyk & Niedźwieńska, 2013), the task used was adapted from one used by Casey and Bjorklund (2014). Children were given some stickers at the start of the session, which were then put aside for safe keeping. Children therefore had to remember to retrieve their stickers at the end of the session.

In line with the results reported in Chapter two, children’s CF performance was examined as a function of three different performance types that reflect qualitatively different types of CF on the Response Conflict SwIFT: perseverators, who score 0-2 out of 8; mixed responders, who score 3-5 out of 8; and switchers, who score 6-8 out of 8. In addition, in order to test whether mixed responders are failing to maintain the rule in the face of response conflict, or whether they are simply responding randomly, two univalent trials were included at the end of the post-switch phase. These final two trials removed all response conflict from the stimuli and depicted either the outline of a shape or a patch of colour, depending on the post-switch sorting rule (see Figure 1, Chapter two). If children only demonstrate mixed responding when presented with response conflict, children should show good performance on these final two trials.

**2. Method**

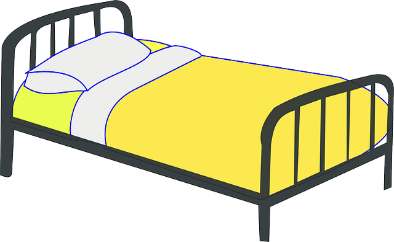
*Participants*

Seventy-one 3-year-olds took part in the study (29 females and 42 males). Data from five children were excluded: one child was later diagnosed with Specific Language Impairment, and four failed to understand the task instructions. The remaining sample of sixty-six children were split into two age groups: 34 3-year-olds (*M* age: 3;4 years; range: 3;0 years – 3;6 years) and 32 3.5-year-olds (*M* age: 3;10 years; range: 3;7 – 4;1 years). Children were recruited either from a database of local families who had expressed an interest in participating in research, or from local schools. All children were monolingual, were from homes or schools in working-class and middle-class areas of the UK, and the majority were white British. Informed consent was obtained from parents before testing began. Ethical approval was obtained from the department’s ethics sub-committee (see Appendix 1)..

*Materials*

The Spin the Pots task used eight visually distinct boxes attached to a rotating circular wooden tray, and six colourful stickers (as described in Chapter two). For this task, the stickers that children won formed part of the naturalistic prospective memory task (Remember the Stickers). For this task, a small yellow drawstring gift bag was used (approximately 6cm x 8cm). For the Self-Ordered Pointing task, laminated A4 sheets of paper were used, depicting different cartoon animals. For the Find the Pets task, three A4 pictures were used: one picture of a cartoon family standing by a house, another picture showing the same family standing by a different house, and a sheet showing four different pet animals (a dog, a cat, a hamster and a goldfish). Two square boxes were also used: one large box (25cm x 25cm x 25cm) and one small box (12cm x 12cm x 12cm), as well as a set of 36 small laminated cards depicting household items (size: 8cm x 10cm; see Figure 7 for an example of the pictures used). Sixteen of these showed pictures of small household items (e.g., lamps, cutlery). These items are both small in real life, and were also depicted as a small picture on the cards. Sixteen cards showed pictures of big household items (e.g., beds, settees); these were household items that are big in real life, and were also depicted as a big picture on the cards. Four cards depicted the pet animals (a dog, a cat, a hamster and a goldfish). These were all medium sized. The Conflicting SwIFT was administered on a touchscreen computer (see Chapter two for a description of the materials used).

Figure 7. Find the Pets. An example of each of the three different types of card used in the task: one card depicts small household items, one depicts big household items and one depicts a pet animal.



*Procedure*

Children were tested in a single session, either in the University Developmental Lab with their caregiver present, or in a quiet area of their nursery. Throughout the tasks, the child sat at a table next to the experimenter. Children completed five tasks in a fixed order: Spin the Pots, Find the Pets, Self-Ordered pointing, Response Conflict SwIFT and Remember the Stickers.

*Spin the Pots:* Children first completed the Spin the Pots task as a measure of their processing and updating ability (Hughes & Ensor, 2007). See Chapter two for a description of the procedure. Spin the Pots task scores are reverse coded for ease of interpretation (16 minus the number of attempts taken to find all the stickers).

*Remember the Stickers (part one):* After children had found all of their stickers, they were put into a gift bag. The experimenter checked that the children would like to take them home (all children said yes). The experimenter then told the child that they would play some more games, so the experimenter would look after them by placing them in a set location (which was always at the end of the table to the right of the experimenter). Children did not walk past this location on the way out. The child was told that the experimenter could be forgetful, so it was important once they had finished playing for the child to remember to get their stickers on their way out.

*Find the Pets:* This measure of prospective memory was adapted from Mahy *et al*., (2014). Children had to help a family move house by putting pictures of household items into big or little boxes according to their size (see Appendix 2 for the exact wording). Children were told that the family were also looking for their pet animals, who were hiding amongst the household items. Children were instructed that if they saw a pet animal, they needed to ring a bell and not put the pet in a box. To help explain the story, children were first shown a picture of a cartoon family beside a house and then shown a second picture of the family beside a new house that looked very different. Children were told that the family needed their help sorting their household items into boxes to take to their new house. Children were then shown a large square box and a small square box, which were placed on the table in front of the child. The experimenter asked to the child to identify the large box and the small box (all children were able to do this). The location of the boxes was counterbalanced across children (half the children had the big box on the right side and half had it on the left side). Children were then shown the deck of 36 laminated cards comprising 32 non-target cards depicting items of big and small household items (including four for demonstration and practice trials) and four target cards depicting the pet animals. These target cards were placed in positions 9, 18, 24 and 29 in the deck (the cards stayed in the same order for each child). Children watched the experimenter complete two demonstration trials (one of each household item’s size) and then completed two practice trials with feedback (one of each household item’s size). Children were then told that the family had four pet animals hiding among the household items, and it was the child’s job to find them and not put them in the boxes. Children were then shown pictures of the four pets, and were asked to name each one of them. The experimenter then repeated the instruction that these animals were hiding in the household items and the child needed to find them. If they saw the animal, they had to ring a bell which was placed in front of the child in between the two boxes. To engage them, children practiced ringing the bell. The experimenter then passed the children the remaining 32 cards to sort. Children received a score for the number of non-target household items cards correctly categorised as big or little (this ranged from 0-28), known as ongoing task performance. Prospective memory was calculated as the number of animal cards identified and not sorted into the boxes (this ranged from 0-4).

*Self-Ordered Pointing:* This task was adapted from Willoughby, Blair and Greenberg (2011) as a second measure of children’s processing and updating ability. In the task, children were presented with a laminated A4 sheet depicting different animal pictures. Children had to point to a picture on each trial with the aim of giving each of the animals ‘a turn.’ In other words, children had to select all animals across trials, and point to each animal only once. Children first watched a short demonstration trial and then completed a practice set of two animals. The experimental phase consisted of three sets of two animals and three sets of three animals. The task ended if children got two trials in any block incorrect (by pointing to a picture they had already chosen). The spatial arrangement of the animals on the page varied randomly across the trials so that the spatial location was not informative. Therefore, children had to rely on their memory for which animal they had selected previously. Children received a score of one if they pointed correctly to an animal they had not selected before. The first point is not scored as this simply served as a reference from which all other responses are calculated. Scores ranged from zero to nine.

*Conflicting SwIFT:* Children completed the same Conflicting SwIFT task as reported in Chapter two (twelve pre-switch trials and eight post-switch trials). The key feature of this task was that when the rule changed, children needed to resolve response conflict as the incorrect answer matched the prompt on the previously relevant rule. In this study, two univalent stimuli trials were added right at the end of the task (see Figure 1 in Chapter two for an example of univalent stimuli).

*Remember the Stickers (part two – test phase):* This was a test of children’s prospective memory in a naturalistic context. It was adapted from tasks used by Ślusarczyk and Niedźwieńska (2013) and Causey and Bjorklund (2014).When children completed the last trial of the SwIFT, the experimenter said “Well done, we’re all finished now!” and stood up as a cue to children that they had finished playing. The experimenter then proceeded to walk out of the testing room with the child. If the child remembered to retrieve the stickers without any further cue, the child received a score of three. If the child and experimenter got the door without the child remembering the stickers, the experimenter gave them a prompt: “Was there something that you needed to remember?” Children received a score of two if they remembered the stickers on this prompt. If this did not cue them remembering the stickers, children were given a second prompt: “Was there something you were supposed to ask me for?” Children received a score of one if they remembered the stickers on this prompt. If children did not remember the stickers, the experimenter retrieved the stickers for the child and they received a score of zero. The overall time from first finding the stickers on the Spin the Pots task to the end of the session was approximately 15 minutes.

1. **Results**

First, preliminary analyses were run to check for any effect of gender or initial sorting rule (colour first or shape first) on task performance. Chi-square analyses found no significant effect of sex or initial rule on CF (*p* = .33). A series of independent-samples t-tests found no significant effect of sex on working memory or prospective memory (*ps*  = .26 - .64). All children were able to categorise over two-thirds of the non-target household items cards correctly (all children sorted at least 20 out of 28 cards correctly) on Find the Pets, suggesting children understood the task rules and were engaged in the ongoing task (range: 20-28, *M* = 25, *SD =* 2.43). Finally, 92% of children got both of the univalent trials correct at the end of the post-switch phase on the SwIFT (*N* = 61). Of the five children that made an error on these two univalent trials, four had perseverated in the post-switch phase and one had been a mixed responder in the post-switch phase.

Age-related analyses were also run to examine whether there were significant differences between 3 and 3.5-year-olds on the tasks. Three-year-olds and 3.5-year-olds performed significantly differently on the Conflicting SwIFT, *X*2 (2, *N* = 66) = 8.46, *p* = .02 (see Figure 8). Three-and-a-half-year-olds were significantly more likely to switch rules on the Conflicting SwIFT, and were significantly less likely to show mixed responding. A one-way ANOVA found a significant effect of age on all of the memory tasks. Three-and-a-half-year-olds performed significantly more accurately than 3-year-olds on Spin the Pots (*p* = .01), Find the Pets (*p* = .002), and Self-Ordered Pointing (*p* = .004). They were also significantly more likely to remember their sticker at the end of the session (*p* = .003) (see Table 6). Therefore, age was controlled for in the individual difference analyses. Because this is one of the first studies to examine different working memory skills in preschoolers, correlational analyses are of interest in assessing the extent to which these skills are related. Partial correlations were run, after controlling for age in months (see Table 7).

Figure 8. The percentage of children classified as mixed responders, perseverators or switchers per age group on the Conflicting SwIFT.

Table 6. Mean memory task scores by age group

3-year-olds 3.5-year-olds

Spin the Pots (0-10) 7.56 (2.27) 8.97 (1.58)

Find the Pets (0-4) 1.53 (1.97) 3.00 (1.70)

Self-Ordered Pointing (0-9) 5.53 (3.05) 7.47 (2.013)

Remember the Stickers (0-3) 1.44 (1.26) 2.22 (.66)

Note: Standard deviations are in parentheses. On all of the tasks, 3.5-year-olds performed significantly better than 3-year-olds.

Table 7: Correlations between the memory tasks after partialling out age

1 2 3 4

1. Spin the Pots

2. Find the Pets .17

3. Self-Ordered Pointing .29\* .46\*\*

4. Remember the Stickers .22† .35\*\* .35\*\*

Note: † p < .10 \* p < .05 \*\* p < .01.

To test for associations between CF, working memory and prospective memory, a multivariate ANOVA was run with CF performance type (perseverator, mixed responder, switcher) on each memory task score, with age as a covariate. Ongoing task performance (i.e., the number of household items cards that children sorted correctly) in the Find the Pets task was also included as a proxy measure for motivation, to check whether CF would be related to performance on a task where no relation would be predicted. Age was a significant covariate on Spin the Pots (*p* = .02) and ongoing task performance (*p* = .03). Age was not a significant covariate on Find the Pets (*p* = .23), Self-Ordered Pointing (*p* = .10) or Remember the Stickers (*p* = .11). After accounting for age, CF performance type was a significant predictor of performance on Spin the Pots, *F* (2,62) = 4.24, *p* = .02, η 2*partial* = .12, Find the Pets, *F* (2,62) = 8.50, *p* = .001, η 2*partial* = .22, Self-Ordered Pointing, *F* (2,62) = 3.40, *p* = .04, η 2*partial* = .10 and Remember the Stickers, *F* (2,60) = 4.63, *p* = .01, η 2*partial* = .13 (see Figure 9). Importantly, there was no significant effect of CF performance type on the numbers of household items cards children sorted correctly *F* (2,60) = 1.33, *p* = .27.

To follow up the significant effect of CF performance type, Bonferroni *post-hoc* tests were conducted. For Spin the Pots, mixed responders performed significantly worse than switchers (*p* = .02). For Find the Pets, mixed responders were significantly poorer than switchers (*p* < .001), and perseverators were marginally poorer than switchers (*p* = .053). For Self-Ordered Pointing, mixed responders were significantly poorer than switchers (*p* = .03). For Remember the Stickers, mixed responders were significantly poorer than switchers (*p* = .02). No other comparisons were significant (*p* = .12 – 1.0).

To test whether there was a significant effect of performance type on Find the Pets after controlling for ongoing task performance (number of household cards sorted correctly), an ANCOVA was run also controlling for age. Ongoing task performance was a significant covariate, *F* (1,61) = 7.50, *p* = .008, η 2*partial* = .11 and age was not, *F* (1,61) = .23, *p* = .63 Crucially, the effect of performance type on prospective memory remained significant after controlling for both age and ongoing task performance, *F* (2,61) = 6.81, *p* = .002, η 2*partial* = .18.

Figure 9 Mean memory task scores each performance type on the Conflicting SwIFT

1. **Discussion**

This study sought to better understand why 3-year-olds have difficultly switching in the presence of response conflict by examining their performance on various measures of working memory and prospective memory. CF performance was associated with both working memory and prospective memory. However, this was specific to children who were classified as mixed responders on the Conflicting SwIFT. Mixed responders had significantly poorer working memory than switchers. This finding is consistent with the results reported in Chapter two which showed that mixed responders had the poorest working memory on the Spin the Pots task. The present results not only replicate that finding, but also extend the finding to a different measure of working memory. The present study went further to show that mixed responders also had significantly poorer prospective memory. This was found both on a task-based measure and on a naturalistic measure. On the measures of prospective memory, mixed responders were significantly more likely to neglect the task goal. The relation was to some extent also found in perseverators who had marginally poorer prospective memory on the task-based measure. However, this was not found on the naturalistic prospective memory task, nor on the measures of working memory. Together, these findings suggest that mixed responding is a distinct type of error from perseveration, and that it reflects an inability to both maintain and process the current task rule.

The strongest relation was found between children’s CF and their prospective memory. This suggests that rule maintenance is the more crucial aspect of working memory that underpins CF and not the combined processing andupdating of information. Mixed responders had significantly poorer prospective memory compared to switchers. What is interesting about both of the prospective memory measures was that maintaining and responding to the rule was rewarding and motivating for preschoolers: children either got to ring a bell or got their stickers. However, some children still failed to carry out this instruction. These children were more likely to show mixed responding on the Conflicting SwIFT. The relation between children’s CF and prospective memory was robust: CF predicted their performance on these measures of prospective memory better than age.

The relation between prospective memory and switching in the presence of response conflict is likely to be due to the common requirement on both tasks for rule maintenance. On the Conflicting SwIFT, rule maintenance is required because the currently relevant rule cannot be inferred from the task array and therefore must be maintained in working memory. On this version of the task, the stimuli can be sorted by the old rule or the new rule, therefore it is essential that children maintain the current sorting rule. Similarly, rule maintenance is the crucial component of prospective memory tasks, as children must remember to carry out a particular action. On prospective memory tasks, rule maintenance is thought to be more important than rule retrieval. In support of this, both adults and children have been found to actively maintain the rule on prospective memory tasks (Smith, 2003; Leigh & Marcovitch, 2014). Evidence for this comes from examining reaction times on non-target trials. For example, Leigh and Marcovitch (2014) had 4- to 6-year-olds categorise stimuli according to whether it was a food or an animal. However, when children saw a duck or an apple, they had to instead select a smiley face at the top of the screen. They found that all children were significantly slower at categorising non-targets when they were given the prospective memory instruction, compared to a control version where children simply categorised the stimuli. What this suggests is that children use an active maintenance strategy throughout the task, rather than retrieving the rule when the target appears.

Interestingly, performance on the Spin the Pots task was not significantly correlated with Find the Pets, and was only marginally correlated with Remember the Stickers. However, it did correlate with the other measure of processing and updating: Self-Ordered Pointing. The lack of relation between Spin the Pots and prospective memory is not consistent with research suggesting that prospective memory and working memory are related in middle childhood (Kerns, 2000; Mackinlay, Kleigel & Mantyla, 2009). However, it suggests that at least for 3-year-olds, these two tasks are measuring separable skills. This may be because the Spin the Pots task places more demands on working memory capacity and updating. On the task, children have to maintain increasingly large amounts of information over time as they find each sticker (each sticker they find means children have to maintain memory of another empty box to avoid searching there) and they have to update the information every time they find a sticker. In contrast, Find the Pets places more demands on maintaining a small amount of information but over a longer duration. This may place greater demands on the strength of children’s rule maintenance, as opposed to their working memory capacity.

It is noteworthy that mixed responders were significantly poorer on Remember the Stickers. This naturalistic measure of prospective memory was assessed according to whether children remembered to retrieve their stickers at the end of the testing session. This suggests that mixed responders may be less likely to maintain goals in everyday life, given that this measure is akin to what children need to do in everyday situations. The relation between mixed responding and children remembering to retrieve their stickers remained significant after controlling for age. This suggests that it is not simply because younger children are likely to perform more poorly on the Response Conflict SwIFT and retrieving their stickers. Interestingly, the result suggests that the very same rule maintenance processes that children use to succeed when switching in the presence of response conflict are also used to help maintain goals in everyday situations. Mixed responders – who show a complete absence of top-down controlled behaviour – are more likely to maintain their own personal goals over time.

Children’s performance on the two univalent trials helps to shed light on children’s mixed responding. Accuracy was near-ceiling on these two trials that removed all response conflict and were placed at the end of the post-switch block. This shows that mixed performance does not arise simply because children are failing to engage with the task and are responding erratically. If this was the case, children would have made errors on these two trials. Only one child who made an error on these trials had been a mixed responder in the post-switch phase. Instead, performance was mostly at ceiling, suggesting that children’s difficulties switching only arise when children are presented with bivalent stimuli and children have to either resolve response conflict or ignore distracting information.

These data strongly suggest that perseverative errors and mixed responding errors reflect qualitatively different stages of CF development. Both the results from this study and the results presented in Chapter two suggest that the developments in children’s ability to switch in the presence of response conflict between the ages of 3 and 3.5 years may be being driven by improvements in rule maintenance. It is notable that between the ages of 3 and 3.5 three skills appear to rapidly develop: response conflict switching, working memory and prospective memory. Improvements in CF are due to a significant decrease in mixed responding. Therefore, this suggests that developments in rule maintenance skills between 3 and 3.5 years of age mean that children’s performance becomes more stable and either children become switchers who can maintain the new rule, or they may become perseverators and inappropriately maintain the no longer relevant rule. Either way, the data suggest that mixed responding is a qualitatively different type of error to perseveration and that mixed responding reflects a complete absence of top-down rule-guided behaviour. This research suggests that perseverative errors are not solely due to poor working memory or rule maintenance. Perseverators were only marginally poorer on the prospective memory task than switchers, and were not significantly different to switchers in terms of working memory. This suggests that perseveration is not caused by the same processes as mixed responding. The results from the thesis so far suggest that perseveration is a developmental stage that follows on from mixed responding. Therefore, perseveration is a marked improved on mixed responding as it represents children making errors in a systematic way that may reflect improvements in rule maintenance. Improvements in rule maintenance introduces stability in responding because children inappropriately maintain the pre-switch rule.

Overall, the results help us to both: (i) better understand the relation between working memory and children’s ability to switch in the presence of response conflict and (ii) add support to the idea that mixed responding is a qualitatively different type of error from perseveration. Successful CF performance on the Conflicting SwIFT was associated with better working memory, both in terms of rule maintenance and in terms of children’s ability to process and update information. Three-year-olds who failed to maintain the goal on the CF task showed mixed responding and these children had poorer working memory and prospective memory – both on a task-based measure and in a naturalistic context – compared to switchers and perseverators. Overall, this suggests that mixed responding is caused by 3-year-olds’ difficulty in maintaining rules strongly in working memory when they have to resolve response conflict. The results are in line with the Graded Representations account of CF development in suggesting that it may not be children’s capacity *per se*, but the strength at which children can maintain goals (e.g., Blackwell *et al*., 2007).

Chapter Five

Does working memory training improve cognitive flexibility in three-year-olds?

Chapters two and four reported an association between preschoolers’ working memory and their ability to switch in the presence of response conflict. This study tested whether working memory causally underpins CF in 3-year-olds. The study focuses on 3-year-olds, the age at which children’s ability to switch in the presence of response conflict significantly develops. Working memory training has been shown to improve older children’s performance on non-trained measures of working memory and executive functions. However, to date there have been no training studies conducted with 3-year-olds. In this experiment, 34 3-year-olds were randomly assigned to either a working memory training program or to an active control condition. Children in both groups completed computerised tasks in four short weekly sessions. Children in the training group significantly improved their performance on a non-trained measure of working memory relative to an active control group. In addition, there was some evidence that training improved children’s CF. Together, the results suggests that working memory at 3 years of age may causally underpin children’s ability to switch in the presence of response conflict.

**1. Introduction**

Cognitive training has been shown to improve a variety of executive functions in school-age children (e.g., Melby-Lervåg & Hulme, 2013). Many of these studies have focused on working memory training. The idea is that by completing several sessions of computerised working memory tasks, children’s working memory capacity or working memory efficiency will improve. While evidence for the effectiveness of working memory training in adults is very mixed (see Shipstead *et al*., 2012), developmental studies have consistently shown that between 14 and 25 sessions of working memory training improves children’s performance on non-trained measures of working memory, compared to an active control group (Dunning, Holmes & Gathercole, 2013; Henry, Messer & Nash, 2014; Thorell *et al*., 2009). The current study utilised this approach to test whether working memory and switching in the presence of response conflict are causally related. Both in Chapter two of this thesis and in previous research, working memory has been shown to be associated with children’s CF (e.g., Chevalier *et al*., 2012; Marcovitch *et al*., 2010). However, this evidence is correlational, and thus it remains important to test this relation in a causal way. Training studies provide a means to address this question. If targeted cognitive training programs lead to specific improvements in a skill, this suggests that the skills are causally related. Surprisingly, however, research using cognitive training studies in this theoretically motivated way are lacking (Wass, 2015). In the present study a short working memory training program is tested to examine if this would lead to improvements on non-trained measures of working memory, and whether this in turn would improve 3-year-olds’ ability to switch in the presence of response conflict.

Cognitive training studies are a potentially useful methodological tool to find out about the nature of CF. However, to date, CF training research has focused on giving children training on task specific CF skills as opposed targeting the executive functions underpinning CF using cognitive training. Previous studies have utilised different training designs – such as guided practice sorting by a dimension – to learn more about CF. For example, in two separate studies Mack (2007) and Ramscar, Dye, Gustafson, and Klein (2013) had 3-year-olds first complete a task where they were trained to attend to both dimensions of a stimulus. Children then completed the DCCS. In both of these studies, children who completed the training task subsequently did better on the DCCS compared to children who completed an unrelated task. Similarly, Perone, Molitor, Buss, Spencer and Samuelson (2014) had 3-year-olds complete a colour matching memory game before completing the DCCS. Three-year-olds who completed this game were significantly more accurate on the DCCS specifically when switching from shape to colour. By using a training study design, these studies demonstrate that there are causal relations between children’s ability to selectively attend to dimensions and CF performance. Extending this training study approach to examining whether working memory underpins CF using a training designed to target specific cognitive functions is likely to be informative.

There are no studies to date that have used a cognitive training approach to test what skills underlie CF. However, a handful of studies have trained school-age children and adolescents on CF tasks directly. Karbach and Kray (2009) gave 8-year-olds and adults four sessions of CF training. The CF training task was an alternating runs paradigm. Alternating runs paradigms involve sorting stimuli by one rule for two trials and then switching to sorting stimuli to another rule for two trials. This sequence of switching after two trials repeats throughout the task. Children and adults who received this CF training showed reduced switch costs on a non-trained alternating runs CF paradigm, compared to an active control group. In addition, trained children and adults improved their performance on measures of inhibitory control and working memory. The findings from this study are important because they suggest that there are causal relations between CF and working memory and inhibitory control in older children and adults. However, other researchers have argued that Karbach and Kray’s training program was really targeting working memory as opposed to CF; on alternating runs paradigms, participants must keep track and remember when to switch rules, demands which are likely to tax working memory. This may also explain why there was such widespread transfer to other skills (Pereg, Shahar & Meiran, 2013). This demonstrates how crucial it is to clearly specify what skills the training tasks are targeting. In this respect, homogenous training programs that target one specific cognitive skill are thought to be preferable when understanding causal mechanisms (Wass, 2015).

The majority of previous cognitive training studies have focused on middle childhood (see Wass, 2015). Very little research has examined the effectiveness of cognitive training programs designed toIt is target specific cognitive functions in early childhood. It is noteworthy that to date there have been no cognitive training studies conducted in 3-year-olds. This is surprising because it has been argued that cognitive training may be more effective during the period from infancy to preschool, when there is greater plasticity in prefrontal cortex networks thought to underlie executive functions (Wass, Scerif & Johnson, 2012; Heckman, 2006). In line with this, meta-analyses have found greater effect sizes for transfer of training in younger children compared to older children (Melby-Lervåg & Hulme, 2013). The three-year-old age group is of particular interest, as this is when there are rapid developments in children’s ability to switch in the presence of response conflict (see Chapter two).

The present study tests the effectiveness of a working memory training program for 3-year-olds. The training program was short, designed to be easily administered in a school setting. Three- to four sessions of cognitive training have been previously shown to be effective in leading to transfer in older children (e.g., Karbach & Kray, 2009) and infants (Wass *et al*., 2011) although such short training programs are rare. Most cognitive training studies typically have between 20 and 25 sessions. In the present study, 3-year-olds completed four sessions of working memory training. In every session, children completed three tasks tapping various different aspects of working memory including maintenance, processing and updating. Some of these tasks required children to maintain information over periods of time, and others required children to maintain increasingly large amounts of information. One important lesson from previous training research is that the training tasks used are most effective when they are adaptive: that is, they get harder when a participant’s performance gets better on the tasks (Shipstead *et al*., 2012). However, because preschoolers’ performance is known to be variable within executive function tasks (van Bers *et al.*, 2011), to minimise potential within-task variance, two out of the three training tasks were only adaptive *between* each session. These two tasks were chosen because they were made adaptive by manipulating the amount of time children had to maintain information. It was felt that timing manipulations may lead to within-task variance because they are less intuitive to explain to preschoolers than more concrete features (such as the number of items children need to maintain). To robustly test the effectiveness of training, improvements were assessed by examining whether children improved on very different, non-trained measures of executive function and CF compared to an active control group. This ensures that training is improving the construct, as opposed to improving performance on a specific task. In addition, an active control group was also included where children completed tasks not requiring working memory.

It was predicted that only children in the training group would improve their working memory following training. Furthermore, it was predicted that only children in the training group would improve their ability to switch in the presence of response conflict. In line with the findings presented in Chapter two, children’s CF was examined in a categorical way, according to whether they were mixed responders, perseverators or switchers. The results from this thesis so far have strongly suggested that these categories reflect qualitatively different performance types, with mixed responding reflecting the most immature form of CF, followed by perseveration and then successful switching. Therefore, this approach is continued in the present study. Measures of inhibitory control were also included to test whether working memory training leads to widespread executive function transfer. A measure of processing speed is also included to test how far training improves basic cognitive processes.

**2. Method**

*Design*

Children completed baseline measures of working memory, inhibitory control, CF and processing speed. Children were then randomly assigned to either the Training group or the Control group, with the sole constraint that children were randomly allocated from each of the four participating preschools to ensure that children were distributed equally across the two groups. Both groups completed four weekly 15-minute sessions of computerised tasks. Baseline measures were readministered one week after training (the post-test session). The post-test assessments were conducted by an experimenter blind to the child’s condition.

*Participants*

Initially, 48 children were recruited from four preschools in lower- or middle-class areas of the UK. Seven children missed a training session and seven missed the post-test session, so the final sample comprised 34 children: 17 in the Training group (*M* age = 3;7 years, range = 3;2 years – 3;11 years, *SD* = 2.88; 12 males, 5 females), and 17 in the Control group (*M* age = 3;7 years, range = 3;0 years – 3;11 years, *SD* = 3.45; 11 males, 6 females). Informed consent was obtained from teachers and caregivers. Children received a small gift after the final session. Ethical approval was obtained from the University’s Psychology ethics sub-committee (see Appendix 1).

*Procedure and Materials*

Children were tested individually in their preschool. All training and control tasks were administered on an Iiyama touchscreen connected to a PC running E-Prime software (Psychology Software Tools, Pittsburgh, PA). To make the training and control tasks as similar as possible, identical stimuli were used in the training and control tasks, and feedback was provided in all tasks. Stimuli varied between each session (for example, from jungle animals to farmyard animals) for both groups to help maintain children’s interest in the tasks over time.

*Training Tasks*

The three training tasks were adapted from existing measures of working memory to make them age appropriate for 3-year-olds. One targeted working memory maintenance (the Span task; Adams & Gathercole, 2000); one targeted working memory updating (the One-back task; Tsujimoto, Kuwajima, Sawaguchi, 2007); and one targeted working memory maintenance and processing (the Six Boxes task; Diamond, Prevor, Callender & Druin, 1997). Tasks were administered in the same order every session: the Span task, the One-back task, and the Six Boxes task. Two of the tasks were adaptive between each training session: the One-back task and the Six Boxes task. On these tasks, if children were accurate on 75% or more of trials in a session, the level of difficulty increased in the following session. The Span task was adaptive within the session, depending on children’s performance on the previous block of trials. If children scored 75% in a block, the number of items they had to remember increased in the next block.

*The Span Task:* In this task children had to find items they had seen being hidden behind objects. Nine identical objects (for example, trees) were arranged on a screen using the same arrangement as in the Corsi block measure of spatial working memory (see Adams & Gathercole, 2000). Children saw a character hide items behind the different objects. Each time an item was hidden, the object would move from side to side and a short sound would be played for three seconds. This ensured that there was enough time for children to attend to where the item had been hidden. For example, in one version of the task, children saw a squirrel hiding acorns behind trees. The squirrel would appear at each tree, hide the acorn and then the tree would move from side to side and a rusting sound would be played. Children could select objects to search by pressing the object on the screen. If children selected an object where an item had been hidden, then the item would appear. If children made an error by selecting an object with no item behind it (or by selecting an object that had previously been searched), the object would move from side to side to indicate it had no item behind it. Children first completed two practice trials of two items. Then children completed up to three blocks of four trials. In each trial within a block, between two and six items would be hidden, depending on children’s performance in the previous block. The task began with two items. The game ended after 12 test trials, or if children made three consecutive errors. If children were accurate on 75% or more of trials in a given block, the number of items hidden increased in the next block (up to a maximum of six). This places greater demands on children’s working memory capacity.

*One-back task:* In this task, children were shown a succession of images (e.g., animals), presented one at a time. Children were told to touch the image on the screen if it matched the image that had appeared on the preceding trial. Children first observed a demonstration block where they watched the experimenter complete five trials, two of which were ‘hit trials’ (whereby the image shown had also appeared on the previous trial, and therefore required a response). Children then completed a practice block of five trials, two of which were hit trials, followed by three test blocks of 15 trials (of which one-third were ‘hit trials’). Children received feedback throughout the task in the form of a pre-recorded “well done!” A short beep was played if children made a false alarm by selecting an image where the same one had not appeared previously. The dependent variable was hit-trial accuracy. Images were presented for 1000ms with an ISI of 1000ms. If children were accurate on 75% or more of trials, the ISI in the next session increased by 500ms (to a maximum of 2000ms). This placed greater demands on children’s maintenance abilities.

*Six Boxes task:* In this task, children were asked to find items (e.g., stickers) hidden behind six different objects (e.g., coloured boxes). To begin with, all of the objects hid an item. If children selected the correct object by pressing it on the screen, the item would be revealed. If they were incorrect (i.e. by selecting an object they had already searched), no item was revealed. Therefore, children could only find items behind objects not already searched. Between trials, objects were moved so that their locations were different to the previous trial. Children completed this task twice consecutively in each session. The task ended when children had found all of the items, or when children made three consecutive errors. The dependent variable was the number of trials taken to find all items across both tasks. In the first training session, the ISI lasted for 2000ms. If children scored 75% correct or better, the duration of the ISI was increased by 2000ms (to a maximum of 6000ms), so that children had to hold information in mind for longer.

*Active Control Tasks*

The Control group completed three tasks that required children to make simple perceptual judgements. The first task required children to decide whether two pictures were the same or different; the second task required children to search for a particular image amongst distractors (for example, they had to find the space rocket in an array containing distractor images such as stars and planets); and the third task required children to decide which of two pictures belonged to a particular category (e.g., “which one lives in the sea?”). The control tasks used the same stimuli and lasted the same duration as the training tasks.

*Pre and Post-test Assessments*

To assess training improvements, five tasks were administered together, at two different time points: one week prior to training (baseline) and one week after training (post-training). The tasks were adapted from existing measures of executive function and CF, so that they were age-appropriate for 3-year-olds. Working memory was measured using the Listening Recall task (Gathercole, Pickering, Ambridge & Wearing, 2004) and the Spin the Pots task (Hughes & Ensor, 2007); inhibitory control was measured using the Whisper Task (Murray & Kochanska, 2002) and the Flanker task (Rueda, Posner & Rothbart, 2005a); CF was measured using the response conflict SwIFT (see Chapter one). A measure of processing speed was also included: the Bubble Popping task. Tasks were administered in the following fixed order at each assessment: the Whisper Task, the SwIFT, Listening Recall, the Spin the Pots task, the Flanker task, and the Bubble-popping task. The pre- and post-test assessment tasks were chosen specifically because they did not share the same surface features or instructions as the training tasks.

*Working Memory*

In the standard Listening Recall task (Gathercole *et al*., 2004), children hear a series of short sentences and have to (i) report if the sentence was true or false, and (ii) remember a word from the sentence. To make the task age appropriate for 3-year-olds, the task was adapted so that children listened to statements about different animals (e.g., “worms have legs”), had to verify if that statement was true or false, and then had to recall the animal that the statement was about. The task progressed in difficulty by increasing the number of sentences that children heard before they had to recall the animal (from a span of one to three). Children completed four trials at each span length. The task ended if children got two trials incorrect at any span length. The dependent variable was the number of sentences correctly recalled.

See Chapter two for a description of the procedure for Spin the Pots scores (Hughes & Ensor, 2007). Note that scores are reverse coded for ease of interpretation (16 minus the number of attempts taken to find all the stickers).

*Inhibitory Control*

The Whisper task (Murray & Kochanska, 2002) measures effortful control which is considered an aspect of inhibitory control. This reflects children’s ability to regulate a dominant behaviour or emotional response. In this task, children were shown a number of pictures of familiar cartoon characters (e.g., Mickey Mouse, Scooby Doo) one at a time, and were asked to whisper their name. The experimenter first checked that children could understand the instructions by asking children to whisper their own name. For each trial, children received a score of three if they whispered, a score of two if they did not respond, a score of one if they responded in a normal tone of voice and a score of zero if they shouted. Children had to respond to at least half of the trials for their data to be included (this was in order to rule out non-compliance, or children not knowing the cartoon character). Five children were excluded on this basis.

The Flanker task measures interference control, another aspect of inhibitory control (Rueda, *et al.*, 2005). Children were presented with a line of three stimuli (fish) and asked to indicate which direction the central stimulus was facing (left or right). Children first completed four practice trials and then ten experimental trials. Half the trials were congruent (stimuli were all left-facing or all right-facing); and half were incongruent (the middle stimulus faced the opposite direction to the flanking stimuli). Stimuli remained on screen until children responded. In between trials, there was a fixation lasting 1500ms.

*Cognitive flexibility*

The Conflicting SwIFT was used to measure CF, using the same version as that reported in Chapter two. The task yields qualitatively different performance types: mixed responding (a score of three to five out of eight), perseveration (a score of zero to two out of eight) and switching (a score of six to eight out of eight) (see Chapters two and four).

*Processing speed*

Processing speed was measured by a simple task in which children “popped” bubble stimuli appearing on a touchscreen computer by touching them as quickly as they could. When children touched the stimulus, a picture of a burst bubble appeared in its place. Children were given a short demonstration. There were then eight test trials. The ISI varied randomly between 800ms and 1200ms. The dependent variable was the mean reaction time.

**3. Results**

*Preliminary Analyses*

To check for baseline group differences, independent-samples t-test were run with group on age and baseline task performance. There were no group differences in age, or on any of the tasks at baseline (*ps* = .59 - .92); in addition there was no significant effect of sex on task performance (*ps* = .13 - .84).

*Training Improvements*

The One-back task and the Six Boxes task had three levels of difficulty, and children progressed to a higher level of difficulty as a function of good performance on a previous level. Because task accuracy on different levels of difficulty are thus not directly comparable, these data are only analysed descriptively. For the One-back task, 77% of children improved over training, of whom 59% reached the highest level by the final session. For the Six Boxes task, 76% of children improved over training, of whom 35% reached the highest level by the final session. On the Span task, the difficulty level increased within the session depending on children’s accuracy in the previous block of trials. To test whether children improved significantly on this task over training, a repeated measures ANOVA was run with span level at the end of each session as the dependent variable (from two to six). There was a significant improvement in children’s working memory span over training, *F*(3,45) = 28.61, *p* < .001, η 2*partial* = .67. Bonferroni *post-hoc* tests revealed that children’s span significantly improved between session one (*M* = 2.5; *SD* = .52) and session two (*M* = 3.56; *SD* = 1.03), *p* = .001 and between session two and session three (*M* = 4.44; *SD* = 1.41), *p* = .004; but not between session three and session four (*M* = 4.75; *SD* = 1.53), *p* = .81.

*Transfer to the non-trained tasks*

To test whether training transferred to the non-trained EF tasks, a repeated measures ANOVA was performed separately for each task with time (baseline vs. post-test) and group (as a between subjects factor: Training vs. Control) on each task score. For the Listening Recall task, one child did not complete the task at pre-training due to non-compliance, so the analysis was run using data from the remaining 32 children. There was a significant main effect of time (*F*(1,31) = 14.27, *p* = .001, η 2*partial* = .32) and a significant effect of group (*F*(1,31) = 4.24, *p* = .048, η 2*partial* = .12) on the Listening Recall task. This was qualified by a significant interaction, *F*(1,31) = 6.53, *p* = .016, η 2*partial* = .17. Children in the training group significantly improved their listening recall from pre-training relative to the active control group (see Table 8). For the Spin the Pots task, two children did not complete the task at pre-training due to non-compliance, so analyses were run on the remaining 31 children. There was a significant main effect of time on the Spin the Pots task (*F*(1,30) = 7.86, *p* = .01, η 2*partial* = .21) but no significant main effect of group (*p* = .53), and no interaction (*p*  = .87).

Table 8: Mean scores by group at the pre- and post-test assessments.

Active Control Group Training group

Pre (T1) Post (T2) Pre (T1) Post (T2)

Whisper (*N* = 29) 12.79 (6.6) 11.00 (6.15) 11.56 (5.82) 13.35 (4.87)

Listening Recall (*N* = 33) 2.56 (2.07) 3.12 (2.40) 2.76 (2.61) 6.0(3.0) Spin Pots (*N* = 32) 7.80 (2.65) 9.00 (1.69) 8.00 (1.40) 9.35 (1.12)

Flanker (*N* = 29) 3.47 (1.13) 2.85 (2.04) 3.42 (1.56) 3.53 (1.51)

Proc Speed (ms) (*N* = 33) 1280 (331) 1373 (488) 1256 (378) 1109 (457)

Note: Standard deviations are in parentheses.

When analysing performance on the SwIFT, using an ANOVA to examine training-related gains is inappropriate as ANOVAs rely on measures of central tendency. As the results from Chapter two showed, performance on the SwIFT is most accurately characterised by splitting children’s performance into qualitatively different categories. Therefore, to analyse improvements, a difference score was calculated according to whether children’s CF performance (mixed, perseveration or switching) stayed the same (score of 0); improved (if they went from perseverating to switching, or from mixed responding to perseverating, they would get a score of 1; if they went from mixed responding to switching they would get a score of 2); or got worse (e.g., if they went from switching to mixed responding this would result in a score of -2). Therefore, scores ranged from -2 to 2. Two children were excluded because they failed to understand the task instructions at the baseline assessment (one in the training group and one in the control group) leaving 32 children. To test for improvements in CF, a Mann-Whitney U test was run, since the dependent variable was not normally distributed. Children in the training group significantly improved their switching performance from pre- to post-test, *U =* 84.0*, p* = .04*, r* = -.36(see Table 9).There were no other significant main effects or interactions on effortful control, inhibitory control or processing speed (*ps* = .16 - .92). Finally, there were no significant correlations between training-related gains and transfer on the Listening Recall task or the SwIFT (*ps* = .14 - .99).

Table 9: Transition matrix showing the number of children whose performance stayed the same, improved or got worse on the Conflicting SwIFT from pre- to post-training in both groups.

Training Group (*N* = 16) Control Group (*N* = 16)

*Improvement* Mixed - Switcher 2 0

Perseverator - Switcher 1 1

Mixed – Perseverator 3 1

*No Change* Switcher – Switcher 7 8

Perseverator - Perseverator 2 3

Mixed – Mixed 1 1

*Decline* Switcher – Mixed 0 1

Switcher – Perseverator 0 1

Perseverator – Mixed 0 0

**4. Discussion**

This is the first study to test the effectiveness of a working memory training program for improving executive functions in 3-year-olds. Four sessions of working memory training improved children’s performance on a separate and distinct untrained measure of working memory: the Listening Recall task. However, the Listening Recall task does require both the maintenance and processing of information, which were the working memory skills targeted in training. This gives us greater confidence that the training intervention directly improved working memory, and did not lead to improvements simply due to practice or greater familiarity with instructions. Interestingly, there was some evidence for far transfer of training to CF, specifically, children’s ability to switch in the presence of response conflict. Significantly more children in the trained group improved their performance type on the Conflict SwIFT relative to the active control group. No transfer was observed to inhibitory control or processing speed. Together the results suggest that working memory may be causally underpin children’s ability to resolve conflict when switching from one task to another. Furthermore, the results suggest that for young children, training programs can be effective even when as short as four sessions. This may be because training programs are most effective when they target skills at a time when they are rapidly developing (Wass *et al*., 2012).

Improvements following training were found on a very different measure of working memory to the tasks that children were trained on. Improvements were found on the Listening Recall task – a task chosen because it shares no surface features with the training tasks and required a different aspect of working memory to those targeted in training. Working memory is a complex cognitive skill that encompasses a variety of functionally distinct components as well as separate components depending on the modality of the information, specifically: visuospatial working memory and verbal working memory (see Baddeley, 1992). The training tasks primarily focused on visuospatial working memory and transfer was found to the Listening Recall task which measures verbal working memory. This is notable because previous working memory training research with older children has often only found transfer to the same aspects of working memory targeted for training which tends to be visuospatial working memory (see Dunning *et al.,* 2013). In the current study, transfer was found from visuospatial and updating working memory tasks to verbal working memory raises the interesting possibility that aspects of working memory may be less distinct in younger children - much like executive functions. There is some evidence that working memory tasks are more strongly correlated in 5-year-olds compared to 9-year-olds (Tsujimoto *et al*., 2007) and that verbal and visuospatial working memory comprise distinct factors in children as young as six (Gathercole *et al.,* 2004). However no research to date has examined the extent to which distinct aspects of working memory are separable in preschoolers. This would be an interesting direction for future research as it would bring much-needed clarity to working memory models in young preschoolers.

However, improvement following training were not found on all of the measures of working memory. No improvement was found on the Spin the Pots task which is surprising given that two of the training tasks specifically targeted visuospatial working memory which the Spin the Pots task requires. For the Spin the Pots task, there was a significant main effect of time, indicating that repeated practice on this task is enough to significantly improve performance. This suggests that completing the task just once makes the task easier a second time around. This is because children competed the Spin the Pots task twice – with just four weeks in between – and no effects of time were found on the other tasks suggesting that this is not down to very rapid developments in working memory. Rather, it is more plausible that both the children in the training and the control group learned how to perform more efficiently on the Spin the Pots task after playing it once (for example, perhaps they learn that they need to pay attention to the two empty boxes). In addition, because 3-year-olds typically only make between one and three mistakes on this task, small improvements in understanding task instructions are likely to lead to ceiling performance. In support of this, Table 1 shows children in both groups were near ceiling on the Spin the Pots task at post-test. This could explain why no transfer was found on this task.

The study provides some support for the idea that working memory causally underpins children’s ability to switch in the presence of response conflict. Significantly more children improved their performance in the training group relative to the control group. Six children in the training group improved their performance, whereas only two children in the control group did. The working memory training targeted skills in the maintenance and updating of information which may have lead children to become better able to maintain and update the rule on the SwIFT. This supports research presented in Chapters two and four of this thesis, and also previous research showing that working memory is important for children’s ability to resolve response conflict while switching (Chevalier *et al*., 2012; Marcovitch *et al*., 2010). The present study adds to this by showing for the first time that working memory may causally underpin CF in 3-year-olds.

It is interesting to note that three children trained on working memory went from mixed responding to perseverating. Although at first this may seem an unlikely result of training, as children’s overall accuracy decreases, it supports the idea that the shift from mixed responding to perseveration may reflect improvements in working memory which introduces systematic errors. As discussed in Chapters two and four, mixed responding reflects very poor rule maintenance in working memory as children’s behaviour is not guided in a top-down way. In order to demonstrate systematically *incorrect* behaviour (as in perseveration) there may need to be some working memory in order to inappropriately retain the pre-switch rule. However, although this is interesting, strong conclusions cannot be drawn from this finding, particularly as the sample size was so small and actually many more children stayed the same rather than improving. It will therefore be important to replicate this finding in a larger sample.

There was no evidence of far transfer to either aspect of inhibitory control: effortful control (as measured by the Whisper task) nor interference control (as measured by the Flanker task). Effortful control has been shown to be closely associated with children’s temperament, so therefore it may reflect a stable trait that is less amenable to improvement via training (Kochanska *et al.,* 2000). Regarding interference control, work with adults suggests there are strong links between working memory and interference control, particularly in extreme cases (i.e., people with poor working memory tend to show marked impairments in interference control; Redick & Engle, 2006). However, this relationship is often not found in children (Stins, Polderman, Boomsma, de Geus, 2005). This may explain why no transfer was found to the measures of inhibitory control. More broadly, the results add to a growing number of studies that fail to find transfer to inhibitory control. In two separate studies, working memory training (Thorell *et al*., 2009) and attentional control training (Rueda, Rothbart, McCandliss, Saccomanno, Posner, 2005b) did not transfer to inhibitory control in children. In the latter study, a flanker task was used like in the present study. Together, this suggests that either (i) inhibitory control is less amenable to training than working memory or (ii) that working memory does not causally underpin inhibitory control in 3-year-olds.

Based on the current findings it cannot be determined what aspects of training lead to the transfer found. Improvements over training did not correlate with transfer: children who improved the most did not show greater improvements on the non-trained measures of working memory and CF. Without this information, it is difficult to ascertain what specific aspect of training led to improvements on the non-trained tasks. For example, it is unclear whether training a particular aspect of working memory would be most beneficial for improving CF: the maintenance and processing of information, updating, or both. The lack of correlation could suggest one of two things: (i) that transfer is due to aspects unrelated to the training, or (ii) that perhaps any level of working memory training is beneficial for children of this age even if the training is conducted at a low level of difficulty. For children who remained at the lowest level of difficulty, this may still have been enough to challenge their working memory and lead to improvements on a different working memory task. Because there is such a paucity of work with this age group, a definitive explanation for this finding cannot be provided. It is worth noting that very few training studies with young children have reported analyses examining whether transfer is related to training gains (e.g., Rueda *et al.,* 2005b; Thorell *et al*., 2009; Wass *et al*., 2011; Wass *et al*., 2012) making it difficult to determine whether this is a common theme among developmental training studies.

One question that remains open, and that remains an open question for the field as a whole, is the extent to which training improvements are maintained over time. There are three challenges in answering this question when working with young preschoolers: (i) there are few age-appropriate working memory and inhibitory control tasks that can be used to measure executive functions over a broad developmental age range; (ii) executive functions are so rapidly developing that ceiling performance on a particular task may be reached at even a three month follow up and (iii) the nature of testing in preschools makes it hard to keep track of the children over time. Therefore, conducting long-term follow-ups will require both the development of new measures of working memory and inhibitory control that can be used across a larger age span to avoid ceiling effect, and considering conducting follow up tests in the home. Despite these challenges, this remains an exciting new area of research. Given that working memory has been strongly linked to academic outcomes and schools readiness, improving working memory early on in development is likely to have important implications for interventions that seek to support children’s development and learning before they start school. It is this point that the next Chapter will seek to address.

Chapter Six

A short executive function training program improves preschoolers’ working memory

The study reported in this Chapter is based on the published paper: Blakey, E., & Carroll, D. (2015) A short executive function training program improves preschoolers’ working memory three months post-training. *Frontiers in Developmental Psychology.* It directly follows on from the finding reported in Chapter five that cognitive training improved 3-year-olds’ performance on a non-trained measure of working memory, to test whether cognitive training improvements are maintained over time, and whether cognitive training benefits children’s mathematical skills. The present study tests the effects of a short four-session executive function training program in 54 four-year-olds. The training group significantly improved their working memory from pre-training relative to an active control group. Notably, this effect extended to a task sharing no surface features with the trained tasks, and continued to be apparent three months later. In addition, the benefits of training extended to a measure of mathematical reasoning three months later, indicating that training executive functions during the preschool years has the potential to convey benefits that are both long-lasting and wide-ranging.

**1. Introduction**

Executive functions are the set of high-level cognitive skills – including working memory, inhibitory control, and CF – that underpin goal-directed behaviour (Miyake *et al*., 2000). Working memory and inhibitory control are two core executive functions that develop rapidly during the preschool years, leading to significant improvements in children’s ability to control and regulate their behaviour (see Garon *et al.,* 2008). Working memory allows children to maintain and process information, and inhibitory control allows children to suppress distracting information or automatic but task-inappropriate behaviours. During the preschool years these two executive functions play an important role in supporting school readiness and children’s developing mathematical skills (Best, Miller & Naglieri, 2011; Bull, Espy & Wiebe, 2008; Clark, Pritchard & Woodward, 2010). Understandably, therefore, the question of whether executive functions can be improved via cognitive training has received much attention. Surprisingly, however, little of this research has focused on the preschool years – when executive functions undergo significant developments.

Despite the importance of the preschool period for executive functions (e.g. Zelazo, 2006, Wiebe *et al.,* 2011), very little training research has been conducted with this age group (see Wass *et al.,* 2012 for a review). Many studies have focused on school-age children, and have targeted working memory specifically for training. These studies have shown that working memory training improves children’s performance on non-trained measures of working memory (Henry, Messer & Nash, 2014; Karbach *et al.,* 2014; Jaeggi, Buschkuehl, Jonides & Shah, 2011; Rode, Robson, Purviance, Geary & Mayr, 2014). Other studies have targeted multiple executive functions during training, including working memory, inhibitory control and planning, and have found this training improves children’s performance on a variety of non-trained measures of executive function (Goldin *et al*., 2014; Traverso, Viterbori & Usai, 2015). For example, Goldin and colleagues trained 6- to 7-year-olds on a 20- to 25-session combined executive function training program targeting inhibitory control, working memory and planning. The trained children significantly improved their performance on different non-trained measures of attention, CF, language and mathematics compared to an active control group.

However, despite the fact that there has been a growing interest in classroom and meta-cognitive-based programs aimed at improving self-regulation in preschoolers (see Diamond & Lee, 2011 and Moriguchi, Sakata, Ishibashi & Ishikawa, 2015), very little computerised executive function training research has focused on the preschool years (though see Bergman Nutley *et al.,* 2011; Rueda *et al.,* 2005b; Thorell *et al.,* 2009). This is a surprising oversight: a strong argument has been made that interventions may *a priori* be more successful in younger children due to greater plasticity in relevant neural networks (Wass, 2015). Consistent with this view, transfer from executive function training is greater in younger children than older children (Melby-Lervag & Hulme, 2013), with significant negative correlations being found between the age of the participants and the transfer observed (Wass *et al*., 2012). Thus, a renewed focus on cognitive training in the preschool period is clearly needed.

We highlight two questions of particular interest addressed by this study. The first is the extent to which cognitive training improves executive functions, as opposed to merely improving performance on a specific task. Progress in answering this question has been hindered by the use of transfer tasks that share the same surface features as the trained tasks, as well as by the use of passive control groups (Shipstead *et al.,* 2012; Green, Strobach & Schubert, 2014). The second question regards possible benefits of training gains to mathematical skills. This is important, since much of the utility of executive function training rests on its effectiveness in improving real-life outcomes. Of the few studies that have looked at this, three found no transfer to mathematical skills (Dunning, Holmes & Gathercole, 2013; Henry *et al*.,2014; Karbach *et al*.,2014), and two did find transfer to mathematical skills (Goldin *et al.,* 2014; Rode *et al.,* 2014). This question remains unaddressed in preschoolers. Furthermore, based on current research, it is unclear how intensive training interventions need to be in order to produce a lasting effect. Training improvements have been reported after as many as 25 sessions and as few as three sessions (see Karbach & Unger, 2014 and Wass, 2015 for a review). The potential impact of cognitive training is likely to be inversely proportional to the time and effort required to bring about improvements. The effectiveness of shorter training programs is therefore of particular interest.

The present study examined whether a short executive function training program improved non-trained executive functions in preschoolers, using a randomised-control pre-test post-test design. Importantly a short four-session program delivered over one month was used which targetted working memory and inhibitory control, two core executive functions in early childhood (Chevalier *et al*., 2012; Garon *et al,*, 2008; Hughes, Ensor, Wilson & Graham, 2009) thought to be critical for children’s developing mathematical ability (Gilmore *et al.,* 2013; Raghubar, Barnes & Hecht, 2010). The study had three key aims: first, to examine whether the benefits of training transfer to working memory and inhibitory control tasks that share very few surface features with the trained tasks, and also to assess far transfer to cognitive skills not targeted in the training program (namely CF and processing speed). Second, to examine whether transfer effects are maintained three months post-training. Third, as preschool executive function has been consistently shown to relate to mathematical ability, but standardised scores of mathematical ability are not available for UK children under five years (Wechsler, 2005), measures of mathematical ability were taken at the three-month follow-up once children had started school, to examine whether the training program leads to improvements in children’s mathematical skills.

**2. Method**

*Design*

Children completed baseline measures of working memory, inhibitory control, CF and processing speed. They were then randomly assigned to either the Training group or the Control group, with the sole constraint that children from each of the two participating preschools were distributed equally across the two conditions. Both groups completed four weekly 20-minute sessions of computerised tasks. Baseline measures were readministered one week after training (the post-test session), and again three months later (the follow-up session). Measures of mathematical ability were included at the three-month follow-up.

*Participants*

Initially, 60 children were recruited from two preschools in lower to middle-class areas of the UK. Five children missed a training session, and one did not understand the task instructions, so the final sample comprised 54 children: 26 in the Training group (*M* age = 4;4 years, *SD* = 3.65; 13 males, 13 females), and 28 in the Control group (*M* age = 4;4 years, *SD* = 3.50; 14 males, 14 females). Informed consent was obtained from teachers and caregivers. Children received a small gift after the final session. Ethical approval was obtained from the University’s Psychology ethics sub-committee (see Appendix 1).

*Procedure and Materials*

Children were tested individually in their preschool. All training and control tasks were administered on an Iiyama touchscreen connected to a PC running E-Prime software (Psychology Software Tools, Pittsburgh, PA). To reduce incidental between-group differences, identical stimuli were used in the training and control tasks, and feedback was provided in all tasks. To maintain interest in the tasks, stimuli varied between each session (for example, from jungle animals to farmyard animals). To check for baseline differences in classroom engagement, one teacher in each preschool blind to children’s condition rated children using the teacher-rated Classroom Engagement Scale (Pagani, Fitzpatrick, Barnett, & Dubow, 2010). In addition, to check for differences in motivation between groups, at the end of the four weeks all children indicated on an age-appropriate Likert scale how much they had enjoyed playing the games (from 1, ‘A lot’, to 4, ‘Not at all’).

*Training Tasks*

Four training tasks were used adapted from existing established measures of preschool executive function. Two targeted aspects of working memory: the Six Boxes task (Diamond, Prevor, Callender & Druin, 1997) and the One-back task (Tsujimoto *et al.,* 2007); two targeted aspects of inhibitory control: interference control (the Flanker task: Rueda *et al.,* 2005a) and response inhibition (the Go/No-Go task: Simpson & Riggs, 2006). Each task lasted approximately five minutes. As preschoolers’ performance is known to be variable within executive function training tasks (van Bers *et al.,*, 2011), the aim was to minimise within-task variance by using an adaptive training regime between each session, such that if children were accurate on 75% or more of trials in a session, the level of difficulty for a particular task increased in the following session. Tasks were administered in the same order: the Six Boxes task, followed by the Flanker task, the One-back task, and the Go/No-Go task.

*Working Memory Training*

Six Boxes task: children were asked to find rewards (e.g., stickers) hidden behind six different objects (e.g., coloured boxes). To begin with, all of the objects hid a reward. If children selected the correct object, the reward would be revealed. If they were incorrect (i.e. by selecting an object they had already searched), no reward was revealed. Therefore, children could only find rewards behind objects not already searched. Between trials, objects were moved so that their locations were different to the previous trial. Children completed this task twice consecutively in each session. The game ended when children had found all of the rewards. The dependent variable was the number of trials taken to find all items across both tasks. In the first training session, the ISI lasted for 4000ms. If children scored 75% correct or better, the duration of the ISI was increased by 2000ms (to a maximum of 8000ms).

One-back task: children were shown a succession of images (e.g., animals), presented one at a time. Children were told to touch the image on the screen if it matched the image that had appeared on the preceding trial. Children completed three blocks of 20 test trials (of which one-third were ‘hit trials’, whereby the image shown had also appeared on the previous trial, and therefore required a response). The dependent variable was hit-trial accuracy. Images were presented for 2000ms with an ISI of 1000ms. If children were accurate on 75% or more of trials, the ISI in the next session increased by 1000ms (to a maximum of 3000ms).

*Inhibitory Control Training*

Flanker task: children were presented with a line of 5 stimuli (e.g., rockets) and asked to indicate which direction the central stimulus was facing (left or right). Children completed three blocks of 20 test trials. Half the trials were congruent (stimuli were all left-facing or all right-facing); and half were incongruent (the middle stimulus faced the opposite direction to the flanking stimuli). Stimuli were presented for 4000ms, with a fixation in between trials lasting 1000ms. If children were accurate on 75% or more trials in a session, the amount of time that stimuli appeared on the screen was reduced by 1000ms (to a minimum of 2000ms).

Go/No-Go task: children were required to touch a series of stimuli appearing on the screen (e.g., a fish) but to make no response when a specific “no-go” stimulus appeared (e.g., a shark). Children completed three blocks of 20 test trials (Go:No-go trial ratio 2:1). In the first session, the stimuli appeared on screen for 2000ms. If children were accurate on 75% more of no-go trials, this time reduced to 1500ms, and again to 1200ms.

*Active Control Tasks*

The Control group completed three tasks that required children to make simple perceptual judgements. The first task required children to decide whether two pictures were the same or different; the second task required children to search for a particular image amongst distractors (for example, “find the cat in the tree”); and the third task required children to decide which of two pictures had more objects in it. The control tasks used the same stimuli and lasted the same duration as the training tasks.

*Baseline Measures*

To assess training improvements, five tasks were administered at three different time points: one week prior to training (baseline), one week after training (post-training), and three months post-training (follow-up). Executive function tasks were chosen specifically because they did not share the same surface features or instructions as the training tasks. Tasks were administered in the following fixed order: the SwIFT, the Backward Word Span, the Peg-tapping task, the FIST, and the Bubble-popping task. In addition, two tasks measuring mathematical ability were administered at the three-month follow-up.

*Working Memory*

In the Backward Word Span (Davis & Pratt, 1996), children were shown pictures of familiar objects one at a time (e.g., a cat and a spoon) and were asked to recall them in a backwards order. Children completed two practice trials and then up to nine experimental trials, three of each span length (two, three and four). If children got at least two out of the three trials correct, the span length increased. The dependent variable was the number of trials correctly recalled in a backwards order.

*Inhibitory Control*

In the Peg-tapping task (Diamond & Taylor, 1996), children were instructed to tap twice with a stick when the experimenter tapped once; and to tap once when the experimenter tapped twice. After watching a demonstration from the experimenter, children completed twelve trials in a fixed pseudo-random order (six of each rule, with no more than three consecutive trials of one rule). The dependent variable was the correct number of responses.

*Cognitive Flexibility*

The SwIFT (Switching, Flexibility and Inhibition Task: Blakey, Visser & Carroll, 2015) was a rule-switching task administered using a touchscreen computer. Children had to match colourful shapes on the relevant dimension for that trial (either colour or shape). Children completed a pre-switch phase of eight trials using one rule; then a post-switch phase of eight trials using a different rule; and finally two mixed blocks of 12 trials each where the rule switched in a pseudo-random order between trials (no more than four repetitions of a rule). Each trial began with a prompt stimulus appearing at the top of the screen. After a delay of 1000ms, two response stimuli appeared in the lower left and right corners of the screen. One stimulus was the target (the correct response, as it matched the prompt on the currently relevant dimension), and the other was a distractor (the incorrect response). The distractor always matched the prompt on the non-relevant dimension. The distractor and target were equally likely to appear on the lower left or right corner of the screen. Children were given rule reminders on every trials using a pre-recorded instruction (e.g., “touch the one that’s the same colour”). Rule order was counterbalanced. The dependent variables were post-switch accuracy and mixed-block accuracy.

In the FIST (Flexible Item Selection Task; Jacques & Zelazo, 2001), children were presented with three different pictures of familiar objects and asked to select two pictures (out of three) that go together on one dimension (such as colour, shape or size), and then to select two pictures that go together on a different dimension. For example, on one trial children were presented with a small pink flower, a small green ball and a large blue ball. Therefore children could select the small flower and small ball because they match on size, and the green ball and the blue ball because they match on shape. There were twelve trials. The dependent variable was a proportion score, calculated by dividing the number of correct responses for selection two by the total number of correct trials for selection one.

*Processing speed*

Processing speed was measured by a simple task in which children “popped” bubble stimuli appearing on a touchscreen computer by touching them as quickly as they could. When children touched the stimulus, a picture of a burst bubble appeared in its place. Children were given a short demonstration. There were then eight test trials. The ISI varied randomly between 800ms and 1200ms. The dependent variable was the mean reaction time.

*Mathematical Ability*

Two measures of mathematical ability from the Wechsler Individual Achievement Test-II battery were used: Numerical Operations and Mathematical Reasoning (Wechsler, 2005). The Numerical Operations subtest comprised 22 questions assessing children’s ability to identify, write, and count numbers, and to solve arithmetic calculations. The Mathematical Reasoning subtest comprised 30 questions assessing children’s ability to identify shapes, extract information, and solve multi-step word problems. Standardised scores for each task were used as the dependent variable.

**3. Results**

There were no group differences in age or on any of the tasks at baseline (*ps* = .32 – .90). Teacher-rated classroom engagement scores did not differ between groups, *t*(52) = -.94, *p* = .35 (see Table 10). In addition, children’s self-rated enjoyment scores did not differ between the Control group and the Training group, *t*(33) = -.64, *p* = .53. See Table 11 for correlations between executive functions and mathematical ability sub-tests.

Each training task had three levels of difficulty; children progressed to a higher level of difficulty as a function of good performance on a previous level. Because task accuracy on different levels of difficulty are thus not directly comparable, these data are only analysed descriptively. For the Six Boxes task, 62% of children improved over training, of whom 75% reached the highest level by the final session. For the One-back task, 96% of children improved over training, with all of these reaching the highest level by the final session. For the Flanker task, 73% of children improved over training, of whom 74% reached the highest level by the final session. For the Go/No-Go task, all children improved over training, with 92% reaching the highest level by the final session.

To test whether training transferred to the five non-trained executive function tasks, a repeated measures ANOVA was run separately for each task with time (baseline vs. post-test) and group (as a between-subjects factor: Training vs. Control) on each task score. For working memory, there was a significant main effect of time, *F*(1,52) = 13.21, *p* = .001, η 2*partial* = .20) and no significant effect of condition, *F*(1,52) = 1.55, *p* = .22). This was qualified by a significant interaction between time and group, *F*(1,52) = 4.21, *p* = .045, η 2*partial* = .08. Only children in the Training group significantly improved from baseline on the Backward Word Span (see Table 10).

There were significant main effects of time on: inhibitory control; FIST performance; and mixed block accuracy on the SwIFT. This indicates that children in both groups got more accurate on these tasks from pre-test to post-test (*ps* = .001 – .04; η 2*partial*  = .08 - .22). There was no significant main effect of time on post-switch accuracy on the SwIFT (*p* = .45), nor on processing speed (*p* = .13), indicating that children did not get better on these tasks from pre- to post-test. There was no significant main effect of condition on: inhibitory control; FIST performance; SwIFT post-switch accuracy and mixed block accuracy; nor processing speed (*ps*  = .13 – .81). Finally, there were no other significant interactions between time and condition on any other task (all *ps* = .13 – .91).

Table 10: Mean scores and standard deviations by group at the pre, post, and 3 month follow-up assessments.

Active Control Group Training group

Pre Post Follow-up Pre Post Follow-up

BWS 2.43 (1.50) 2.75 (1.62) 3.32 (2.04) 2.54 (1.82) 3.69 (1.93) 4.96 (1.64)

Peg Tapping 7.43 (4.56) 8.79 (3.78) 10.20 (3.12) 7.73 (3.66) 10.85 (1.49) 11.17 (1.44)

Post-switch 6.46 (2.24) 6.46 (2.35) 7.32 (1.03) 6.38 (2.58) 6.81 (1.96) 7.00 (2.27)

Mixed Switch 15.64 (4.36) 17.61 (4.72) 19.60 (3.64) 16.88 (4.69) 18.19 (3.80) 20.17 (3.64)

FIST .72 (.22) .78 (.21) .83 (.16) .73 (.24) .80 (.20) .84 (.20)

Proc Speed 1114 (281) 1105 (457) 975 (264) 1089 (295) 925 (200) 931 (195)

Classroom Eng 2.51 (.36) 2.61 (.43)

Num Ops 89.67 (8.69) 92.91 (11.54)

Maths Reas 98.83 (8.62) 103.64 (6.45)

Note: BWS is backward word span; Proc speed is in ms; standard deviations are in parentheses; mathematical scores are standardised.

Table 11: Correlations between the tasks at baseline.

1 2 3 4 5 6 7 8 9

1. Backward Word .24† .01 .27\* .25† -.05 -.00 .31\* .33\*

2. Peg Tapping -.01 .32\* .28\* -.10 .37\*\* .45\*\* .53\*\*

3. Post-switch .26† .12 .07 .19 .12 .22

4. Mixed switch .47\*\* .27\* .30\* .18 .27†

5. FIST .01 .27\* .23 .14

6. Proc Speed -.32\* -.14 -.26†

7. Classroom Eng .08 .16

8. Num Operations .61\*\*

9. Maths Reasoning

Note. (*N=* 59) † p < .10 \* p < .05 \*\* p < .01.

To test whether the effect of training on working memory persisted at the three-month follow up, an ANOVA was performed as described above with working memory scores at follow up. Six children were unavailable for testing at the three-month follow-up, leaving a final sample of 48 children (Training group *N* = 23; Control group *N* = 25). There was a significant main effect of time on working memory, *F*(1,46) = 37.66, *p* < .001, η 2*partial* = .45) and no significant effect of condition, *F*(1,46) = 3.61, *p* = .06). This was qualified by a significant interaction between time and group for working memory, *F*(1,46) = 9.18, *p*= .004, η 2*partial* = .17. Only the Training group improved from baseline on the Backward Word Span at the three-month follow-up (see Table 1).

Two additional tasks were included at follow-up: Mathematical Reasoning and Numerical Operations. A further two children were unavailable for this testing session, leaving a final sample of 46 children. A one-way ANOVA found an effect of training on Mathematical Reasoning, *F*(1,44) = 4.51, *p* = .039, η 2 = .09. Children in the Training group scored higher on Mathematical Reasoning than children in the Control group (see Table 1). The effect remained when baseline working memory was included as a covariate, *F*(1,43)= 4.71, *p* = .036, η 2*partial* = .10. There was no significant effect of training on the Numerical Operations sub-test, *F*(1,44) = 1.17, *p* = .29.

To examine whether working memory improvements were related to training gains, Spearman’s rank-order correlations were run between the level obtained in the final session of training (lowest, intermediate, or highest level) on the Flanker and the Six Boxes task only (since performance reached ceiling on the One-back and Go/No-Go tasks) and a mean difference score calculating improvement on the Backward Word Span between pre and post-test. For the Six Boxes task, 10 children stayed at the lowest level, four children got to the intermediate level and twelve children reached the highest level. There was a significant positive correlation between improvements in working memory and training gains on the Six-Boxes task, *rs*(26) = .47, p = .02. For the Flanker task, seven children stayed at the lowest level, five children got to the intermediate level and 14 children reached the highest level. There was a significant positive correlation between improvements in working memory and training gains on the Flanker task, *rs*(26) = .60, *p* = .001. Working memory improvements at the 3-month follow-up were not significantly correlated with training gains on either the Six Boxes task (*p* = .92) or the Flanker task (*p* = .27). Mathematical Reasoning performance was also significantly positively correlated with both training gains on the Six Boxes task (*rs*(22) = 0.53, *p* = 0.01) and the Flanker task (*rs*(22) = 0.58, *p* = 0.01).

**4. Discussion**

A four-session executive function training programme significantly improved preschoolers’ working memory. Specifically, the improvement was found on the Backward Word Span, a task sharing few surface features with – but the same underlying executive function demands as – the training tasks. Importantly, this indicates genuine training of executive functions, and not simply increased familiarity with a particular task. This point is further emphasised by the fact that improvement on an untrained working memory task was significantly associated with the degree of improvements on the trained measures of working memory and inhibitory control. Furthermore, the benefit of training on working memory was maintained three months post-training. This is an important finding, as if training is to have genuine utility as a basis for future interventions, it is essential that its effects are not merely transient, but persist over time. This enduring effect in the current study is striking, given the relatively short training program involved. These results with preschoolers are consistent with previous research demonstrating the maintenance of cognitive training benefits in older children (e.g. Dunning *et al.,* 2009), and provide support that shorter programs may be as effective as longer programs. This is particularly important given the positive impact this could have on children before they start school and begin learning in a structured environment – something children with poor working memory find particularly difficult (Gathercole *et al.,* 2008).

The training program had unique benefits for preschoolers’ working memory. No evidence of transfer to inhibitory control or CF was found – a pattern of results consistent with results from both Chapter five and previous research, which taken together suggest that working memory may be particularly amenable to training (Thorell *et al.,* 2008; Karbach *et al.,* 2014). Typically, improvements in CF only occur following computerised training programs specifically targeting CF (e.g. Karbach & Kray, 2009; Zinke *et al*., 2012). This may be due to the complexity of CF: it is generally considered to be an emergent executive function arising from multiple cognitive skills including attention, meta-cognition, working memory and inhibitory control (Blakey *et al*., 2015; Garon *et al*., 2008). It is possible that our training program was not intense enough, or did not tap enough cognitive skills, to improve CF. Likewise, no transfer to inhibitory control was found despite improvements in inhibitory control over training (a result also found by Thorell *et al.,* 2005). However, improvements in inhibitory control and working memory over training *did* transfer to a non-trained measure of working memory. One possible explanation for this is that our executive function training program was more successful at training interference control than response inhibition and therefore was more likely to transfer to a non-trained measure of working memory than response inhibition. These different facets of inhibition are considered distinct processes at both the behavioural and the neural level (Groom & Cragg, 2015; Martin-Rhee & Bialystok, 2008; Nigg, 2000; Verbruggen, Liefooghe, Vandierendonck, 2004), and interference control is known to be important for working memory (Kane & Engle, 2003; Redick & Engle, 2006).

Children in the Training group showed better Mathematical Reasoning compared to the control group three months post-training. This is a finding of potentially great importance. To our knowledge, only two studies have found evidence that executive function training improves mathematical ability in children (Goldin *et al.,* 2014; Rode *et al.,* 2014). It is interesting to note that of the two studies that find this effect, Goldin and colleaguestargeted a variety of executive functions known to be important for mathematical skills (as in the present study), and Rode and colleagues incorporated mathematical problems within the training tasks. This may suggest that for domain-general training programs, it is important to target both inhibitory control and working memory in order to see benefits to children’s mathematical skills. Given prior research on the importance of both working memory and inhibitory control to children’s developing mathematical skills, it is plausible that training these executive functions might lead to benefits for mathematical skills. However, it is remarkable that in the present study benefits were observed three months post-training and after such a short training program. It is notable that the effect was specific to Mathematical Reasoning. The reasoning sub-test requires children to engage in multi-step operations, whereas Numerical Operations focus on retrieval of information from long-term memory, with the former thought to place more demands on working memory (Titz & Karbach, 2014).

Because measures of mathematical skill were only available at follow-up, it cannot be ruled out that this difference arose due to undetected between-group differences in mathematical ability. However, this unlikely: the two samples were very similar in cognitive ability, as there were no baseline differences between groups in terms of age, processing speed, classroom engagement or executive function ability; and the effect of training on Mathematical Reasoning remained even when baseline working memory was included as a covariate. However, based on the current study design, this cannot be definitively ruled out. A further limitation of the current study was that in assessing transfer to academic skills, only measures of mathematical skill were included. In addition to mathematical skills, executive functions have been linked to children’s literacy and self-regulation in the classroom (see Blair & Razza, 2007). Therefore, future cognitive training research would benefit from including a wider variety of academic achievement measures to examine how far cognitive training can enhance a range of real-life outcomes for children.

While the question of how far cognitive training transfers to academic skills remains open, the present study shows that such training has the potential to support and improve executive functions during childhood. A relatively short training program of just four sessions led to a specific improvement in working memory that was maintained after a three months. This raises an interesting suggestion for future research that focusing training interventions on preschoolers may be one way to scaffold cognitive development before children start school.

Chapter Seven

General Discussion

The Chapter will begin with a summary of the studies and the results presented in this thesis. It will discuss how this research has addressed the three important gaps in our understanding of CF that were set out in the Introduction. It will describe how the research has contributed to our theoretical understanding of how CF develops in early childhood. In addition, it will set out how this research has informed applied goals in understanding how researchers and educational professionals may intervene and improve executive functions in children. The discussion will close by considering the limitations of the work and directions for future research.

The goal of this research was to better understand how CF develops in early childhood. To that end, three main approaches were taken to address this question: 1) to use a paradigm capable of examining different types of flexible behaviour; 2) to go beyond the previous focus on the 3- to 4 shift in CF to study CF development in 2-year-olds; and 3) to test between the two different theoretical accounts of CF development. Previous research on CF development has tended to focus on studying 3- to 4-year-olds on a single paradigm that involves children switching from one task to another while resolving response conflict. This has led to the pervasive, but simplistic idea that children achieve CF when they overcome perseveration at age 4 (e.g., Munakata, 2012; Zelazo *et al*., 2003). Consequently, theoretical accounts of CF development have focused on explaining how preschool children overcome perseveration. Perseveration has been explained as either a failure of working memory *or* a failure of inhibitory control. The research presented in this thesis challenges this assumption by proposing that: overcoming response conflict is not the only way children can demonstrate flexible behaviour; that key developments in CF occur prior to age 3; and that while both working memory and inhibitory control contribute to CF development, they do so in quite different ways.

**7.1 Overview of the studies and the main findings**

Chapter two aimed to understand how different types of CF develop in a younger and broader age range than typically studied. Two- to 4-year-olds completed two different versions of the SwIFT – a newly developed CF task suitable for use with 2-year-olds as well as 3- to 4-year-olds. In one version (the Conflicting SwIFT), children had to resolve response conflict when the rule changed, as it was possible for them to continue to sort by the no longer relevant rule. In the other version (the Distracting SwIFT), children had to overcome distraction from task-irrelevant information when the rule changed. The results showed that these two types of flexible behaviour – resolving response conflict and ignoring task-irrelevant information – are distinct types of CF that develop during the preschool years. Evidence for this comes from the finding that each type of CF showed a different developmental trajectory, and performance on the tasks related to different executive functions. Children’s ability to resolve response conflict when switching significantly developed between 3 and 3.5 years, and was related to children’s working memory. In contrast, children’s ability to overcome distraction from task-irrelevant information when switching developed between 2 and 3 years, and was related to children’s inhibitory control. In addition, many 2-year-olds did not err by perseverating on the Conflicting SwIFT. Instead, they showed mixed responding – neither perseverating nor switching. This is consistent with the idea that young preschoolers’ behaviour is not guided in a systematic, top-down controlled way and this is due to their inability to strongly maintain task rules. Perseveration was an error that *increased* between the ages of 2 and 3 consistent with the idea that perseveration should: (i) not be considered the starting point of CF development and (ii) should actually be considered a developmental milestone.

Chapter three built directly on these findings to investigate the cause of 2- to 3-year-olds’ distraction errors when response conflict is removed from CF tasks. Distraction errors refer to children making unsystematic errors by selecting task-irrelevant information. This is in contrast to perseverative errors which involve children consistently selecting information that matches according to the no-longer-relevant rule. To date, there has been no research examining the cause of distraction errors on CF tasks. In this study, the type of distracting information that 2- and 3-year-olds had to ignore when the rule changed was varied across four experimental conditions. This allowed us to systematically examine why distraction errors arose by testing three specific hypotheses: 1) that distraction errors are caused by an inability to maintain the rule when the to-be-ignored information is related to the previously relevant rule; 2) that distraction errors are caused by poor selective attention which leaves children unable to switch in the presence of any kind of task-irrelevant information; and 3) that distraction errors are caused by negative priming which means children cannot sort by information they have previously ignored in the pre-switch phase. When the task-irrelevant information was a novel dimension that children had not come across on the task, children showed little difficulty in ignoring the information; with performance being indistinguishable from a condition where children did not switch tasks at all. This shows that distraction errors are not caused by poor selective attention. Children did not make any more distraction errors when they had to sort by a dimension they had previously ignored in the pre-switch phase. This shows that distraction errors are not caused by negative priming. Together, the results show that young preschoolers make distraction errors chiefly because they fail to inhibit their attention towards information related to the previous rule. The results show that children’s distraction errors can be described as goal-related in nature: children made significantly more errors when the to-be-ignored information was a dimension that children had previously sorted by – that is, when it was related to a previous goal. More broadly, the results also demonstrate that systematically maintaining goal-directed behaviour in the face of distractions is a fundamental milestone in the development of flexible cognition that emerges between the ages of 2 and 3.

Chapter four aimed to investigate specifically how working memory supports children’s ability to switch in the presence of response conflict. The Graded Representations account of CF development states that working memory supports children’s ability to maintain rules on CF tasks. However, this account lacks specificity, and to date, no studies have investigated the precise role of working memory in CF using an individual differences approach. Three-year-olds completed the Conflicting SwIFT and four different measures of memory: two tapping working memory requiring the processing and updating of information; and two tapping prospective memory requiring rule maintenance skills. Children’s CF was significantly associated with their ability to process and update information on the working memory tasks. Children’s CF was also significantly associated with children’s prospective memory, their ability to maintain a rule – both on an experimental task and in a naturalistic context. Across all of the tasks, mixed responders had the poorest working memory and rule maintenance skills. The results suggest that mixed responding reflects children’s inability to maintain task rules. Mixed responding significantly decreased between the ages of 3 and 3.5 years, in line with significant improvements in children’s working memory and prospective memory. Together the evidence suggests that working memory supports children’s CF in situations with response conflict by supporting their rule maintenance.

Chapter five used a randomised controlled cognitive training study design to causally test the relation between working memory and CF in 3-year-old children. Three-year-olds first completed a baseline assessment with tasks measuring response conflict switching (using the Conflicting SwIFT), working memory, inhibitory control and processing speed. Children were then randomly assigned to either a working memory training group or an active control group. Both groups completed three computerised tasks in four weekly sessions. One week after training, the baseline assessment was repeated. Children in the training group significantly improved their performance on a different non-trained measure of working memory relative to the active control group one week after training. In addition, there was some evidence that children in the training group also improved their CF performance: more children in the training group improved their performance on the Conflicting SwIFT compared to the active control group. In sum, the study successfully trained working memory in 3-year-olds based on a very short intervention, and furthermore shows that working memory and response conflict switching may be causally related.

Chapter six aimed to test the extent to which cognitive training can improve executive functions in preschoolers, and how durable any such benefits are over time. This study also investigated whether executive function improvements following training benefit preschoolers’ mathematical skills. Therefore, the study focused on 4-year-olds as this is when individual differences in executive functions have been shown to begin to predict mathematical skills. With this more applied goal in mind, the training program targeted both working memory and inhibitory control – two core executive functions in the preschool years thought to relate to children’s mathematical skills. Four-year-olds first completed a baseline assessment measuring CF, working memory, inhibitory control, and processing speed. Children were then randomly assigned to a working memory and inhibitory control training group or an active control group. Both groups completed computerised tasks in four weekly sessions. Children in the training group significantly improved their performance on a non-trained measure of working memory relative to the active control group. This improvement was maintained three months later. In addition, children in the training group significantly outperformed children in the control group on a measure of mathematical reasoning three months post-training. This supports the idea that training executive functions in preschoolers may be a way to scaffold children’s cognitive development before they start school.

Together, these findings greatly inform both our theoretical understanding of CF development, and the debate regarding the efficacy of cognitive training interventions in childhood.

**7.2 Contributions to our understanding of cognitive flexibility development**

In the introductory Chapter, three gaps were highlighted that needed to be addressed in order to gain a more comprehensive understanding of how CF emerges and develops in early childhood: first, it was important to examine ways in which different kinds of flexible behaviour develop; second, research needed to go beyond examining just 3- to 4-year-olds and examine 2-year-olds to learn more about the emergence of CF; and third, the theoretical impasse between two main accounts of CF development: the Graded Representations account and the Attentional Inertia account needed to be broken in order to determine which one better explains its development. This section will discuss how this research has contributed to addressing these gaps and thus our understanding of how CF develops.

*7.2.1 Cognitive flexibility development is more than just resolving response conflict*

By using a CF task that allows for different types of error, this research found that CF is not a single process, but rather it comprises of distinct subtypes. Specifically, the ability to resolve conflict while switching and the ability to overcome task-irrelevant information when switching are distinct processes. This is important for the field because for the last 20 years, children’s CF has been measured only using tasks that require children to switch to a new rule whilst resolving response conflict from the previously relevant rule (e.g., Deák, 2003; Espy, 1997; Jacques & Zelazo, 2001; Karbach & Kray, 2009; Zelazo *et al.,* 1996). While this work has been informative in explaining how preschoolers develop the ability to resolve response conflict, one problem with this exclusive focus is that all errors that children make on CF tasks have been described as perseverative in nature. This is because on these tasks, children can only err by persisting with the previously relevant rule. As such, theoretical accounts have solely focused on explaining how children overcome perseverative errors. This limited focus has meant researchers have missed other key developments occurring during the preschool years and that our definition of CF has been incomplete.

This research found that when children completed a CF task that did not require response conflict, young preschoolers still had difficulty switching rules. Their difficulties were in overcoming distraction from task-irrelevant information when the rule changed. The information was task-irrelevant because children could not match target stimuli by this information, and it was therefore uninformative. If CF development is only about how children overcome response conflict, then it would be expected that children would perform at ceiling on this task, because response conflict is removed. However, the results from Chapters two and three showed that a significant proportion of 2- and 3-year-olds made distraction errors on this task. These findings are consistent with research by Chevalier and Blaye (2008) who used a novel CF paradigm to test whether distraction errors or perseverative errors were most prevalent in preschoolers. They found that preschoolers made as many distraction errors as perseverative errors when the rule changed. Our research was the first to explain why preschoolers make distraction errors. Children only made errors when the task-irrelevant information contained the dimension that children sorted by in the pre-switch phase. This research suggests that distraction errors in 2- and 3-year-olds are goal-related in nature: they reflect persisting attentional biases towards the first dimension that children sort by. Even though children cannot continue to match stimuli by this task-irrelevant information, they are still occasionally biased towards this information during the post-switch phase, which leads them to make distraction errors. This research demonstrates that flexible behaviour can be achieved in different ways depending on the task demands, and highlights the importance of not defining CF development solely on the basis of 3- and 4-year-olds’ performance on a single type of task. As the studies in this thesis demonstrate, CF is not a unitary skill only involving the resolution of response conflict. It can also involve resisting distraction from task-irrelevant information, and during the preschool years, this is a skill that also significantly develops.

*7.2.2 The emergence of cognitive flexibility in two-year-olds*

The research presented in this thesis has added valuable new insights into how CF first emerges. As stated in the introduction, the majority of CF research in childhood has focused on 3- to 4-year-olds. This has led theoretical accounts to implicitly assume that age 3 is when explicit CF first emerges, and consequently has left a significant gap in our understanding of CF prior to this age. Using a new task suitable for 2-year-olds, this research has identified three findings that significantly add to our understanding of CF development: first, important cognitive developments occur between the ages of 2 and 3 years; second, 2-year-olds already have some skills that may be necessary precursors for the development of full CF; and third, contrary to the assumption of theoretical accounts of CF, perseveration is not the starting point of CF development, nor is it best regarded as a problem that children must overcome.

Testing 2-year-olds on their ability to switch in the presence of distraction has revealed for the first time that there are significant developments in CF between the ages of 2 and 3 years. Studies one and two both found that between the ages of 2 and 3 years there are significant improvements in children’s ability to resist distraction from task irrelevant information when switching. Chapter two showed that by the time children reach the age of 3.5 years, ignoring task-irrelevant information when switching has become trivially easy. Chapter three clarified that this was related to 3-year-olds becoming better able to resist distraction from information related to the first rule they sorted by. Chapters two and three provided evidence that this may be due to increases in inhibitory control that allow preschoolers to become better able to ignore task-irrelevant information. Together, these results suggest that inhibitory control drives the key developments taking place between the ages of 2 and 3 years in children’s ability to suppress their attention to task-irrelevant information when switching their behaviour.

The research has also revealed that 2-year-olds already possess precursor CF skills. Namely, 2-year-olds are able to switch attention from one dimension to another and are able to selectively attend to a single dimension of a bivalent stimulus. Chapter three showed that 2-year-olds could easily switch from sorting a bi-dimensional stimulus by pattern to colour while ignoring a novel dimension (shape). Performance on this version of the SwIFT was identical to a version where children did not have to switch rules at all. Selective attention has been proposed as one explanation for why preschoolers perseverate on measures of CF (Hanania & Smith, 2010). However, our research shows that even 2-year-olds are able to selectively attend to a dimension, providing that the information that they need to ignore is not related to a previously relevant rule. What this research suggests is that 2-year-olds can selectively attend and can switch rules providing that there is: (i) no response conflict, and (ii) the to-be-ignored information is not related to a previous task.

The pattern of 2-year-olds’ errors on the response conflict SwIFT is informative in elucidating how CF first emerges and goes on to develop during the preschool years. This research highlighted for the first time qualitatively different performance types on CF tasks during the preschool years. Influential accounts of CF development have proposed that its development begins with perseveration at age 3 and switching at age 4 (Diamond *et al*., 2003; Munakata *et al*., 2012; Zelazo *et al*., 2003). However, by broadening the study of CF to include 2-year-olds, the research in this thesis suggests a new developmental trajectory of CF development. The first emergence of CF begins with 2-year-olds showing a complete absence of flexible, top-down controlled behaviour. While 2-year-olds are very capable of sorting by a rule, when it changes, they respond unsystematically, neither switching nor perseverating (so called ‘mixed responders’). At around age 3, some children then begin to show perseveration. This marks systematic type of error that may reflect improvements in working memory that lead children to inappropriately maintain the pre-switch rule. Therefore, perseveration – getting it *all* wrong – reflects an *improvement* in children’s CF performance. Indeed, in two studies reported in this thesis (Chapters two and four) mixed responding was associated with the poorest working memory and prospective memory. This is consistent with the idea that mixed responding reflects children’s inability to maintain either rule strongly in working memory and use this as a basis to guide behaviour. In contrast, the working memory of perseverators was no different to the working memory of switchers. At age 4, children show flexible behaviour: they are able to consistently switch from sorting by one rule to another. We suggest that 4-year-old’s working memory ability means that they can update their behaviour in line with a new rule, and maintain this new rule and use this to guide their behaviour. This developmental pattern of mixed responding, perseveration and switching has been identified in infants on the A-not-B task (e.g., Clearfield *et al.,* 2006) but has gone unidentified in preschoolers, and is therefore not addressed in theoretical accounts of CF development. Interestingly, together with research by Clearfield and colleagues, this work suggests that improvements in working memory across development may at first lead children to perseverate before becoming fully flexible.

*7.2.3 Both Working Memory and Inhibitory Control contribute to the development of cognitive flexibility*

Our research aimed to test how two influential accounts of CF development contribute to CF. The Graded Representations account proposes that working memory underpins CF development (e.g., Blackwell *et al.,* 2007) by allowing children to maintain task rules. In contrast, the Attentional Inertia account argues that inhibitory control is crucial to CF development as it allows children to suppress their attention to the no longer relevant dimension when the rule changes. Both accounts can explain why 3-year-olds perseverate and 4-year-olds can switch their behaviour. Very little research has successfully tested between these two accounts, as manipulations designed to reduce either working memory or inhibitory control demands on tasks can be plausibly explained as reducing both. For example, Kirkham *et al*., (2003) had children label the relevant dimension during the post-switch phase of the DCCS. They found children were better able to switch on this version of the task than the standard version and argued this was because it helped children re-direct their attention to the relevant dimension, thus reducing inhibitory control demands. However, the same manipulation could also be explained improving children’s ability to hold in working memory the current task rule. To overcome this problem, this research used an individual difference approach to test how performance on separate measures of working memory and inhibitory control relate to different types of CF.

The research in this thesis shows that both working memory and inhibitory control contribute to the development of CF, by meeting different task demands. The individual difference data in studies one and three support the idea that working memory helps children to switch under conditions of response conflict. When children had to resolve conflict between the previously relevant rule and the new rule, children’s working memory ability was a better predictor of how well they were able to switch than their age (Chapter two). Chapter four showed that 3-year-olds’ rule maintenance skills – both an experimental task and a naturalistic paradigm – was associated with children’s ability to switch in the presence of response conflict. In particular, 3-year-olds who showed mixed responding were significantly poorer at maintaining an extra sub-task goal and maintaining a personal goal over a short amount of time than 3-year-olds who could switch. In addition, the randomised controlled trial in 3-year-olds found that working memory and switching in the presence of response conflict may be causally related. Chapter five found that children trained on working memory tasks improved their ability to switch in the presence of response conflict compared to children in the active control group. Together, this work is consistent with the Graded Representations account which proposes that as working memory develops, children are better able to maintain task representations that help children to guide their behaviour (e.g., Munakata, 2001). It adds to this account by suggesting that improvements in working memory in the early preschool years can at first lead to *more* errors before flexible behaviour is achieved. Importantly, the results constrain this account by proposing that working memory is not important in all CF tasks. When response conflict is removed, and children have to ignore task-irrelevant information, working memory is not related to children’s CF. Therefore, the Graded Representations account cannot fully explain CF development.

The evidence presented in this thesis suggests that working memory is crucial to CF when there are strong requirements for children to maintain the task goal. This idea supports previous research with older preschoolers which finds that working memory is particularly important on switching tasks when there is a strong need to maintain the current task goal (Marcovitch *et al*., 2010). Interestingly, this research is also consistent with work in adults which shows that working memory plays a unique role in resolving cognitive conflict – when relevant and irrelevant task information elicit competing responses that need to be resolved (Meier & Kane, 2015). In this study, adults’ working memory performance predicted their ability to resolve conflict between stimuli that elicited competing responses – where maintenance of the current task goal is crucial. Together, this research suggests that across development, working memory aids the resolution of response conflict through the maintenance of task goals.

Inhibitory control was shown to be important to CF when children had to switch while ignoring task-irrelevant information. For both 2-year-olds and 3-year-olds, performance on different measures of inhibitory control was associated with their ability to overcome distraction from task-irrelevant information (studies one and two). This research suggests that inhibitory control helps children to overcome attentional biases towards information that is related to the previous rule. This idea is central to the Attentional Inertia account, which was originally intended to explain why 3-year-olds perseverate on measures of CF (Diamond & Kirkham, 2005; Kirkham *et al*., 2003). However, our work suggests that this account is better suited to explaining why young preschoolers make occasional distraction errors, as inhibitory control was not related to children’s performance when they had to switch in the presence of response conflict.

Overall, our work proposes a more nuanced account of CF development. We propose that neither the Graded Representations account nor the Attentional Inertia account can fully explain CF development. Instead both explain aspects of CF development, but their specific contributions vary according to different task demands.

**7.3** **Contributions to Executive Function training research**

The work addressed in this thesis also contributes to our understanding of the effectiveness of cognitive training, with the more applied goal of improving executive functions early in childhood. Across the two training studies reported in this thesis, there was strong evidence that aspects of preschoolers’ working memory could be improved using randomised controlled pre-post-test designs (studies four and five). This is an important topic given the robust links between working memory and later academic success, particularly in mathematics (Alloway, Gathercole, Kirkwood & Elliott, 2009). In our studies, training transferred to very different, non-trained measures of working memory. Crucially, this suggests that cognitive training was truly improving the construct, as opposed to leading to improvements via task-specific practice or greater familiarity with task materials. In addition, working memory improvements were still evident three months later. Furthermore, benefits were found to children’s mathematical skills three months later. This work is some of the first to examine the effectiveness of cognitive training in preschoolers, and the findings suggest that even short training programs can convey cognitive benefits that are long-lasting and wide-ranging.

This research found some evidence that working memory training transfers to CF. Based on the research in Chapters two and four, it was predicted that working memory training would improve 3-year-olds CF. There was some evidence of transfer: significantly more children improved their CF performance in the training group than the active control group. This included some children that went from mixed responding to perseverating. However, the small sample size, coupled with the non-parametric way in which the CF data had to be analysed, makes it difficult to be certain whether this is a genuine effect. It is possible that if the training had targeted rule maintenance specifically then a stronger effect may have been observed. Instead, our training tasks focused mainly on the maintenance and processing aspects of working memory. No evidence was found that training working memory and inhibitory control improved CF in 4-year-olds. This may be because 4-year-olds’ CF is primarily measured in terms of set shifting – the ability to switch back and forth between tasks – which is likely to rely upon a number of different cognitive skills (Cragg & Chevalier, 2009).

Both training studies found no transfer to non-trained measures of inhibitory control. This is consistent with previous research which found little transfer to inhibitory control following cognitive training (see Diamond & Lee, 2011). For Chapter five, this could have been because working memory is not related to performance on the inhibitory control tasks used – indeed, no significant correlations were found between baseline measures of working memory and inhibitory control. For Chapter six, when inhibitory control was targeted in training, it could be that the training program was more successful at improving interference control – a separate aspect of inhibitory control involving the inhibition of attention towards a task-irrelevant stimulus (e.g., Nigg, 2000). Other researchers have argued that the lack of transfer from training to inhibitory control tasks could be because on these tasks (unlike working memory tasks) children are only required to engage their inhibition on a sub-set of trials, meaning there is less opportunity for training (Thorell *et al*., 2008). To improve inhibitory control, researchers have proposed that context monitoring should be targeted, the idea being that monitoring for when to engage inhibitory control is crucial to success on inhibitory control tasks (Chevalier, Chatham & Munakata, 2014). Researchers in this study compared two different training programs. One focussed on training response inhibition, by having children practice stopping a motor response in line with an explicit cue. The other focussed on training context monitoring, by having children practice monitoring a particular stimulus (a yellow banana) for when it changed colour (became a brown banana). The children who were trained on the context monitoring task showed greater improvements in response inhibition relative to the children who directly practiced motor response inhibition. Training context monitoring may also be one avenue for improving CF in older children where monitoring for cues on CF tasks with multiple switches has been shown to be important (e.g., Chevalier *et al*., 2011).

More broadly, the results show that shorter training programs may be just as effective in improving working memory as the longer training programmes of 20-25 sessions that are typically used (Dunning *et al*., 2013; Jaeggi *et al*., 2008). In two studies, just four sessions of executive function training lead to improvements in working memory, and there was evidence of maintenance up to three months later. In addition, there were wide-ranging benefits to preschoolers’ mathematical skills three months later. This suggests that the preschool years may be a time particularly amenable to such interventions, consistent with the idea that there is greater plasticity in executive function development during this time (e.g., Wass, 2015).

**7.4 Limitations**

There are two main limitations of this work that need to be considered. The first relates to the availability and validity of executive functions tasks that can be used across the preschool years. The second relates to the cross-sectional study design used in this research. Regarding the availability of executive function tasks, this research was somewhat constrained by a lack of choice in what age-appropriate measures of working memory and inhibitory control could be used with preschoolers. For working memory, most of the tasks measured rule maintenance and the combined processing and updating of information. Due to a lack of age-appropriate tasks, it was not possible to get a single measure of children’s updating skills, although this was an additional demand on some of the working memory tasks. Researchers have proposed that updating may play an important role in CF. Specifically, Chatham, Yerys and Munakata (2012) argued that some children may be good at maintaining information in working memory, but poor at updating. This may lead children to strongly maintain the incorrect rule, due to a failure to revise the rule. Updating in working memory is not a mechanism commonly studied in preschoolers, and it has not been considered in developmental theories of CF. However, it may well be important in helping children to monitor their environment for when to switch, and in revising information in working memory accordingly (Chevalier *et al* 2011). Future research would benefit from developing updating tasks so the hypothesised link between updating and CF can be empirically tested in preschoolers.

Some of this research was also limited by a lack of age-appropriate inhibitory control tasks. This was especially the case in Chapter two, where younger preschoolers and older preschoolers had to be tested using different measures of inhibitory control. Because the tasks were different, this limits the age-related comparisons that can be made about the nature of the relation between inhibitory control and CF across the preschool years. Three-year-olds also performed at ceiling on their measures of inhibitory control, which meant that it was not possible to draw any conclusions about the relation between inhibitory control and CF in 3-year-olds in this study. However, it is interesting to note that despite two different tasks being used, the relation between inhibitory control and CF was found across two different age groups in Chapter two (2-year-olds and 3.5-year-olds). This suggests that the relation is robust across different tasks. Nevertheless, it is important to note that in Chapter three, the relation was not found in 2-year-olds using a different task (though it was in 3-year-olds). These apparent inconsistencies are likely to be due to the different tasks being used and the extent to which the tasks tap response inhibition or attentional inhibition. There is a clear need to develop inhibitory control tasks that can be used across the preschool years, and that can measure different aspects of inhibitory control.

The lack of preschool measures of executive function is especially limiting for executive function training studies, where it is crucial to measure transfer to tasks that are different to the ones used in training. In Chapter five (the executive function training study for 3-year-olds), the limited choice of well-developed executive function tasks raises some concerns about the validity of the tasks used in this research. In particular, the lack of correlations between baseline measures of executive function in this sample was surprising, and also no relation was found between training gains and transfer in this study. This stands in stark contrast to robust correlations between baseline executive functions skills – particularly between measures of working memory and inhibitory control – and relations between training gains and transfer in the training study with 4-year-olds (Chapter six). This raises the possibility that the tasks used in Chapter five were not as sensitive at measuring 3-year-olds’ executive functioning.

The second limitation refers to the cross-sectional study design employed in this research. The cross-sectional design was useful in highlighting age-related change and developmental trends. However, it does not tell us about the development of individual children. One pertinent question that remains relates to the finding that perseveration may be a developmental milestone. While the evidence in Chapter two does suggest that CF development begins with mixed responding, followed by an increase in perseveration before flexible behaviour, a longitudinal study would offer a more robust evidence for this by clarifying whether this really is a developmental stage-like progression, or whether this reflects sub-groups of children who are consistent perseverators or mixed responders. Clearfield and colleagues employed a longitudinal study design to track the development of infants’ performance on the A-not-B between seven and twelve months of age (Clearfield *et al*., 2006). Much like the research in this thesis, the study showed that perseveration emerged following a period in which infants were severely limited in their ability to produce systematic behaviour. This was informative in showing that perseveration reflects an *improvement* in CF. The same approach would be able to more conclusively address the question of whether perseveration is a discrete developmental stage.

**7.5 Future research**

This research has highlighted two primary areas for future study. More broadly, these relate to the need for developing accounts of CF that address its development across a broader age range. Specifically, the finding that the presence of task-irrelevant information leads children to make distraction errors is a novel finding and to the best of my knowledge, this has not been reported in older children and adults. In contrast, much work has reported links between working memory and response conflict in adulthood (e.g., Kane & Engle, 2003; Meier & Kane, 2014). It would be interesting for future research to address whether older children and adults are similarly disrupted by task-irrelevant information, by testing whether its presence leads to similar impairments in CF via slowed RT. In addition, whether inhibitory control supports the ability to overcome distraction from task-irrelevant information when switching across development. This would help to determine whether biases towards task-irrelevant information related to a previous task persist across development.

It will also be crucial going forward to develop sensitive measures of executive function that can be used with infants and toddlers. Our research has begun to study the period around 2.5 years of age - the so-called ‘dark ages of cognitive development’ (Carlson *et al*., 2004) but there is still a lot of work that needs to be done in understanding executive function development in even younger children. By developing more sensitive measures for 2-year-olds this would enable researchers to begin to bridge gaps between the work that has been done in infancy on precursors to CF and the work on rule-governed explicit CF in preschoolers. In particular, whether the ability to follow a single rule systematically that emerges around age two reflects an important precursor to switching rules that emerges at 2.5 years of age. This remains an exciting area for further study, where both longitudinal studies and training studies would shed important light on how executive functions develop during this time.

**7.6 Conclusion**

In sum, the work presented in this thesis presents three important and novel results that help us to better understand CF development: firstly, previously unidentified key developments occur between the ages of 2 and 3 in children’s ability to suppress distractions; second, in contrast to the prevailing view of CF development, perseveration should not be considered the starting point of CF development nor should it be considered an impairment that children must overcome; and thirdly, the work has substantially advanced the way in which we think about CF and the specific executive functions that underpin CF breaking the theoretical impasse that has dominated the field. The research has found that two different types of CF develop in the preschool years and are underpinned by different executive functions. These results represent an important advance in our understanding of CF.

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**Appendix**

1. Ethical Approval Confirmation Email
2. **Ethical approval for studies in Chapters two to four:**

Date of approval: 27/11/2012

Your submission to the Department of Psychology Ethics Sub-Committee (DESC) entitled "The role of working memory and inhibition in 2- to 4-year-oldsâ™ flexible cognition." has now been reviewed. The committee believed that your methods and procedures conformed to University and BPS Guidelines.

I am therefore pleased to inform you that the ethics of your research are approved. You may now commence the empirical work.

Yours sincerely,

Prof Paschal Sheeran

Chair, DESC

1. **Ethical approval for studies in Chapters five to six:**

Date of approval: 30/04/2014

Your submission to the Department of Psychology Ethics Sub-Committee (DESC) entitled "Executive function training: a causal study of cognitive flexibility in children and adults." has now been reviewed. The committee believed that your methods and procedures conformed to University and BPS Guidelines.

I am therefore pleased to inform you that the ethics of your research are approved. You may now commence the empirical work.

Yours sincerely,

Prof Paschal Sheeran

Chair, DESC

**C. Example Parent Information Sheet and Opt-In Consent Form**



The

Department  
 Of  
 Psychology

Dear Parent or Guardian,

Your nursery has kindly agreed to take part in a study of child development being run by the Developmental Psychology Research Group at the University of Sheffield. My name is Emma Blakey and alongside Dr Dan Carroll I’m conducting research into the development of children’s basic thinking skills – skills like memory and attention – to determine how they develop as children get older.

I will be coming to [Nursery] on [dates] to play some fun, short games with the children there. One of the games involves hiding and then remembering where to find stickers among some colourful pots. The other games involve matching colours and shapes on a touch-screen computer. We are interested to see how children respond to the games as they get older. The games are fun to play and have been used many times before in Sheffield with children of this age range. Children generally find these games very enjoyable, though if any child does not wish to take part, they will never be unduly encouraged to do so. All data recorded will remain completely anonymous, and will not be passed on to anyone else. Children’s dates of birth will be recorded to help us analyse our results, but no other personal information will be recorded. This study has received ethical approval from the Department of Psychology ethics sub-committee.

If are happy for your child to take part in this research then please return the attached slip to your child’s teacher by [date].

Please feel free to contact me if you would like more information about this project.

Many thanks,

Emma Blakey

Child Development Research Group

University of Sheffield

Tel: 0114 222 6563

[e.blakey@sheffield.ac.uk](mailto:e.blakey@sheffield.ac.uk)

I agree for my child to take part in Emma’s study.

Child’s name \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Parent’s signature \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ Date \_\_\_\_\_\_\_\_\_\_\_\_\_

**D. Example Parent Information Sheet and Opt-Out Consent Form**



The

Department  
 Of  
 Psychology

Dear Parent or Guardian,

Your nursery has kindly agreed to take part in a study of child development being run by the Developmental Psychology Research Group at the University of Sheffield. My name is Emma Blakey and alongside Dr Dan Carroll I’m conducting research into the development of children’s basic thinking skills – skills like memory and attention – to determine how they develop as children get older.

I will be coming to [Nursery] on [dates] to play some fun, short games with the children there. One of the games involves hiding and then remembering where to find stickers among some colourful pots. The other games involve matching colours and shapes on a touch-screen computer. We are interested to see how children respond to the games as they get older. The games are fun to play and have been used many times before in Sheffield with children of this age range. Children generally find these games very enjoyable, though if any child does not wish to take part, they will never be unduly encouraged to do so. All data recorded will remain completely anonymous, and will not be passed on to anyone else. Children’s dates of birth will be recorded to help us analyse our results, but no other personal information will be recorded. This study has received ethical approval from the Department of Psychology ethics sub-committee.

If you do not wish for your child to take part in this research please fill in the slip below and return it to your child’s teacher by [date].

Please feel free to contact me if you would like more information about this project.

Many thanks,

Emma Blakey

Child Development Research Group

University of Sheffield

Tel: 0114 222 6563

[e.blakey@sheffield.ac.uk](mailto:e.blakey@sheffield.ac.uk)

I do not want my child to take part in Emma’s study.

Child’s name \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Parent’s signature \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ Date \_\_\_\_\_\_\_\_\_\_\_\_\_

1. Find the Pets script

**Introduction:** “In this game we need to help a family move to a new house. Here is the family, and they live in this house [point to family and old house card]. But they are moving to a new house [point to the family and the new house card]. They are moving from this house [point] to this house [point]. So we need to help them move all of their things to the new house! They have lots of furniture. To help us move their things, we have two boxes [put the boxes on the table in front of the child]. We need to put the big things in the big box and the little things in the little box. Can you see these boxes here? Which one is the big box? And which one is the little box?”

**Demonstration:**“Here is all the furniture that we need to sort into the boxes. “The *big* furniture [point to the card] goes into the *big* box like this” [put in box]. The *little* furniture [point to card] goes into the *little* box like this [put in box]

**Practice:** “Here you have a practice. Where does this card go? [This is repeated for each practice card]. *If children are correct:* “Well done! You’re right, it is big [or little] so it does go into the big [or little] box!” *If children are incorrect:* [retrieve the card from the box] “This is a big [or little] so it goes in the big [or little] box” [place card in correct box].

**Animal instructions:** “There is something I need to tell you though. The family have some pet animals that they are taking to their new home. The pets are being naughty and are hiding in the furniture! But we don’t want to put the pets in the boxes do we? Oh no we don’t. Here is what the pets look like [show them the pictures of each pet]. Can you name the pets, what is this one? [Go through each of the four pets in turn and if children don’t know give feedback]. If you see one of the pets [point to the pets] you must ring the bell here [place the bell on the table in between the two boxes]. This means we can make sure the pets don’t end up in the boxes! Can you do that for me? Do you want to have a practice ringing the bell?” [Let children ring the bell].

**Manipulation check:** “So when should we ring the bell?”

**Experimental phase: “**OK, let’s sort the things into the boxes.” [Give the child each card in turn, with no feedback].

1. The term set-shifting has been used synonymously with CF. However, in general, CF is a term more commonly used by developmental researchers to refer to preschoolers’ ability to switch their behaviour in line with changes in a *single* task rule. [↑](#footnote-ref-1)
2. In this thesis, I will use the term response conflict to refer to situations when bivalent stimuli can be sorted by two different rules, and where top-down guidance is therefore necessary in order to ensure that the appropriate rule is selected. [↑](#footnote-ref-2)