The Role of Perceptual Task Parameters in Children’s Inflexible Dimensional Switching

by

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Abstract

Children at a certain age often have difficulty in flexibly shifting attention between different representational schemes. One example of such cognitive inflexibility occurs in the Dimensional Change Card Sorting (DCCS) task in which 3-year-old children have difficulty switching between sorting dimensions. For instance, after initially sorting the cards by one dimension (e.g., colour) they are unable to sort the cards by a second dimension (e.g., shape). This finding has been primarily associated with problems in attention or inhibition. The present study investigated the role of perceptual information on children’s dimensional shift abilities by manipulating the perceptual characteristics of both task-relevant (the colour or shape of the images on the cards) and task-irrelevant (the background colour or shape of the actual cards themselves) aspects of the task materials between the pre- and post-switch experimental phases. Across three experiments better performance was observed when either task-relevant or task-irrelevant information was changed, with this improved performance occurring when these changes were salient enough to induce a stimulus novelty effect.
Experiment 4 investigated yet another perceptual feature of the task; the degree of stimulus realism (abstractness) on children’s cognitive flexibility. Children successfully sorted the cards when three-dimensional stimuli were used but perseverated when using two-dimensional cards, providing evidence for the role of representational status of the stimuli in influencing children’s dimensional switching.

Manipulations made to increase the salience of the task material as well as those resulting in reduction of similarity between the two phases of the tasks (or increased novelty) were used to enhance children’s cognitive flexibility. Overall, these findings highlight the critical role played by the perceptual information of the overall experimental context, and have important implications for theories of cognitive flexibility.
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Chapter 1

Children’s Cognitive Flexibility on the Dimensional Change Card Sort Task

Rule learning and rule switching skills are essential to human behaviour. Action in the world constantly requires people to not only modify their behaviour in accordance with rules, but to also flexibly shift their attention and subsequent behaviour to a new rule (or set of rules) in response to situation demands (e.g., DeLoache, 1991; Jacques & Zelazo, 2005; Kendler & Kendler, 1959; Welshe, Pennington, & Grossier, 1991; Zelazo, Müller, Frye, & Marcovitch, 2003). Although such rule selection and rule switching behaviour seems easy and automatic for adults, research has demonstrated that children experience great difficulty in tasks requiring this form of flexible attentional shift, ranging from strategy use (Chen, 2007; Kendler & Kendler, 1959) to symbolic reasoning (DeLoache, 1991, 1995a, 1995b; DeLoache & Burns, 1994; Jowkar-Baniani & Schmuckler, 2012) to social cognition (Carlson & Moses, 2001).

The ability to flexibly guide attention in response to contextual demands is typically referred to as cognitive control or cognitive flexibility. Cognitive control is thought to encompass a variety of high-level cognitive skills, such as attention, inhibition, working memory and planning (Miller & Cohen, 2001); all of which are of great importance for researchers and are critical for cognitive and social development with important implications in adulthood (Carlson, 2005; Mundy & Newell, 2007; Ruff & Rothbart, 1996).

One of the classic examples of studies on cognitive flexibility is the Piagetian A-not-B task (Piaget, 1954). In this task, infants are shown an initial location of a hidden toy (A) and are required to search for the toy at that location. After a few attempts, the location of the toy is
changed requiring infants to search at the new location (B). The A-not-B error occurs when infants incorrectly search at the previous location of the toy despite seeing the toy hidden at the second location. This error has been associated with infants’ lack of cognitive flexibility and an inability to update their representation of the toy’s location, necessary to override searching at the previous location (Diamond, 1985, 1991a).

Another task commonly used in childhood to assess children’s cognitive flexibility is the Dimensional Change Card Sort (DCCS) task (Zelazo & Frye, 1998; Zelazo, Frye, & Rapus, 1996). In the standard version of this task children see cards depicting objects that differ on two dimensions, such as colour and shape (e.g., red and blue flowers, red and blue boats), and are asked to sort the cards by one of these dimensions (e.g., sort by shape, thereby grouping together blue flowers with red flowers). After successfully sorting the cards by this first dimension, children are asked to sort the same cards by the second dimension (e.g., sort by colour, thereby grouping together red boats with red flowers). Despite understanding the instructions and receiving the sorting rule on every trial, 3-year-olds often succeed during the first phase, but fail in the second phase, typically perseverating in sorting by the previously relevant dimension (Kirkham, Cruess, & Diamond, 2003; Kirkham & Diamond, 2003; Perner & Lang, 2002; Zelazo & Frye, 1998). In contrast, 4- and 5-year-olds are typically successful in both phases, sorting correctly by both the pre- and the post-switch rules (Zelazo et al., 2003). This developmental trend is robust, with the same pattern of performance emerging for different pairs of dimensions (Frye, Zelazo, & Palfai, 1995), when verbal rather than manual responses are required (Zelazo et al., 1996) and even when children observe the cards being sorted by puppets or another adult rather than sorting the cards themselves (Jacques, Zelazo, Kirkham, & Semcesen, 1999; Moriguchi, Lee, & Itakura, 2007).
Theoretical Perspectives

Many theories have been proposed to explain the observed age-related changes in the DCCS task, each emphasizing a distinct aspect of children’s errors. These theories include: the Cognitive Complexity and Control (CCC), the Attentional Inertia, the Negative priming and the Graded memory accounts. Each account is described in detail below.

Cognitive Complexity and Control

One of the initial theories of the DCCS task proposed by Zelazo and colleagues (1997, 1998) is the “Cognitive Complexity and Control” (CCC) account, proposed based on age-related changes in the complexity of the rule systems that children can represent. These rules refer to the representation of the relations between a set of antecedent conditions and actions, and the complexity of this system is determined by the number of embedded structures present. This theory assumes the existence of two different types of systems: a response-based mechanism that learns and stores behavioural routines in an unconscious manner and a conscious representational system that controls the operation of this response-based system (Zelazo & Frye, 1998).

To correctly switch their sorting rules in the DCCS task, children need to first consider the two sets of lower order rules (colour and shape) that apply to the same situation, and then construct a higher order, embedded “if-if-then” rule for selecting the post-switch rules (e.g., if we are playing by colour, then if red……here, if blue….there, but if we are playing by shape, then if rabbit….here, if flower…. there”). The problem according to this account is that children’s abilities to represent rules changes developmentally. Prior to the second year of life, infants are only able to represent a single goal. Infants are conscious of their goals, but not the representation of the goals or the means to attain the goals, suggesting that infants cannot use a rule to guide their behaviour as they lack the ability to make explicit decisions about when to
invoke an action plan to attain their goal. In the second year children begin to form explicit representations of the rules. According to the CCC account, at this stage children are capable of “desire”, defined as the conscious representation of a goal, but still incapable of “deliberation”, referred to the active consideration of alternative means and ends. One way to measure infants’ ability to consciously employ means and goals is to examine infants’ surprise in response to unexpected events. For instance, Frye (1991) presented eight, sixteen and twenty-four-month-old infants with variations of Piaget’s (1952) support task in which a toy could be moved into reach by pulling a cloth on which the toy was resting. To create unexpected results, the situation was changed such that moving the cloth either did not move the toy or actually moved the toy farther away. Infants of all ages demonstrated surprise in response to such task manipulations. To further examine infants’ true awareness of the consequence of moving the cloth, a mismatched condition was created. In this situation an action which should not have any effects on the toy actually brought the toy closer to reach. If infants have an understanding of the relation between the action of pulling the cloth and its consequence on the toy, they should be also surprised when a desired action is achieved via the wrong means. Only the 24-month-olds and few 16-month-olds were surprised at this event, demonstrating that awareness of means and goals emerges closer to the end of the second year. By around 2.5 years, children begin to represent rules, but this is often limited to only one rule (e.g. red cards go in this box); by 3 years of age children can represent both rules of one dimension (if sorting by colour, red cards go in this box, blue cards go in this box), but cannot embed these rules within a higher order rule (if sorting by colour, follow red-blue rules, if sorting by shape follow different rules). And by 4 to 5 years children are able to represent the complete rule hierarchy. Thus, since the DCCS task contains conflicting rule sets across the pre- and the post-switch (e.g., A blue boat can be sorted by either colour as
blue or by shape as a boat), the CCC account places strong emphasis on children’s ability to form rule hierarchies in resolving such conflict and performing successfully on the DCCS task. Given better performance on the DCCS task among 4- compared to the 3-year-olds, the CCC account claims that as children’s ability to represent rule hierarchies develops, their performance on the DCCS task is improved.

To investigate the CCC’s claim, a number of studies have manipulated the rule structure of the task. If children’s perseveration stems from an inability to form hierarchical rule structures in the presence of conflicting rule sets, if such conflict no longer exists, the need for forming these hierarchical rule structures would also disappear. To create an experiment with no conflict among rule sets, Zelazo and Reznick (1991) presented the 3-year-olds with four cue cards (e.g., a garden hose and a truck affixed to one box as examples of items found outside the house, and a bed and a chair to another box as example of items found inside the house). Two cue cards were used on each box to provide more examples of each task rule. Instead of a standard DCCS task with the pre- and post-switch phases, this task only consisted of one phase in which children were told two rules for sorting the cards, such as “if it is something that is found inside the house, it goes in this box, and if it is something that is found outside of the house, it goes in this box”. Children were then given sorting cards showing objects, such as a snowman or a telephone and were asked to sort these cards. Three-year-olds who typically fail the DCCS task successfully sorted the cards, since each card could only be sorted in one way (either inside the house or outside and never both), removing the conflict between the sorting rules.

Other predictions of the CCC theory have been also tested in other studies. Children’s perseveration could be the result of perseveration on the sorting dimensions (e.g., colour or shape), perseveration on the rule pairs (e.g., blue or red for the colour dimension), or
perseveration on the specific stimulus values or features (e.g., red car or blue truck). The CCC theory suggests that 3-year-olds perseverate on a pair of rules, such as “red ones go here; blue ones go there”, in contrast to other views derived from research on discrimination learning, which suggest children’s perseveration of the sorting dimension (colour or shape). If children perseverate on a dimension *per se*, then perseveration should occur regardless of whether the rule values of that dimension were changed (i.e., the actual colour or shape of the sorting rules, such as red and blue). To test this, Zelazo and colleagues (1995) created what is called the total change version of the DCCS task. In this version, the values of the dimensions on the pre-switch phase were completely changed to the new ones in the post-switch. For instance, children sorted red and blue rabbits and boats on the pre-switch and green and yellow cars and flowers on the post-switch. If children attended solely to the sorting dimension (colour or shape), they should have continued to perseverate in the post-switch, since the dimensions were not changed (colour and shape dimensions were present on both the pre- and the post-switch). But if they are perseverating on specific rules, then they should not perseverate on the total change version in which there is no interference between the two pairs of rules. As predicted by the CCC theory, children had no problem sorting the cards correctly on this version of the task in which the values of both colour and shape rules have been changed.

However, it is still possible that perseveration on the DCCS task reflects learned responses to unique stimulus features (values of each sorting rule) that are not necessarily conceptualized as instances of a single dimension (e.g., red car or blue flower). If that is the case, then children should perseverate only in the presence of those specific features. To further differentiate between the specific rule account as suggested by the CCC account and the specific stimulus values account, a partial change version of the task was created, such that only the
values of the dimension that was *irrelevant* in the pre-switch were changed in the post-switch. For instance, if children first sorted red and blue boats and rabbits by colour on the pre-switch phase, they were asked to sort red and blue flowers and cars by shape during the post-switch. This manipulation still allows children to perseverate on specific rules, such as “if it’s red, then the card goes here and if it’s blue it goes there”, but it prevents them from perseverating based on responses to specific stimuli, such as a red boat, as such stimulus is no longer present on the post-switch. If children perseverate on the specific stimulus values, then this version should also result in improved performance similar to the total change version. Children, however, showed a great degree of perseverative errors on this task by applying old pre-switch rules to the new stimuli they had never seen before. Hence, children’s failure in the partial change version of the task provided evidence that children perseverate on specific rules and have difficulty forming hierarchical rule structures related to the colour and shape dimensions rather than perseverating on responses to specific stimulus values.

The CCC theory has been criticized with regards to the role that memory might play in children’s performance. For instance, it might be hard for children to remember the additional rules presented to them in the post-switch (Brainerd, 1983; Case, 1992; Cummings & Bjork, 1983; Diamond, 1990). In order to address this issue, Zelazo and colleagues (1995) created a version of the task; what they referred to as the 4-Rule version in which children were presented with four sorting rules (as opposed to the standard 2 rules), thus increasing the memory demand of the task. However, all the four rules involved one dimension only (e.g., red, blue, purple and yellow for the colour dimension), asking children to match sorting cards to four cue cards with no need for switching, thus eliminating the hierarchical relations among the rules. If children’s difficulty can be attributed to memory demands of the task, then performance on this version is
expected to be poorer compared to the standard task. Children however, showed better performance in this version of the task compared to the standard task, demonstrating that memory demands of the task cannot account for children’s poor performance. These results provided more evidence for the CCC theory, suggesting that perseveration stems from an existing conflict between the rules that need to be applied to a single card, and not due to any cognitive load produced by the task as a result of the existence of multiple rules.

**Attentional Inertia account**

In contrast to the CCC theory, Kirkham, Cruess, and Diamond (2003) suggest that 3-year-olds’ perseveration is the result of deficits in inhibitory control. Specifically, according to this “Attentional Inertia” account, children perseverate because they fail to suppress attention to the pre-switch rule sets. For instance, after sorting red rabbits and blue boats by colour, children’s attention remains focused on the colour dimension, and thus they fail to redirect attention to the shape dimension on the post-switch trials. Accordingly, despite knowing the correct response on the post-switch trials, children cannot overcome their attentional inertia and therefore respond incorrectly on these latter trials. This idea is consistent with the CCC theory in that both theories emphasize the inhibitory control demands of the task. However, the CCC theory claims that construction of the embedded rule structures allows inhibition to occur, whereas the attentional inertia account suggests that children’s difficulty stems from their inability to inhibit attention to the previously relevant task dimensions.

Support for the attentional inertia theory comes from studies showing better performance when the task decreases the salience of the pre-switch dimensions and reducing the inhibitory demands of the task. For instance, some studies have demonstrated better performance when children are asked to sort the cards face down, when there are no cue cards fixed to the sorting
locations or when children rather than the experimenter label the relevant dimension of the cards on each trial (Kirkham et al., 2003; Perner & Lang, 2002; Towse, Redbond, Houston-Price, & Cook, 2000).

Similarly, better performance is observed when colour and shape values are spatially separated on the cards (Diamond, Carlson, & Beck, 2005; Kloo & Perner, 2005; Kloo, Perner, Aichhorn, & Schmidhuber, 2010). For instance, Kloo and Perner (2005) found improved performance when the colour and shape dimensions were separated. Colourless shapes were presented on the cards with the colour information presented as a coloured patch beside each of the shapes. Kloo et al., (2010) further distinguished between spatial and object-wise separation by creating a condition in which the colour and the shape dimensions were not integrated in the same object, but were displayed at the same location. This “overlapping” condition consisted of presenting children with cards in which the colour and the shape dimensions were separated, such that instead of showing children a green apple, a colorless apple was shown with a green circular ring surrounding the apple. In this case, the dimensions were separated, but both still appeared in the same location. The results of this separated but spatially overlapping condition indicated better performance compared to the standard condition, but comparable performance to the spatially distinct version. These findings suggest that the critical factor affecting children’s performance is the removal of integration of the two dimensions rather than their spatial separation.

Finally, Zelazo, Müller, Frye, & Marcovitch (2003) found that changing the values of the sorting dimensions from the pre-switch to the post-switch affected children’s performance. Whereas children still perseverated in the partial change version of the task in which only the values of the previously irrelevant dimension were changed (e.g., children sorted red and blue
rabbits and boats by shape on the pre-switch and sorted green and yellow rabbits and boats by colour on the post-switch), they were very successful in the total change version in which the values of both dimensions were changed between pre- and post-switch (e.g., sort red and blue rabbits and boats by shape on the pre-switch and sort green and yellow flowers and cars by colour on the post-switch). By removing the values of the previously relevant dimension in the post-switch phase children could no longer attend to those values and could thus attend to the current sorting dimension.

Other evidence in support of the attentional inertia account comes from studies demonstrating children’ difficulty in selectively attending to the relevant task dimensions. Selective attention is the ability to focus on a particular aspect of a stimulus and is based on the idea that introduction of distractors usually impairs performance (Bedi, Halperin, & Sharma, 1994; Jerger, Martin, & Pirozzolo, 1988; Jerger, Pearson, & Spence, 1999; Pick & Frankel, 1973). In a card sorting task the investigation of the effect of such distractors or irrelevant stimulus dimensions dates back to the early 1970s with the introduction of the widely studied phenomenon of the Garner effect (Garner, 1974; Garner & Felfoldy, 1970). The Garner effect refers to the slowing of classification when cards differ on several dimensions in addition to the one used for sorting. Strutt, Anderson and Well’s (1975) examination of this effect demonstrated slowed classification in the presence of one or two irrelevant dimensions, with this interference decreasing as a function of age between 6 to 12 years. A similar pattern has been also demonstrated in other card sorting studies (Shepp & Swartz, 1976; Well, Lorch, & Anderson, 1980), as well as in other tasks, such as the auditory word identification task, where slower performance has been observed in the presence of irrelevant variations in the speaker’s gender (Jerger et al., 1999).
The main supporting evidence for the role of selective attention in the card sorting tasks is seen in research demonstrating children’s improved performance when the task does not require selective attention to the relevant dimension, but only a switch in responses. For instance, Perner and Lange (2002) employed a “reversal shift” task. In this task children were shown two boxes (one cued with a sun and the other with a car). Children were first asked to sort the cards by putting together all of the suns in the “Sun” box and all of the cars in the “Car” box. After sorting the cards, children were told to now simply reverse their response, placing the suns in the “Car” box and placing the cars in the “Sun” box. Because children always sorted based on the shape of the objects, this task only required a shift in response (which cards go together), but not a shift in attention. According to the attentional inertial account, children successfully sorted the cards in this task. However, when the irrelevant dimension of colour was added to the cards, such that the cards were not of the same colour, previously successful children perseverated, even when the task did not require a switch between the shape and the colour dimensions. The findings of these studies point to children’s difficulty in selective attention to the relevant task dimensions in the presence of irrelevant information.

Kirkham, Cruess and Diamond (2003) further argued that this type of attentional deficit was also evident in adults, a finding difficult to explain by the CCC theory. For example, many studies requiring adults to switch between tasks have found a slowing of response and even perseveration (e.g., Monsell & Driver, 2000; Rogers & Monsell, 1995). For instance, Rogers and Monsell tested adults on a letter and digit identification task in which participants were asked to make a decision regarding whether the letter was a consonant or a vowel and whether the digit was odd or even. When the stimuli were bivalent (e.g., B3) and when the task required switching of response from attending to the letter to attending to the digit, adults were much slower to
respond compared to the conditions that did not require such a switch in response. Since adults have no difficulty constructing hierarchical rule structures, their difficulty cannot be explained by the CCC theory.

Furthermore, children’s success in answering the knowledge questions, which typically ask children if they know where “red” cards or “flowers” should go, raises difficulty for the CCC theory. According to the attentional inertia account, these knowledge questions are typically created to remove the conflicting information often available in the standard DCCS tasks. For instance, when asked “where do red ones go?” the cards are only labeled by the prevalent dimension and there is no conflicting shape information available. Thus, there is no need for children to attend to any irrelevant information. In fact, children show similar perseverative errors in response to knowledge questions that contain conflicting information (where do red cars go?) (Munakata & Yerys, 2001).

**Negative Priming**

In contrast to the attentional inertia account, which focuses on the attention to the task-relevant dimension, an alternative account suggests that children’s problems are the result of difficulty engaging attention to the formerly irrelevant task dimension, when these values become relevant in the post-switch. This account, thus, suggests that failure in the DCCS task might arise from an inability to re-attend to a formerly irrelevant dimension after it has been previously ignored. This phenomenon, called “Negative Priming” (NP) has been investigated extensively with adults (e.g., Fox, 1995; Milliken & Tipper, 1998; Neill, 1977; Neill & Westberry, 1987; Neumann & DeSchepper, 1991; Tipper, 2001) and children (Amso & Johnson, 2005; Pritchard & Neumann, 2004; Tipper, 1985), as well as in a variety of tasks (Lowe, 1985; Tipper & Driver, 1988; Treisman & DeSchepper, 1996). The principle study to investigate the
development of selective attention and sensitivity to interference in children using the NP paradigm was done by Tipper and colleagues (1989). A variant of a Stroop task was used to investigate whether children would demonstrate less NP compared to adults due to an immature ability to inhibit distracting information. These results found higher levels of distractor intrusion and little evidence of NP in children in a Stroop task, while lower levels of distractor intrusion and significant levels of NP were found in adults. In contrast, other studies investigating NP in location-based tasks have found significant levels of NP in children (Simone & McCormick, 1999; Tipper & McLaren, 1990).

Although the findings on the role of NP in children are mixed, Zelazo et al. (2003) provided indirect support for the effect of NP in the DCCS task. The authors administered a version of the task in which the values of the relevant pre-switch dimension were removed and replaced in the post-switch by (now irrelevant) different values (sorting red rabbits and blue boats according to shape in the pre-switch and red flowers and blue cars according to colour on the post-switch). According to the attentional inertia theory, because the relevant values in the pre-switch dimension (shape – rabbits and boats) were no longer present on the post-switch, these values could no longer interfere with post-switch performance, and thus children should perform well in this version of the task. Surprisingly, 3-year-olds still showed high levels of perseveration on this task. Zelazo et al. (2003) interpreted these findings as consistent with the possibility that performance on the DCCS task could be partly explained by an inability to attend to the formerly irrelevant dimension (e.g., negative priming). Children performed poorly in the post-switch task because they were unable to re-attend to the dimension they had just ignored in the pre-switch phase. Thus, although the values of the previously relevant dimensions were changed on the post-switch, children’s suppression of the previously irrelevant values had
carried over to the post-switch, making it difficult for them to re-attend to the previously suppressed values once they became relevant on the post-switch.

Müller, Dick, Gela, Overton and Zelazo (2006) further investigated the situations in which negative priming could be elicited in the DCCS task. One possibility is that negative priming only occurs when there is a conflict between two ways of matching the cue and the sorting cards. The authors suggested that if NP occurs only in the presence of a conflict between cue and sorting cards, then negative priming can be reduced by drawing attention to the relevant sorting dimension, reducing children’s need to inhibit irrelevant values on the pre-switch. Cue cards and sorting cards were thus created such that they could be only matched on one dimension (the sorting dimension relevant on the pre-switch). For instance, children were presented with a blue rabbit and a red boat as cue cards and were asked to sort yellow rabbits and green boats by shape (hence, cue and sorting cards could be only matched on the shape dimension). This was done to facilitate children’s attention to the relevant shape dimension and reduce the need to suppress the irrelevant colour dimension on the pre-switch. Improved performance was seen on this task, suggesting that once suppression of the formerly irrelevant dimension was reduced children could more easily re-attend to these values when they became relevant on the post-switch. This finding is similar to Zelazo and colleagues’ (2003) improved performance in the NP redundant pre-switch version in which cue cards and sorting cards used in the pre-switch were made identical, reducing children’s need to select the relevant rule in the presence of a competing alternative rule during the pre-switch.

Müller and colleagues (2006) also investigated other factors in producing negative priming. One factor commonly seen to affect NP is the frequency of interfering trials, such that larger proportion of interfering trials results in increased levels of NP (Lowe, 1998). In addition,
the recency of such interference seems to play a role, as increasing the proximity of the alternate response has been found to result in greater switch costs (Allport & Wylie, 2000). Since the presence of conflict between cue and sorting cards was found to affect the occurrence of NP, Müller and colleagues (2006) manipulated the frequency and the recency of conflict trials in a DCCS task by varying the number of times such incompatible sorting cards were paired with cue cards during the pre-switch phase. Two versions of the DCCS task were created: the random NP and the recency NP. Both versions consisted of the presentation of mismatching cue-sorting card pairs in half of the pre-switch trials. However, in the random version such conflict trials were randomized during the pre-switch phase, whereas in the recency version all conflict trials occurred at the end of the pre-switch phase. The recency of presentation of the conflict trials was found to affect children’s performance, with better performance observed in the random version compared to the recency version. The relative frequency of this conflict over the entire pre-switch phase, however, was not found to have any effects. Thus, such mismatch between cue and sorting cards forces children to suppress attention to the irrelevant sorting dimension on the pre-switch. This effect is then carried to the post-switch, making it more difficult for children to re-attend to this previously-suppressed dimension, leading to proper performance. A greater effect is observed when this mismatch occurs closer to the post-switch phase, as seen by the poorer performance on the recency condition.

Overall, the findings of the negative priming literature point to children’s difficulties in selectively attending to one task dimension, inhibiting the previously-relevant dimension, as well as engaging attention to the previously-ignored sorting dimensions.
Graded working memory (Active-latent memory)

This account investigates the age-related changes in cognitive flexibility by exploring the distinction between active and latent memory traces. At the cognitive level, active memories are explained by notions of recall, working and short-term memory, whereas latent memories are related to notions of habit and long-term memory (e.g., Munakata, 1997). Short term memory requires active maintenance of representations in memory, whereas past experience or contextual supports facilitate forming more long term memories.

At the neural network level, active traces take the form of sustained activities of neural networks with latent traces act as changes to the strength of connections among these networks, which can be modified by experience or learning (Cepeda & Munakata, 2007; Jordan & Morton, 2008; Morton & Munakata, 2002; Yerys & Munakata, 2006). Thus, exposure to a task activates the relevant neuronal network (forming active memory traces), with experience and exposure to the task strengthening the connections among these networks and building latent memory traces. The latent memory system builds up memories as a behaviour is repeated, leading to a bias to repeat that behaviour, whereas the working memory actively maintains information, providing top-down support for task-relevant information (Brace, Morton, & Munakata, 2006; Cepeda & Munakata, 2007; Cohen, Dunbar, & McClelland, 1990; Diamond, 1985; Morton & Munakata, 2002).

In a DCCS task, this model describes performance according to three input layers (visual features, verbal features and the sorting rule), an internal representation layer, a prefrontal cortex layer and an output layer (Morton & Munakata, 2002). The visual features layer is responsible for encoding the colour (e.g., red and blue) and the shape (e.g., cars and flowers) of the cards. The verbal features layer encodes verbal statements as part of the task (e.g., red ones go here,
blue ones go there) and description of the cards (e.g., here’s a red one). The rule layer encodes the statement about the rule (e.g., we are playing a colour game). The output units represent the sorting trays that are marked by cue cards. Feedforward connections between the units change with experience such that connections between units that are simultaneously active increase in strength. For instance, when the pre-switch rule is to sort based on colour, units coding for colour show increased activity and thus connections between these units become stronger. The strengthening of the connections between the colour units as a result of experience sorting by the pre-switch rule builds a latent memory for the colour rule. On the post-switch the shape units begin to show activity (forming an active memory), but strong connections among the units coding colour (the latent memory for colour) lead to a response bias for sorting by colour, resulting in perseverative errors. Thus, perseverance occurs when active representations for the post-switch rules formed by the working memory system are not strong enough to overcome the latent traces of the pre-switch rules.

The evidence for the importance of such an active-latent distinction comes from neurophysiological studies showing that neurons show the ability to remember information both in an active manner through firing in response to stimuli and in a latent manner through changes in firing threshold. For instance, sustained firing of cells in the prefrontal cortex of monkeys has been observed in response to the stimuli that needed to be remembered across delays (Fuster, 1973; Goldman-Rakic, 1987). Similarly, this type of activity in the prefrontal cortex has been found critical for maintaining information over a long period of time (Miller, Erickson, & Desimone, 1996), while recognition of familiar stimuli has been associated with decreased firing in cells in the temporal cortex (Miller & Desimone, 1994). This type of active-latent interference has been also found important in accounting for perseveration errors in the Stroop task (Cohen et
al., 1990). According to the neural network model, separate pathways process the colour and the word meaning of the stimuli. Experience in reading the words strengthens the connections between processing units of the word reading pathway compared to the connections in the colour naming pathway, creating a latent trace for word reading. In a Stroop task when the task requires naming the colour of a word, the colour naming units become active, but such active traces are not sufficient to overcome strong latent traces of word-reading units, resulting in perseverative responding observed as the Stroop effect (for a review see MacLeod, 1991).

Such an account can also explain dissociations that are typically observed between children’s knowledge of the tasks and their performance in a variety of domains including perception, attention, memory, executive functioning and language (Farah, 1991; Hu & Goodale, 2000; Wallace & Farah, 1992; Yonelinas, 1997). According to this account certain tasks tap weaker representations, while others require stronger representations, leading to dissociations in behaviour. For instance, infants demonstrate memory for hidden objects within the first few months of life in violation-of-expectation studies (e.g., Baillargeon, 1993), while failing to search for desired objects that are presented and then hidden. Most accounts of this dissociation suggest that infants’ failure in these tasks is not related to the memory of the hidden objects, but separate systems of acting on this memory are underdeveloped (e.g., problem solving system for lifting the cover to retrieve the toy) (Baillargeon, Graber, Devos, & Black, 1990; Diamond, 1991b). Even after controlling for problem solving demands for retrieving visible and hidden objects, infants tend to successfully retrieve visible objects, but nonetheless fail to demonstrate memory for hidden objects (Shinskey & Munakata, 2001). According to the graded memory account, the abilities of infants to represent hidden objects become stronger with development resulting in more dissociations in memory for hidden objects, because weak representations of
hidden objects suffice for some tasks but not the others (Shinskey & Munakata, 2001). This suggests that weak representations of hidden objects might be sufficient to recognize a strange event, but might not suffice for reaching for hidden objects (Munakata, 2001). A neural model has been also developed to support such findings in memory development (Shinskey & Munakata, 2001), which can explain infants’ preference for searching for familiar compared to novel toys after they were hidden, while searching more for novel toys if they were visible.

Similar dissociations have been observed in tasks of executive functioning and in the context of the DCCS task. For instance, children can verbally report the new rules they need to sort by on a card sorting task, but despite their knowledge, incorrectly sort the cards according to the previous rule (Milner, 1963; Zelazo et al., 1996). For instance, children correctly respond if asked “where do red cards go in the colour game” or “where do flowers go in the shape game?”, but incorrectly sort the red cards or flowers. According to the graded memory account, such dissociations occur as a result of weak pre-frontal representations that might suffice in some tasks (verbally reporting the rule or looking to the correct hiding location), but not other tasks. For instance, stronger representations might be required to resolve conflict when sorting the cards or searching for the toy (Munakata, 2001). In fact, as predicted by this account adding conflict to verbal measures by asking children “where do red flowers go in the colour game?” rather than simply asking “where do red ones go?” resulted in perseverative errors (Munakata & Yerys, 2001).

One prediction of this network is the role of scaffolding on performance. Scaffolding in this context refers to providing the network with guided practice in using the post-switch sorting dimension before testing it on the post-switch phase, as a means of facilitating its ability to use the new sorting dimension. The model predicts that scaffolding the use of the new rules would
lead to changes in connection weights in favor of the new rules, whereas actively maintaining the new rules with verbal instructions would be difficult for children (Morton & Munakata, 2002). The authors tested this model by using network simulations by providing the network with a series of trials to practice the use of the new rule. After the network sorted conflict cards by colour, eight “scaffold” cards that only contained shape information (with no conflicting colour information) were presented. The network was then successful in sorting conflict trials by shape due to strengthening of the shape connections. Other evidence for such predictions comes from a study, which influenced children’s performance by creating intermediate trials between pre- and post-switch phases (Brace et al., 2006). Children were asked to first sort red and blue trucks and flowers by shape in the pre-switch phase. After completing this sorting procedure, several intermediate trials occurred in which children sorted simple red and blue colour patches by colour. These colour patches were then gradually morphed into shapes by adding shape variation to the cards. Children then ultimately sorted the complete images by colour in the post-switch phase.

In a different manipulation, Jordan and Morton (2008) demonstrated that performance was improved when flankers were presented on either side of the sorting stimuli that were congruent with the post-switch dimension. After children sorted the pre-switch cards by shape, a series of post-switch cards were presented to them in which a bar congruent to the card’s colour was shown beside the post-switch stimuli (e.g., red bars were shown on either side of a red rabbit when sorting based on colour). The presence of flankers congruent to the post-switch colour dimension significantly enhanced performance.

According to the active-latent model, the conflict that arises in the context of the DCCS task between pre- and post-switch dimensions stems from an imbalance in the strength of latent
representations that take the form of connections between units processing either the shape or the colour (or any other stimulus feature). The strength of these latent representations change by experience such that sorting by the pre-switch rule strengthens the connections in the unit representing the pre-switch dimension. This imbalance leads to a conflict in the post-switch as the stronger pre-switch representations leads to an incorrect response. Providing a series of “no conflict” intermediate trials (Brace et al., 2006) or congruent flankers (Jordan & Morton, 2008) influenced performance by strengthening the activations of lower level representations of the post-switch rules in a bottom-up manner (building latent memories), reducing the conflict or the activation imbalance that needs to be resolved by top-down mechanisms (e.g., selective attention or inhibitory control).

The role of the latent memory representations on the DCCS task was also examined in another study by employing stimuli consisting of novel shapes and colours (i.e., shapes and colours not familiar to children) (Yerys & Munakata, 2006). Children participated in a DCCS task in which they were asked to sort cards by shape and colour. However, children either sorted cards which depicted novel shapes (dax and gub) or novel colours made by combining different colours (e.g., purple-gray or brown-green) to create new colours with novel labels (flirp and nust). Performance on this version of the task was significantly better than the standard task. The authors explained this improved performance as a result of reduced strength of the latent memory of the novel sorting dimensions in the pre-switch as children had no previous experience or familiarity with these stimuli, making it easier to switch from sorting by these pre-switch dimensions.

Thus, this account provides a unified approach to understanding cognitive flexibility by describing behaviour in terms of an interactive system sensitive to the strength of
representations, which can vary based on environmental support and experience.

**Factors Influencing Performance in the DCCS Task**

In explaining children’s performance on tasks of executive functioning, a variety of factors has been shown to play a role in influencing behaviour. These factors include: salience of the stimuli, social aspects of the task and motor demands of the task.

**Salience of the Dimensions**

A majority of the existing studies investigating children’s performance on the DCCS task have explored performance by manipulating different aspects of the task, such as modifying the procedural details of the task (e.g., asking children to sort cards face down or providing them with feedback), or the visual organization of the illustrations on the cards (e.g., spatial segregation of the dimensions, removal of cue cards). However, recently some studies have investigated whether the nature of the sorting dimensions (e.g., the salience of the dimensions) can also influence cognitive flexibility and performance on the DCCS task.

If perseverative errors are thought of as a type of switch cost or decrease in performance after a task switch, the salience of the post-switch cues can be critical in manipulating such costs. Salience in this context is referred to the low-level features of the stimulus that can attract attention including colour, contour density, and luminance. For instance, when viewing a scene a saliency map is first developed that separates the scene based on three elements (colour, intensity and orientation). This map then highlights areas of change to enable the viewer to discriminate one scene from another, and can be used to predict looking patterns in visual tasks (Underwood, Foulsham, van Loon, Humphreys, & Bloyce, 2006). Salient cues have been found to automatically capture attention in both children and adults (Koch & Ullman, 1985; Smith, Jones, & Landau, 1996; Underwood, Foulsham, van Loon, Humphreys, & Bloyce, 2006) and can thus
have a large effect on children’s ability to shift attention between multiple task dimensions in the DCCS task.

One piece of evidence for such an effect on cognitive flexibility comes from studies demonstrating the role of similarity comparison on dimension matching (Medin, Goldstone, & Getner, 1993). Research in categorization (Murphy & Medin, 1985) and visual comparison (Gentner, 1989) has identified two types of similarity comparisons: attribute similarity and relational similarity. Attribute similarity refers to matching objects on the basis of features, such as shapes or colours, whereas relational similarity refers to integration of features or elements across stimuli, such as the overall pattern or arrangement of items. Research has shown a bias toward processing attribute similarity, demonstrating that children and adults attend to visual features, such as the shape and the colour information, before attending to the spatial relations (Casasola, Cohen, & Chirarello, 2003; Goldstone & Medin, 1994; Quinn, Cummings, Kase, Martin, & Weissman, 1996). Given such a bias to attend to visual features of the stimuli, it could be expected that sorting objects based on attribute features would be more salient than sorting based on relational features (Gentner, 1989; Gentner & Rattermann, 1991). In fact, processing object attributes have been found to interfere with processing relations in reasoning (Honomichl & Chen, 2006; Rattermann & Gentner, 1998) and problem-solving tasks (Loewenstein & Gentner, 2005; Pierce & Gholson, 1994).

Honomichl and Chen (2011) investigated this prediction by comparing children’s ability to sort according to attribute-based or relational-based rules. The DCCS task was modified such that children were asked to either switch from sorting by relational rules (e.g., position of the stimulus on the top or bottom of the card) to attribute rules (shape/colour) between pre- and post-switch phases (R-A) or switch from attribute to relational rules (A-R). A standard task was also
administered in which children sorted by attribute rules on both the pre- and post-switch dimensions (A-A). The results demonstrated better performance when children switched from relational to attribute rules (R-A) compared to the reverse order (A-R). Moreover, performance in the R-A condition was better than the performance on the standard (A-A) condition, whereas performance on the A-R condition was not. This type of asymmetric performance is difficult to explain by the CCC account since the hierarchical rule structure of the task was not changed. Thus, the authors suggested that this improved performance could be explained by either the attentional inertia account or the graded memory account. In terms of the attentional inertia account, the salience of the dimensions affects the inhibitory demand of the task such that employing the less salient pre-switch rules reduces the need to inhibit the pre-switch dimension, making it easier for children to attend to the post-switch rules. The graded memory account however, proposes that the conditions leading to perseveration are graded and not absolute and therefore the strength of memory representations of the rules can change based on the salience of the rules. Due to children’s experience and familiarity with using attribute features of objects and their initial bias to categorize objects by attribute rules, the latent representations of such attribute rules might be stronger compared to the relational rules. This facilitates children’s ability to sort based on such rules, but causes difficulty when they are asked to switch from attribute rules to relational rules. Relational rules, on the other hand, are less familiar to children and thus lead to weaker latent representations. These representations formed on the pre-switch are weaker than the stronger attribute representations formed in the post-switch, reducing the interference between the two representations and resulting in enhanced performance.

Rather than changing the nature of the task dimensions employed, Fisher (2011) manipulated the salience of the rules by modifying the values of the task dimensions. More
specifically, a DCCS task was used in which children sorted the cards based on colour and shape rules. However, rather than using two distinct colour values for the colour dimension (e.g., red and blue), two very similar values were used (e.g., red and pink). This modification was based on previous work suggesting that the perceptual salience in the visual domain is a function of similarity of the features of the object (e.g. colour and intensity) (Gao, Mahadevan, & Vasconcelos, 2008) such that increasing the similarity of the two values would decrease the salience of the contrast between them. Thus, the more similar colour values were expected to reduce the salience of the colour dimension, making it easier to switch attention from this dimension. As expected, performance was improved when children were asked to switch from sorting by the less salient colour dimension to sorting by the more salient shape dimension, but poor performance was seen when children switched from sorting by the more salient shape dimension to the less salient colour dimension (Fisher, 2011).

**Motor demands of the task**

Children’s difficulties in response control have been also found to play an important role in their cognitive flexibility (Barkley, 1997; Carlson, Moses, & Hix, 1998; Cuneo & Welshe, 1992; Goldstone, 1969), which could suggest that perseverative errors result from children’s failure to suppress overlearned response tendencies. The importance of motor demands has been also demonstrated in other tasks; one primary example is children’s performance on the A not B tasks. Recent studies have demonstrated that increasing the motor demands of the task by placing a barrier in children’s path to reach the object influences the number of A not B errors made by children (Collimore, 2010; Collimore & Schmuckler, 2008, 2010). Moreover, such motor demands have been also found to influence perseverative walking behaviour in young children (Schmuckler, in press).
However, not much evidence for the role of such motor demands has been found in the context of a DCCS task. For instance, Zelazo et al.’s (1996) investigation of this issue demonstrated that children perseverated on the task even after only one pre-switch trial, making it unlikely that one pre-switch trial can be sufficient for children to form a response habit. Children were also found to perseverate when responding verbally rather than manually (by labeling the correct sorting bin), making it even more difficult to explain children’s performance based on the motor demands of the task and children’s lack of response control.

Diamond (1985) further explored the role of the motor demands using an error detection paradigm. This paradigm, which requires children to detect someone else’s errors after observing their behaviour, can provide a source of children’s difficulty. If children are capable of detecting another person’s problems while failing the task themselves, their failure can result from the motor demands of the task. However, if children also show difficulty in detecting another person’s errors, then their problems cannot be explained by the lack of response control. This type of paradigm has been also used with patients with frontal damage. These patients often show the ability to detect others’ errors on tasks that they themselves fail, demonstrating knowledge of the task, but an inability to execute the same task (e.g., Konow & Pribram, 1970). Similarly, young children often show the ability to detect puppets’ numerical errors even on tasks much harder than those in which they can successfully perform (Briars & Siegler, 1984; DeLoache, Sugarman, & Brown, 1985).

The use of the error detection paradigm in the DCCS task has, however, found rather different results. After watching a puppet sort the cards perseveratively on the post-switch, children were asked to decide whether the puppet had sorted the cards correctly. While most 4- and 5-year-olds detected the puppets’ errors, most 3-year-olds failed to do so, suggesting that the
3-year-olds’ difficulty in these tasks cannot be explained by the motor demands of the task (Jacques et al., 1999). In addition, the authors demonstrated that those children who failed to detect the puppets’ errors also perseverated when asked to sort the cards themselves.

A different approach to this issue was taken by Moriguchi and Itakara (2008) who gave children both a standard and an observation version of the DCCS task. The observation version asked children to sort the cards according to the new rule after observing a model sort the cards based on a previous rule in the pre-switch. A significant correlation was found in performance across the two versions of the task with 3-year-olds often showing difficulty in both tasks. Interestingly, however, 4-year-olds displayed more difficulty in the observation version of the task compared to the standard version. The authors explained this increased difficulty based on the older children’s increased sensitivity to another person’s internal states and the ability of social cognition (refer to the next section on social cues). Overall, there seems to be a lack of evidence to support the role of motor demands of the task and children’s lack of response control in influencing children’s cognitive flexibility on the DCCS task.

**Social Cues**

Cognitive flexibility has been also found to be influenced by social aspects of the task. Many studies have shown significant relations between inhibitory control and social cognition in domains such as emotional knowledge, moral conscience and theory of mind (Carlson & Moses, 2001; Carlson, Moses, & Breton, 2002; Eisenberg et al., 1995; Hughes, 1998; Hughes, Dunn, & White, 1998; Perner, Lang, & Kloo, 2002). Although most studies have only demonstrated a correlation between the two factors, others have shown that improvement in social cognition can contribute to enhancement in children’s inhibitory control abilities (Kloo & Perner, 2003; Perner, 1998). For instance, Kloo and Perner (2003) administrated a training program aimed at
enhancing children’s performance on a variety of theory of mind tasks (e.g., false belief task).

Although, such theory of mind tasks are similar to the DCCS tasks in assessing cognitive flexibility, these tasks assess children’s ability in more social contexts, primarily investigating their ability to take another person’s perspective, while DCCS tasks look more closely at flexibility in attending to multiple dimensions of a stimulus or task. The authors demonstrated that training on theory of mind tasks led to subsequent improvements in children’s performance on the DCCS task.

Similarly, other studies have also investigated children’s sensitivity to the social pragmatics of the task. For instance, Moriguchi and Lee (2007) created different versions of the DCCS task in which children watched an adult model sort the cards incorrectly on the pre-switch. Children were then presented with the cards and were asked to sort the cards according to the post-switch rule. In two of the conditions the model appeared to either know that she had sorted the cards incorrectly or appeared uncertain about her performance. Children showed significant sensitivity to such social information available in the task. Children no longer made any perseverative errors and were successful in sorting the cards by the correct rule on the post-switch when the model was aware of her errors. However, when the model was confident about her sorting or seemed oblivious to her sorting errors, most 3-year-olds made perseverative errors. The authors explained these findings by what they referred to as the social transmission of disinhibition, meaning that disinhibition or a failure to inhibit previous sorting rules in the DCCS task can be transmitted socially from a model to an observer in a manner similar to children’s own difficulty to inhibit the use of the old rules when sorting the cards themselves. When the model appeared to know her errors, children were able to disregard such errors to sort the cards
correctly on the post-switch, however, the model’s lack of knowledge about her pre-switch mistakes was transmitted socially to children, influencing children’s own ability to sort the cards.

These findings cannot be directly explained by the CCC theory as the nature and the complexity of the rule structure of the task was unaffected. The attentional inertia account and the graded memory account, however, might be able to explain these findings. According to the attentional inertia account, watching a model’s sorting could have directed children’s attention to the dimension according to which the model sorted the cards. The model’s awareness of her mistakes or uncertainty about her sorting behaviour, however, helped divert children’s attention from the old dimension to the new sorting dimension. Similarly, the graded memory account explains children’s performance in terms of the strength of the representations formed. When the model was aware of her mistakes or uncertain about her sorting behaviour children might have formed a relatively weaker representation of the pre-switch rules, making it easier to switch to the new rule in the post-switch.

Other studies have also investigated children’s sensitivity to the social aspects of the task by having children observe a robot rather than a human model (Moriguchi, Kanda, Ishiguro, & Itakura, 2010a). Children’s performance on the DCCS task was found to be affected by humans’ actions, but not by robots’ actions. For instance, after watching a human model sorting the cards on the pre-switch, children were unable to switch to sort the cards by the post-switch dimension. However, such difficulty was not seen when children observed a robot rather than a human model. The authors explained the results in terms of sociocognitive perspective of cognitive flexibility, suggesting that children perseverate on the human model’s rules because they mentally simulate the model’s actions while watching. The robot however, failed to induce such a process in children.
But, why did the robot fail to induce such an effect? Some studies suggest that children are sensitive to behavioural cues, such as self-propelledness and contingent responses (Gergley & Csibra, 2003; Johnson, Slaughter, & Carey, 1998; Premack, 1990), while others have emphasized the importance of featural aspects, such as the appearance of the model (Meltzoff, 1995; Woodward, 1998). To investigate these possibilities Moriguchi and colleagues (2010b) observed whether a robot with a human appearance (an android) could elicit perseverative errors in children. Since the android was very similar to the human, any differences in performance in the two versions would be the result of sensitivity to behavioural cues. The authors demonstrated perseverative errors after children watched the android sorting the cards compared to a baseline task in which children sorted the card by one dimension only. Children’s performance was however better when compared to the condition in which they watched a human model instead. These results provided more evidence for children’s sensitivity to the available social cues of the task and suggested that behavioural cues (differences in movement of the android and human model) could affect performance on more cognitive tasks, such as the DCCS task.

**Perceptual Similarity of the Task Material**

After a comprehensive review of cognitive flexibility and its influencing factors, it is clear that the majority of the theories and accounts described so far to explain performance in the DCCS task have in common an underlying assumption that the basic mechanism under investigation is driven by factors operating at a fairly sophisticated, cognitive level. The CCC theory assumes that problems in this task stem from limitations in forming higher-order representations of the task context, the attentional inertia account focuses on children’s failure to disengage attention to a previously relevant dimension, the NP account posits an inability to re-attend to a previously ignored dimension, and the graded memory account highlights the
importance of the strength of active and latent task representations. Although the focus on such higher-order cognitive mechanisms is understandable, it is important to recognize that such a focus overlooks other potentially critical influences on children’s behaviour in this context. For instance, one additional consequence of changing the colour and/or shape of the objects depicted on the cards in the post-switch trials (Müller et al., 2006; Zelazo et al., 2003) is that these cards simply became less perceptually similar to the cards on the pre-switch. This difference is important in that a spate of recent work has begun to demonstrate that a variety of traditional “cognitive” phenomena are dramatically influenced by, and can be understood within the context of basic perceptual and motor processes (Collimore, 2010; Collimore & Schmuckler, 2008, 2010; DeLoache, 1991; DeLoache & Sharon, 2005; Jowkar-Baniani & Schmuckler, 2012; Marzolf, DeLoache, & Kolstad, 1999; Schmuckler, in press; Suddendorf, 2003).

For example, research has highlighted the importance of perceptual information in children’s representational knowledge in symbolic search tasks (DeLoache, 1995a, 1995b; DeLoache & Sharon, 2005; Jowkar-Baniani & Schmuckler, 2011). DeLoache (1995a) demonstrated that the more perceptually similar the symbol is to its referent, the better children are at using the symbol as a representation of the environment. Similarly, Suddendorf (2003) manipulated the perceptual similarity of various testing environments in a symbolic search task and found improved performance when each search was conducted in an environment that was perceptually distinct from the search environment employed on a previous trial. And in a more direct test of this idea, Jowkar-Baniani and Schmuckler (2012) examined the impact of the perceptual similarity of testing environments on children’s search for hidden objects. Using picture and model search tasks employed by DeLoache and others (1991, 1995a, 1995b), these authors systematically varied the degree of perceptual equivalence of the experimental room
between pairs of search trials, and found that environments that were highly similar led to worse performance overall, and increased perseverative responding in particular.

Additionally, more indirect evidence for the role of such perceptual and motor information comes from recent work on the A-not-B error, highlighting the importance of motor processes on perseverative responding. Collimore (Collimore, 2010; Collimore & Schmuckler, 2008, 2010) for instance, examined the impact of motor constraints on the A-not-B error, and found that external motor demands, such as forcing a change in the reach path of the hand and arm between A and B trials, affected the prevalence of the A-not-B error, with fewer errors when the actual reach itself changed. In contrast, intermodal motor constraints, such as handedness, failed to influence the occurrence of this error. And in another example, Schmuckler (in press) investigated the occurrence of perseveration in a locomotor task, and found that perseveration occurs in a motor context (barrier crossing) largely devoid of higher level cognitive (in this case spatial) demands.

Thus, all of these studies demonstrate that perceptual and motor factors are significant (Collimore, 2010; Collimore & Schmuckler, 2008, 2010; DeLoache, 1995a, 1995b; DeLoache, Kolstad, & Anderson, 1991; DeLoache & Sharon, 2005; Jowkar-Baniani & Schmuckler, 2012; Suddendorf, 2003) and can influence children’s behaviour in domains and tasks that are typically conceived of as “cognitive” in nature. These studies, then, highlight the importance of the perceptual context of such tasks, and suggest that children’s behaviour in such domains is significantly dependent on perceptual-motor factors.

Within the context of the DCCS, changes to the relevant and or irrelevant dimensions of the objects depicted on the to-be-sorted cards might thus have an influence on behaviour not because of a failure to understand the appropriate rule hierarchy (as implied by the CCC
account), nor an attentional conflict between the cards (as suggested by the NP account), nor an inability to disengage attention to the previously relevant dimension (as assumed by the attentional inertia account), and nor even an inability to form strong task representations (as claimed by the graded memory account), but instead because of the variation of the actual perceptual characteristics of the cards themselves, resulting in increased salience of the post-switch stimuli. This novelty effect can then operate by resetting children’s attention, increasing attention or vigilance to the new target stimulus. It is also expected that this increased attention is only induced in the presence of a highly salient change that is noticed by children, suggesting that not all changes are equally effective.

Inducing a perceptual change is one way by which the stimulus salience can be modified. The salience of the post-switch dimension can be also increased by employing a highly salient and attractive stimulus in the post-switch. Such a stimulus salient enough to increase children’s attention on the post-switch is also expected to affect performance, even in the absence of a perceptual change.

Although such an explanation is fundamentally an attentional account (dishabituation and novelty are, at heart, attentional phenomena) this explanation differs from the previous theories in that it makes a variety of novel predictions. Most fundamentally, this account suggests that any changes to the to-be-sorted materials that are sufficiently dramatic to invoke a novelty effect should thus cause children to improve their performance on this task. Moreover, such changes need not necessarily be made to the to-be-sorted information per se; any change to the sorting materials, including task-irrelevant features could potentially influence children’s sorting behaviour.
To explore these hypotheses, four studies were designed to investigate the role of perceptual similarity and salience of the task material in children’s cognitive flexibility. Across four studies the perceptual similarity and the stimulus salience were manipulated in two main ways: 1) manipulating task-relevant and task-irrelevant features of the cards consisting of modifying shape and/or colour of objects on the cards or shape and/or background colour of the actual cards themselves (Experiments 1-3), with the expectation that any salient change even those irrelevant to the task would enhance performance, and 2) manipulating the degree of stimulus realism or abstractness (i.e., representational status of the stimuli) across the pre- and the post-switch phases of the DCCS tasks, creating conditions of varying stimulus salience in the post-switch, expecting improved performance when the highly salient 3D stimuli are employed in the post-switch or in the presence of a change in stimulus realism across the two phases of the task (Experiment 4).
Chapter 2

Experiment 1: Manipulating Task-Relevant and Task-Irrelevant Stimulus Features

The principle goal of Experiment 1 was to provide an initial test of the idea that any modifications that varied the degree of perceptual correspondence of the sorting materials between the pre- and post-switch phases of the DCCS tasks would have an effect on performance in this task. Previous work by Zelazo et al. (2003) demonstrated that sorting materials that varied on shape and colour values between the pre- and post-switch phases produced improved performance in this task. Experiment 1 builds off of this finding by varying the perceptual similarity of the task-relevant information of the to-be-sorted cards (i.e., the objects depicted on the cards) as well as varying perceptual similarity by modifying the task-irrelevant information (e.g., the background shape and colour of the cards themselves) between the pre- and the post-switch phases. If the improved performance observed by Zelazo et al. (2003) was indeed due to attentional processes directed at the objects on the cards (as suggested by both the attentional inertia and negative priming accounts), then modification of the task-relevant information, but not the task-irrelevant information, will produce better performance. However, if performance in this task can be influenced simply by the degree of the perceptual similarity of the sorting material affecting performance by inducing a novelty effect and increased attention to the task, then changing either the task-relevant or the task-irrelevant information should result in improved performance in this task.
Method

Participants

Fifty-six 3-year-olds (M = 38.0 months, SD = 3.75 months) and forty 4-year-olds (M = 54.0 months, SD = 5.98 months) participated in the study. Nine additional children also participated, but their data were not included due to a failure to successfully sort the cards on the pre-switch trials (n = 4) or failure to complete the study (n = 5). The names of all participants were obtained from a data base maintained at the Laboratory for Infant Studies at the University of Toronto Scarborough. All participants were recruited from the demographically diverse Greater Toronto area, and received a certificate and a toy for their participation.

Materials

The sorting materials used in the study were either 11 cm x 8 cm laminated rectangular cards, or 10.5 cm diameter round cards containing colour drawings of common objects on one side. Examples of these cards when shape was the pre-switch dimension are shown in Figures 1A-1E (The actual stimuli used in the study consisted of rabbits, flowers, boats and cars, which correspond to schematic illustrations of hearts, stars, triangles and diamonds used here for simplicity). Two white baskets, 20 cm x 20 cm x 14 cm, were used as sorting bins.

Conditions

This study involved manipulating two general dimensions of the sorting materials. The first dimension was the number of changes that could be made to the cards, and consisted of two possible values – One Change or Two Changes. One change meant that only one aspect of the cards (i.e., either the colour or the shape) was changed, and two changes meant that two aspects (i.e., both colour and shape) were modified between pre- and post-switch phases. The second dimension involved the task relevancy of these changes, and could also take one of two values –
Task-Relevant Changes or Task-Irrelevant Changes. Task-relevant changes involved modifying (the shape or colour of) the objects depicted on the cards, and task-irrelevant changes involved modifying the background (shape or colour) of the actual cards themselves. All changes in both dimensions refer to modifications made between the pre-switch and the post-switch phases of the task (refer to Table 1).

Combining these dimensions produced a variety of different conditions. The current experiment examined three of these combinations. In the one change, task-relevant [One-Change (R)] condition, one task-relevant modification was made such that the post-switch cards differed from the pre-switch cards on either the shape or the colour of the depicted object (see Figure 1B); the actual change made (shape or colour) depended on the relevant sorting dimension in the pre-switch phase. This condition is considered a control condition in that previous work employing a similar manipulation (Müller et al., 2006) produced poor performance in the post-switch phase, with strong response perseveration. In the two change, task-relevant [Two-Change (R)] condition, two task relevant modifications (i.e., both colour and shape) were made to the objects depicted on the cards between pre- and post-switch phases (see Figure 1C). This condition represents a replication of the manipulations employed by Müller and colleagues (2006) that has been taken as evidence for the role conflict between multiple ways of matching test and target cards in producing negative priming in the DCCS task. Finally, in the two change, task-relevant, task-irrelevant condition, two modifications were made in total – one to the objects depicted on the cards (the task-relevant change) and one to the actual cards themselves (the task-irrelevant change). This condition represents a test of the role of perceptual similarity in that it dramatically alters the perceptual information available in the sorting materials, with at least part of this information ultimately irrelevant to the task at hand. This condition was further
subdivided depending on the nature of the change to the task-irrelevant dimension. In the first case [the Two-Change (RI\textsubscript{a}) condition], the background colour of the cards was modified from being yellow in the pre-switch to white in the post-switch (see Figure 1D). In the second case [the Two-Change (RI\textsubscript{b}) condition] the shape of the cards was modified from round in the pre-switch to rectangular in the post-switch (see Figure 1E). Altogether, then, there were four conditions in this study – One-Change (R), Two-Change (R), Two-Change (RI\textsubscript{a}), and Two-Change (RI\textsubscript{b}), although the final two conditions represented different versions of the same conceptual modification. These four conditions were run between subjects, with equal numbers of participants (14 3-year-olds and 10 4-year-olds) participating in each condition.
Table 1

Summary of changes to the task stimuli in Experiments 1-4

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Number of Changes</th>
<th>Relevant (R)</th>
<th>Irrelevant (I)</th>
<th>Relevant &amp; Irrelevant (RI)</th>
</tr>
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<td>[Condition Name]</td>
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<td>Irrelevant (I)</td>
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<td>1</td>
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<td>Shape of Cards</td>
<td>Colour of Cards</td>
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<td>[One-Change (R)]</td>
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<td>[Two-change (RI_a)]</td>
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<tr>
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<td>2</td>
<td>Shape &amp; Colour of Depicted Objects</td>
<td>Shape or Colour of Depicted Objects</td>
<td>Shape of Cards</td>
</tr>
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<td></td>
<td></td>
<td>[Two-Change (R)]</td>
<td>[Two-change (RI_b)]</td>
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<td>Experiment 2</td>
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<td>Irrelevant (I)</td>
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<td></td>
</tr>
<tr>
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<td>2</td>
<td>Shape or Colour of Depicted Objects</td>
<td>Shape of Cards</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>[Two-change (RI_c)]</td>
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<td></td>
</tr>
<tr>
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<td>Irrelevant (I)</td>
<td>Relevant &amp; Irrelevant (RI)</td>
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<td>Shape of the Sorting Bin</td>
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<td>[One-Change (I)]</td>
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</tr>
<tr>
<td></td>
<td>2</td>
<td>Shape &amp; Colour of Cards</td>
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<td>[(Two-Change (I)]</td>
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<tr>
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<td>Irrelevant (I)</td>
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<td>Stimulus Realism</td>
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<td></td>
<td>[Zero-Change (2D)]</td>
<td>[Zero-Change (3D)]</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>Stimulus Realism</td>
<td>Stimulus Realism</td>
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<tr>
<td></td>
<td></td>
<td>[One-Change (2D)]</td>
<td>[One-Change (3D)]</td>
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</table>
Figure 1: Examples of Stimuli used in Experiment 1
Procedure

Children either sat by themselves, or on a parent’s lap, in front of a table. Two white baskets were placed on the table in front of the child. Sample cards were affixed to the baskets to indicate the correct placement for the sorting of the cards, with these samples remaining visible to the child throughout the experiment. Each of the four conditions consisted of a pre-switch phase followed by a post-switch phase. In the pre-switch phase children were asked to sort the cards based on either the shape or colour of the depicted images. If shape was the pre-switch rule, the experimenter told the children “We are going to play the shape game. In the shape game, all the rabbits go in this basket and all the boats go in this basket”. Two demonstration trials followed in which the experimenter showed the children how to sort the cards. After the demonstration trials, the experimenter held each card in front of the children and named the card with the relevant dimension. For instance in the shape game, the experimenter said: “Look, I have a rabbit here, where does the rabbit go in the shape game?” Children then placed the cards face down in the baskets. No feedback was given to the children after each trial. Children completed a total of six pre-switch trials (i.e., six different cards) before continuing. If a child failed to sort five of the six pre-switch cards correctly the experiment was continued, but the child’s data was excluded from the final analysis. After completing the pre-switch phase, the post-switch phase began. In this phase new sample cards were attached to the sorting bins, and children were now told: “We are not playing the shape game anymore. We are now going to play a different game, called the colour game. Now in the colour game, blue ones go in this basket and red ones go in this basket.” No demonstration trials were used in this phase. Children were then given six cards, one at a time and were asked to sort them. Similar to the pre-switch phase, each time the experimenter labeled the cards by the relevant dimension and asked the children to
put it face down in one of the baskets.

Results

Although, only the data for the children who successfully passed the pre-switch (sorting 5 or more of the 6 pre-switch trials) were included in the analyses, to ensure that differences in performance among children cannot be attributed to any pre-existing differences in their pre-switch performance, preliminary analysis investigated percentage of correct responses on the pre-switch trials. Since all 4-year-olds sorted all six pre-switch cards correctly, this analysis was only conducted for the 3-year-olds. A between-subject ANOVA was used with the variables of Condition [One-Change (R), Two-Change (R), Two-Change (RI_a), Two-Change (RI_b)] and Order of Presentation of the stimuli between pre-switch and post-switch phases (Shape-Colour vs. Colour-Shape). Neither the effect of Condition, $F(3,48) = .85$, $MSE = 0.002$, $ns$, nor any other main effects or interactions were found to be significant, $p$’s > .11.

Children’s performance as a percentage of correct post-switch trials was then examined using a between-subject ANOVA with the variables of Condition [One-Change (R), Two-Change (R), Two-Change (RI_a), Two-Change (RI_b)], Age (3-year-olds vs. 4-year-olds) and Order of Presentation of the stimuli between pre-switch and post-switch phases (Shape-Colour vs. Colour-Shape). This ANOVA revealed a main effect of Age, $F(1,80) = 22.55$, $MSE = 3.73$, $p < .01$, $\eta_p^2 = .22$, with the 4-year-olds ($M = .90$, $SD = .40$) performing better than the 3-year-olds ($M = .500$, $SD = .44$). In contrast, the main effect for Condition was not significant, $F(3,80) = .82$,

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1 In addition to investigating children’s performance as the percentage of correct trials, the performance of children in all four experiments presented in this paper was also analyzed as a percentage of successful versus unsuccessful children. Success was determined by correctly sorting 5 or more of the cards on the post-switch. Chi-square analysis was conducted in each case, demonstrating the same pattern of findings as shown by the analysis of the percent correct trials.
$MSE = .14$, $ns$. Most importantly, however, the experimentally critical $Condition \times Age$ interaction was significant, $F(3,80) = 2.72$, $MSE = .45$, $p < .05$, $\eta_p^2 = .09$. This interaction appears in Figures 2a-2b, and reveals a difference between the conditions for the 3-year-olds, $F(3,48) = 2.91$, $MSE = .61$, $p < .05$, $\eta_p^2 = .15$ (Figure 2a), but not for the 4-year-olds, $F(3,32) = .67$, $MSE = .067$, $ns$ (Figure 2b). No other main effects or interactions were significant, all $p$’s $> .22$.

A series of independent samples t-tests revealed that for the 3-year-olds, children performed worse in the $One-Change (R)$ condition relative to both the $Two-Change (R)$ condition, $t(26) = -2.79$, $p < .01$, $d = 1.09$, and the $Two-Change (RI_a)$ condition, $t(26) = -2.34$, $p < .05$, $d = 0.92$. Interestingly, however, no difference was found between the $One-change (R)$ condition and the $Two-change (RI_b)$ condition, $t(26) = -1.31$, $ns$. Performances across all three $Two-Change$ conditions did not differ, all $p$’s $> .19$. For the 4-year-olds there were no differences in performance between any of the conditions, all $p$’s $> .15$.

In addition, performance of children on the post-switch trials in all conditions was compared to performance at 0% correct response (complete perseveration). For the 3-year-olds performance in all four conditions was found to be greater than 0%, $t(13)$’s $> 3.4$, $p$’s $< 0.01$, $d$’s $> 0.54$, except for the $One-Change (R)$ condition, $t(13) = 2.00$, $ns$. For the 4-year-olds performance in all the conditions was greater than 0%, $t(9)$’s $> 6.0$, $p$’s $< 0.001$, $d$’s $> 1.89^2$.

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$^2$ This analysis could not be performed on the $One-Change (R)$ condition for the 4-year-olds as no variability in the data was observed.
Figure 2a: Percent correct response as a function of condition for 3-year-olds in Experiments 1-3
Figure 2b: Percent correct response as a function of condition for 4-year-olds in Experiment 1
Discussion

Experiment 1 provided an initial investigation of the role of perceptual similarity on children’s performance in the DCCS task. Specifically, the sorting materials in this study were modified such that both task-relevant and task-irrelevant dimensions were varied between pre-switch and post-switch trials. Replicating previous work, this study found that when only a single relevant dimension was varied, 3-year-olds, but not 4-year-olds, performed poorly on the post-switch trials; this result is a standard finding in the DCCS task (Müller et al., 2006; Zelazo et al., 2003). Intriguingly, this study also observed that varying both of the task-relevant dimensions of the sorting materials improved performance relative to the previous condition. This result also replicates previous work (Müller et al., 2006; Zelazo et al., 2003) and forms the primary support of the various attentional theories described earlier (and most particularly the negative priming approach). Most interestingly, however, this study also found that variation of task-irrelevant parameters of the sorting materials, and specifically the background colour of the actual cards, as opposed to the objects depicted on the cards, similarly improved performance relative to the initial condition. This effect has not been previously demonstrated, and is in keeping with the idea that children’s performance can be modified by any change salient enough to invoke some form of dishabituation or novelty effect. Put simply, any modification that highlights the fact that the post-switch materials are truly different will thus reduce conflict with the pre-switch material. This novelty effect acts as a resetting of behaviour, increasing attention or vigilance to the task, reducing perseverative responding.

Similarly, Mack (2007) suggested that children’s difficulty with the DCCS task might arise due to their lack of understanding of the transition from the pre- to the post-switch and the need for a different response on the post-switch. The authors thus manipulated the task by
providing additional cues to highlight the transition between the two phases of the task. These included removal of the target cards from both boxes at the end of the pre-switch and introducing them again after a short delay or asking an irrelevant question from the children at the end of the pre-switch. These manipulations resulted in improved post-switch performance by potential increase in attention towards the stimulus cards after the delay or after the question.

Theoretically, neither the CCC account, nor the attentional inertia account or the negative priming account can provide a ready explanation for this result. The graded memory account would also have a hard time accounting for the immediate effect of stimulus change as this model uses a Hebbian learning algorithm to model changes in the strength of latent representations that occur with experience using a particular rule. This account however is the only account to explain behaviour as graded in nature (as opposed to the all-or-none effects of other accounts), consistent with the findings of Experiment 1, demonstrating that performance is highly task dependent.

Of course, these findings are qualified by the unanticipated result that when the task-irrelevant change involved modifying the shape of the actual cards, there was no observed impact on children’s ability to sort the cards in the pre-switch phase. The most straightforward explanation for this failure is that the shape modification was not novel enough to produce a change in behaviour. Although somewhat counter-intuitive (an actual change in shape does, naively, appear to be a dramatic modification), there are precedents for the idea that particular perceptual change needs to reach some minimum degree of novelty to be treated in a categorically different fashion by actors and perceivers. Johnson (Johnson, 1997; Johnson & Aslin, 1996), for instance, has proposed that perceptual encoding occurs only after a minimum amount of information has been processed. With regard to the current study, this minimum level
might represent a boundary or transition in categorizing the task, from a familiar to a novel one. Of course, this explanation does beg the question of the nature of the changes needed to induce such an effect. The fact that the change in background colour was sufficient is intriguing, and in fact fits with other work on this task by Coldren and Colombo (2009) who found that manipulating the background colour of the cards such that it matched the sorting dimension colour, improved children’s performance. Still, this does not explain why changing the background shape of the cards did not influence performance. One possibility is that this shape manipulation was so irrelevant that children literally paid little attention to card shape. If true, then modifying the context in a fashion such that the card shape becomes more salient, while still being irrelevant to the sorting task per se, might then produce an impact on the background shape change and on children’s behaviour. Experiment 2 examined this possibility.

**Experiment 2: Salience of the Perceptual Manipulations**

The goal of Experiment 2 was to boost the salience of the change in shape of the cards, while at the same time maintaining its fundamental irrelevance to the sorting task itself. To accomplish this goal, the baskets that were used as sorting bins in Experiment 1 were replaced with round plates. Because the cards used were round, they now fit nicely into these sorting bins. However, when the cards became rectangular in the post-switch phase, they no longer fit well on the round plates, with the edges of the cards overhanging the plates. This created a match between the shape of the cards and the shape of the sorting bins on the pre-switch and a mismatch on the post-switch. If the lack of effect observed in Experiment 1 for modifying the shape of the cards was truly due to children’s inattention to this change, it is anticipated that the current manipulation, which heightens the salience of this shape change, will now increase attention to this dimension, and ultimately lead to improved performance.
Method

Participants

Fourteen 3-year-olds (M = 37.55 months, SD = 2.38 months) participated in the study. The names of the participants were obtained via the same means as Experiment 1, and participants received comparable compensation for their participation. Given the uniformly successful performance of the 4-year-olds in Experiment 1, this study did not extend its investigation to this older age group.

Materials, Conditions and Procedure

The sorting cards used in the study are shown in Figures 3A-3B. This study involved a new two change, task-relevant, task-irrelevant condition [the Two-Change (RIc) condition] in which the post-switch cards differed from the pre-switch cards on one task-relevant (shape/colour) and one task-irrelevant (shape of the cards) dimension. Differing from the Two-Change (R Ib) condition of Experiment 1, however, the sorting bins were now two white 15.5 cm diameter plates. This study employed the same procedure as Experiment 1, with the sole exception that while sorting, children were asked to place the cards face down on two plates (see Table 1). The order of presentation of the shape versus colour rules was counterbalanced across participants.
Figure 3. Examples of stimuli used in Experiment 2

Results

Similar to Experiment 1, preliminary analysis examined children’s performance on the pre-switch based on the percentage of correct responses, by comparing performance on Experiment 1 with performance on Experiment 2. An ANOVA was conducted with the between subjects variable of Condition [One-Change (R), Two-Change (R), Two-Change (RI₀), Two-Change (RI₁), Two-Change (RI₂)], and Order of Presentation of the sorting rules between the pre-switch and the post-switch phases (shape-colour vs. colour-shape). No effect of Condition, $F(4,60) = .66, MSE = 0.001, ns$, or Order of Presentation of the sorting rules was found, $F(1,60)$
= 3.00, $MSE = 0.007$, $ns$. No significant interactions were found, $F(4,60) = 1.60$, $MSE = 0.004$, $ns$.

Children’s performance on the post-switch trials as the percentage of correct trials in this condition was compared to the 3-year-old’s data from Experiment 1 using the same variables. A main effect of Condition was found, $F(4,60) = 2.68$, $MSE = .57$, $p < .05$, $\eta^2_p = .15$. No other main effects or interactions were found, all $p$’s > .26. Figure 2a also shows the 3-year-old’s performance in the Two-Change ($RI_c$) condition. A series of independent sample t-tests were used to demonstrate that performance in this condition was significantly better than that of the 3-year-olds in the One-Change ($R$) condition of Experiment 1, $t(26) = -2.85$, $p < .01$, $d = 1.11$. No difference was found between performance in the Two-Change ($RI_c$) condition and any of the Two-Change condition of Experiment 1, all $p$’s > .17.

In addition, similar to Experiment 1, performance of children on the post-switch trials in the Two-Change ($RI_c$) condition was compared to performance at 0% correct response (complete perseveration), demonstrating better performance in this condition compared to 0%, $t(13) = 5.67$, $p < .001$, $d = 1.52$.

**Discussion**

The primary goal of Experiment 2 was to investigate whether children’s earlier failure to sort the cards when the shape of the cards was changed was due to a simple lack of attention to this background shape. In keeping with this idea, this study found that a modification to the procedure that highlighted the background shape, but was irrelevant to the task itself, did have the predicted effect of increasing the salience of this change in shape, thereby resulting in improved performance in the DCCS task. More generally, this result confirms the idea that any changes to the task materials between the pre- and the post-switch phases that are sufficiently
salient to induce a novelty or dishabituation effect will thus cause an increase in children’s attention to that task overall, thereby highlighting the fact that they are engaged in a new task.

Why did this change in the shape of the sorting bin have such a dramatic effect on children’s performance in this study? The most obvious explanation is that the round sorting bin highlighted the card’s shape because of a change from a match between the card and bin in the pre-switch trials to a mismatch between the two in the post-switch. Of course, it should be recognized that the card shape manipulation of Experiment 1 also produced a similar change in matching between pre- and post-switch trials. However, the two experiments did differ in that in Experiment 1 the mismatch between the card and the bin occurred in the pre-switch phase, as opposed to the post-switch phase in Experiment 2. Assuming that a mismatch in this case is in fact more salient than a match, the occurrence of this mismatch on the critical post-switch trials in this study would thus provide an extra boost to this change in the current study. Moreover, the two experiments were also different in that in Experiment 1 the cards fit into the sorting bin regardless of whether the two matched in their shapes. In contrast, in Experiment 2 when the shape of the cards matched the shape of the sorting bin, the two fit neatly together, but when the shape of the two mismatched, the cards no longer fit well into this bin. This lack of a good fit could have emphasized the mismatch between the two, thereby highlighting the change in shape of the card even more.

Taken together, Experiments 1 and 2 provide compelling evidence that modifications of both task-relevant and task-irrelevant perceptual features of the sorting materials have the potential to influence children’s performance in the DCCS task. What these two studies have not yet fully disentangled, however, is the relation between the number of dimensions changing between pre- and post-switch trials, and the task-relevancy of these dimensions. Specifically, in
both of the previous studies, modifying two dimensions of the stimuli led to the increased sorting accuracy, with one of these dimensions being relevant to the task and the other being irrelevant. Accordingly, it is not clear whether a change in the task-irrelevant dimension must occur within the context of a change in a task-relevant dimension, or whether changes in the task-irrelevant dimensions are in and of themselves sufficient to improve performance in this task. The goal of Experiment 3 was to examine this question.

**Experiment 3: Manipulating the Task-Irrelevant Features**

In Experiment 3, the post-switch cards were modified such that either one or two task-irrelevant dimensions of this material were changed between the two phases. If the previous results truly do imply that performance in this task can be influenced by a sufficiently salient level of change in any of the perceptual attributes of the task materials, then modification of two task-irrelevant dimensions should also be adequate to improve performance in this task. In contrast, the findings of Experiment 1 suggest that change in only a single dimension of the materials, even when it occurs in a task-relevant dimension, is insufficiently salient to increase accuracy. Accordingly, and for completeness, the current study attempted to replicate this finding by examining the impact of change in only a single, task-irrelevant dimension. Given the previous findings, it is expected that in this case children will once again perform poorly in the post-switch phase of this experiment.

**Method**

**Participants, Materials, Conditions, and Procedure**

Fourteen 3-year-olds ($M = 37.0$ months, $SD = 2.82$ months) participated in the study. The names of the participants were obtained via the same means as Experiment 1, and participants
received comparable compensation for their participation.

Two conditions were compared in this experiment (see Table 1). The one-change, task-irrelevant \([One-Change (I)]\) condition was similar to the prototypical card sorting task (Zelazo et al., 2003) in which the same sorting cards were used in pre- and post-switch phases. However, this condition differed from this typical task in that the sorting bins were changed between the two phases (see Figure 4, 1A-1B). In the two-change, task-irrelevant \([Two-Change (I)]\) condition two task-irrelevant features, the background shape and background colour of the cards were modified between the pre- and post-switch phases (see Figure 4, 2A-2B). Specifically, during the pre-switch phase children sorted round, yellow cards by either the shape or colour the object depicted on the cards and in the post-switch phase children sorted white, rectangular cards with the same depicted objects by the previously ignored dimension. The procedure of this experiment was similar to that of the previous two studies, with one important exception – the conditions were run within-subjects, with the order of the conditions counterbalanced across participants, as opposed to between-subjects. A within-subjects design was possible in the current study because only two conditions were compared, in contrast to Experiment 1 in which there were four conditions (thus making a within-subjects design rather impractical). Other work employing within-subjects comparisons for multiple conditions in a DCCS task has demonstrated that subsequent conditions are not especially influenced by children’s performance in previous conditions (Honomichl & Chen, 2011; Kloo et al., 2010). The order of presentation of colour and shape sorting rules in the two conditions was randomized across participants.
1. Pre-switch (Shape)  Post-switch (Colour)

(A) Visual Cue

(B) Sorting Card

2.

(A) Visual Cue

(B) Sorting Card

Figure 4. Example of Stimuli used in Experiment 3
Results

Preliminary analysis investigated children’s performance on the pre-switch phase as percentage of correct responses using a mixed-model ANOVA with the within-subjects factor of Condition [One-Change (I) vs. Two-Change (I)] and a between-subjects factor of Order of Conditions (One-Change (I) followed by Two-Change (I) vs. Two-Change (I) followed by One-change (I)]. No main effect of Condition was found, $F(1,12) = 1.00, \text{MSE} = .001, \text{ns}$. No other main effects or interactions were found, all $p$’s > .34.

Children’s performance as the percentage of correct post-switch trials was analyzed using a mixed-model ANOVA with the within-subjects factor of Condition [One-Change (I) vs. Two-Change (I)] and Order of Conditions (One-Change (I) followed by Two-Change (I) vs. Two-Change (I) followed by One-change (I)). This analysis revealed a main effect of Condition, $F(1,12) = 5.87, \text{MSE} = 1.01, p < .05, \eta_p^2 = .33$, with poorer performance in the One-Change (I) ($M = .25, SD = .39$) condition relative to the Two-Change (I) condition ($M = .63, SD = .47$). There was no main effect of Order of Conditions, $F(1,12) = .298, \text{ns}$, nor any Condition x Order of Conditions interaction, $F(1,12) = 1.12, \text{ns}$, was found.

A series of independent sample t tests compared performance in Experiment 3 with that of Experiment 1 and revealed a significant difference in performance of 3-year-olds in the Two-Change (I) condition of Experiment 3 compared to the 3-year-olds in the One-Change (R) ($M = .23, SD = .42$) condition of Experiment 1, $t(26) = 2.40, p < .05, d = 0.94$. Confirming this increased performance, there were no differences between the performance in the Two-Change (I) condition of Experiment 3 and the Two-Change (R) ($M = .69, SD = .46$) condition of Experiment 1, $t(26) = -.34, \text{ns}$. Finally, there was no difference between the One-Change (I) condition of Experiment 3 and the One-Change (R) of Experiment 1, $t(26) = -.15, \text{ns}$. 
Performance of children on post-switch trials was also compared to performance at 0% correct response (complete perseveration), demonstrating better performance in both the One-Change (I) and Two-Change (I) conditions compared to 0% correct performance, \( t(13) = 2.36, p < 0.05, d = 0.64 \), and \( t(13) = 5.05, p < .01, d = 1.34 \) respectively.

**Discussion**

Experiment 3 further investigated the role of the perceptual correspondence of task materials in the DCCS task by manipulating only the task-irrelevant features of the task material. Consistent with the results of the previous two studies varying features of the sorting materials continued to influence children’s performance even when these changes were completely irrelevant to the task. This finding, thus, provides evidence that the improved performance in Experiments 1 and 2 did not arise through some form of interaction between simultaneous task-relevant and task-irrelevant manipulations. Rather, these results are consistent with the idea that any changes to the task materials perceptually salient enough to produce some form of dishabituation or novelty effect on children’s attention have the potential to increase performance in this task. In this context it is interesting that this increased performance occurred only when the changes were made to the sorting materials themselves, and not to the sorting bins in which these materials were to be placed. Because the actual task of this study required children to attend to parameters of the sorting cards, and not necessarily to the sorting bins themselves, variations in this latter factor may have gone unnoticed by children. Methodologically, this finding provides an important control for the previous study. Conceptually, this finding is of interest in that it demonstrates that simple changes to the sorting bins are insufficiently salient to induce a novelty effect in children, although clearly the sorting bins are relevant in terms of their role in producing a match versus mismatch with the sorting cards. Thus, future work needs to
more carefully examine this aspect of the testing context; this point will be returned to in the General Discussion.
Chapter 3

The Role of Stimulus Realism on the DCCS Task

Experiments 1-3 investigated the role of the perceptual-motor features of the task material in children’s flexible dimensional switching, in addition to examining the nature of modifications leading to improved performance. The results of these experiments demonstrated the importance of such information, suggesting that modifying any aspects of the task salient enough to induce a novelty effect resulted in improved performance, even when such changes were completely irrelevant to the task (e.g., changing the background colour and shape of the sorting cards).

An alternate method of manipulating the perceptual parameters of the task material is to modify the degree of stimulus realism (abstractness). Stimulus realism refers to the representational status of the stimuli and can be manipulated by employing task stimuli of varying dimensionality (e.g., two-dimensional versus three-dimensional displays). Previous investigations of cognitive flexibility using the DCCS task have primarily employed two-dimensional stimuli either in the form of objects depicted on cards or the stimuli presented on a screen. Although this measure has been accepted as the standard means of examining children’s performance on the DCCS task, employing such 2D stimuli is based on the assumption that perceivers can easily generalize information from 2D representations of the displays to their actual 3D counterparts. This transference from 2D to 3D in the context of cognitive flexibility has often been taken for granted and has not been examined directly. Such an assumption is curious, given that there is evidence that transferring from 2D representations to 3D objects is not necessarily automatic. Probably, the best evidence stems from work on visual agnosia in
which patients with brain damage exhibit a multitude of forms of visual object recognition difficulties (Farah, 1990; Grüsser & Landis, 1991; Humphreys & Riddoch, 1987). In addition, there has been a number of reports of patients who appear to retain normal 2D percepts of drawings or pictures, but fail to generalize such representations to their 3D counterparts (Ratcliffe & Newcombe, 1982; Turnbull, Driver, & MacCarthy, 2004). As such, it is reasonable to question how automatic it is to generalize from 2D to 3D displays and how such generalization can influence performance on cognitive measures in which 2D stimuli have been typically employed.

**Children’s Symbolic Competence**

The ability to perceive two-dimensional (2D) representations of three-dimensional (3D) visual arrays is an essential part of our lives. Typically, perceivers are asked to make use of information contained in many 2D representations, including literal representations (photographs), symbolic representations (e.g., “danger” signs), and schematic representations (e.g., line drawings). Accordingly, exploring the perception of such 2D information is critical for understanding visual perception and development.

Developmental studies of the perception of 2D representations have proceeded along multiple avenues; studies on form constancy (e.g., Bornstein, Krinsky, & Benasich, 1986; Caron, Caron, & Carlson, 1979), the fundamental principles of perceptual organization and object perception (e.g., Ferroni, Valenza, Simon, & Umilta, 2000; Ghim, 1990; Kavšek & Yonas, 2006; Quinn & Bhatt, 2005), the perception of structure from motion in adults (Fernandez & Farell, 2008; Gurnsey, Poirier, Bluett, & Leibov, 2006; Norman & Todd, 1993; Todd, 1998), and infants (Arterberry & Yonas, 2000; Johnson, Cohen, Marks, & Johnson, 2003; Johnson, Davidow, Hall-Haro, & Frank, 2008; Johnson & Mason, 2002; Kellman, 1984; Schmuckler &
Proffitt, 1994; Soska & Johnson, 2008; Yonas, Arterberry, & Granrud, 1987), and finally, the use of 2D representations to perceive more symbolic and/or abstract 3D representational information.

One characteristic common to all these studies is the assumption of automatic transfer of information across dimensions. Studies of children’s ability to transfer between 2D and 3D representations have, however, demonstrated the perception of this relation by the second year (Daehler, Perlmutter, & Myers, 1976), and only sometimes earlier (DeLoache, Strauss, & Maynard, 1979; Dirks & Gibson, 1977; Hochberg & Brooks, 1962; Rose, 1977). For instance, Dirks and Gibson (1977) demonstrated that after being habituated to a live face, 5-month-old infants generalized this habituation to a photograph of that same face, but showed recovery from habituation to a new person’s face differing in gender and hair colour. Similarly, Rose (1977) demonstrated that after being habituated to 3D objects of a particular pattern, such as diamonds or squares, 6-month-old infants looked longer at pictures of novel objects, relative to familiar objects. Similar results were observed using pictures as the habituation stimuli and 3D objects as the dishabituation stimuli. Finally, and even more intriguingly, Hochberg & Brooks (1962) demonstrated that picture perception could occur in the absence of any specific experience or special training. In this work Hochberg and Brook’s son “s” was able to identify and name pictures of objects with no prior experience as he was kept away from virtually all pictures until he was 19 months old.

In a similar vein, DeLoache et al. (1979) demonstrated that the ability to transfer from real-world objects to photographic representations was not limited to simple abstract patterns (Rose, 1977) or human faces (Dirks & Gibson, 1977). In this work 5-month-old infants were habituated to a familiar object, a doll, with dishabituation then examined to a colour picture of that same doll or to a novel doll. In this context, infants dishabituated only to the picture of the novel doll,
and not to the familiar doll. Such generalization has been also observed with black and white line
drawings (Jowkar-Baniani & Schmuckler, 2011), suggesting that such recognition is not
dependent on literal colour correspondences between the 3D object and the 2D representation
and can be also seen with more abstract stimuli.

A large number of studies, however, have now shown that simple recognition of pictures is
not necessarily indicative of infants’ or children’s understanding of symbol-referent relations
(DeLoache, 1991, 1995a, 1995b; DeLoache & Burns, 1994; DeLoache, Pierroutakos, & Troseth,
1996), as children often act in a manner that suggests they confuse pictures with the objects they
represent. For instance, DeLoache et al. (1998) found that 9-month-olds responded manually to a
book containing coloured photographs by frequently rubbing, patting, or hitting the images, and
sometimes even trying to pluck the pictures off the page. Other studies have found comparable
results, with 3-year-olds believing that a picture of a rose would smell sweet or a picture of an
ice cream would be cold (Beilin & Pearlman, 1991).

Similarly, although 15 to 24-month-old infants demonstrate the ability to match video-
images of objects to their actual 3D versions (Krcmar, Grela, & Lin, 2007), and 5-month-old
infants have been found to recognize video images of their own arm and leg movements
(Schmuckler, 1996; Schmuckler & Fairhall, 2001; Schmuckler & Jewell, 2007), children show
difficulty in imitating novel actions from video images compared to live models. In the video-
deficit effect infants show more successful and sophisticated imitation when presented with a live
model, as opposed to a videotaped model (Anderson & Pempek, 2005; Barr, Muentener, &
Garcia, 2007; Hayne, Herbert, & Simcock, 2003; Hudson & Sheffield, 1999; Klein, Hauf, &
Aschersleben, 2006; McCall, Parke, & Kavanaugh, 1977; Meltzoff, 1988; Schmitt & Anderson,
2002). This video deficit effect has also been found in object search tasks (Decampo & Hudson,
2005; Schmitt & Anderson, 2002; Troseth, 2003; Troseth & DeLoache, 1998), emotion processing tasks (Mumme & Fernald, 2003) and even language acquisition tasks (Krcmar et al., 2007; Kuhl, Tsao, & Liu, 2003; Sell, Ray, & Lovelace, 1995). Although it is unclear what underlies this difference in the efficacy of live versus video-taped presentations, one obvious possibility involves the basic distinction between 2D and 3D presentation of the to-be-modeled action.

Other work has examined the use of 2D representations as important symbolic referents that can then be used to guide search for a hidden object (DeLoache, 1991, 1995a, 1995b; DeLoache & Burns, 1994). In work such as this, toddlers are shown 2D pictures of 3D rooms in which a toy has been hidden, and are then asked to retrieve the hidden object when presented with the actual 3D room itself. Children younger than 2½ years of age often show difficulty in retrieving the hidden object and understanding the correspondence between the 3D object and its 2D representation.

**Salience of the symbol**

In investigating infants’ ability to understand such 2D-3D associations, many studies have indicated that the salience of the symbol (the more 3D looking and the more attractive an object is) can greatly impact children’s performance. For instance, DeLoache et al. (1998) demonstrated that 9-month-olds distinguished between 3D objects and 2D pictures of objects in that they reached for the real object first when presented with both simultaneously. DeLoache and Pierroutsakos (2003) further demonstrated that the degree of manual exploration towards pictures was related to the realism of the pictures, with the most manual investigation directed toward coloured photographs and the least directed toward black and white line drawings (but see Yonas et al., 2005).
In addition, DeLoache (1995a) demonstrated that the salience of a symbol could influence children’s ability to effectively use that object as a symbol. Specifically, 2½- and 3-year-old children’s search for a toy was examined after being shown the toy’s hiding location in a picture (a less salient object) or a scale model (a more salient object). Although 3-year-olds searched correctly for the toy in both the picture and the model tasks, 2½-year-olds counter-intuitively performed better in the picture task than in the model task. According to DeLoache (1995a, 1995b), this picture-superiority effect arose because the highly salient and attractive nature of the model emphasized the object itself, interfering with children’s understanding of its symbolic status, whereas the less salient picture was more easily recognized as a symbol by the younger children. These findings have been both replicated (DeLoache, 1987, 1991) and extended to the use of video images (Troseth & DeLoache, 1998).

**Stimulus Realism and Cognitive Flexibility**

As can be seen from above descriptions, previous studies investigating children’s representational comprehension and their ability to transfer information across dimensions have demonstrated children’s difficulty in the tasks requiring such knowledge. Although most studies have demonstrated such difficulty early in life, there is evidence that even older children sometimes struggle with similar tasks (Beilin & Pearlman, 1991).

Previous investigations of cognitive flexibility using the DCCS task has, however, often overlooked such important findings by primarily employing two-dimensional task stimuli or displays while measuring children’s performance. Employing 2D stimuli thus assumes children’s ability to generalize information across dimensions and expects similar performance when employing two-dimensional and three-dimensional displays. Given the importance of the role of perceptual features of the task material as demonstrated in Experiments 1-3, and children’s

**Experiment 4: The Role of Stimulus Realism on Children’s Dimensional Switching**

In order to further investigate the role of perceptual-motor factors in cognitive flexibility and on children’s performance on the DCCS task, a sorting task was created such that children either sorted three-dimensional objects or two-dimensional drawings of such objects depicted on the cards. As three-dimensional stimuli tend to be more salient than their two-dimensional counterparts and given children’s difficulty in using such 2D displays, increased attention to highly salient stimuli is expected to result in enhanced performance when using three-dimensional task material compared to the standard version of the task, which employs two-dimensional drawings. This expectation is consistent with DeLoache’s proposed idea on the role of symbol salience in symbolic tasks. However, in the context of a symbolic search task the more salient symbol attracts attention towards itself, making it difficult for children to understand its representational status, leading to more unsuccessful searches. However, in the context of the DCCS task, employing such salient 3D stimuli can enhance performance by directing attention towards the sorting dimension.

To further examine the role of the perceptual similarity of the task dimensions, the degree of stimulus realism was manipulated between the two phases such that 2D or 3D stimuli presented to children on the pre-switch were either changed to their 3D or 2D counterparts on the post-switch trials or stayed the same. If manipulating any aspects of the task material leads to improved performance as suggested by the novelty account, then enhanced performance and
reduced perseveration is expected when task material are changed between the pre- and the post-switch phases (either from 2D to 3D or from 3D or 2D) compared to the standard condition in which no such changes are made.

Alternatively, the effect of stimulus realism might interact with this novelty effect. In this case the effect of stimulus realism might be greater when the more salient 3D objects appear on the post-switch (with or without any additional changes to the task material) as a result of the increased attention to the task and reducing the conflict between the pre- and the post-switch sorting dimensions. In contrast, when the less salient 2D stimuli appear in the post-switch, improved performance (although to smaller extent) is seen when it accompanies a change in the stimuli from the pre- to the post-switch, with the commonly observed poor performance seen on the standard task employing 2D stimuli.

**Methods**

**Participants**

Thirty-two 3-year-olds ($M = 37.1$ months, $SD = 1.8$ months) participated in the study. The names of the participants were obtained via the same means as Experiments 1-3, and participants received comparable compensation for their participation.

**Material**

Stimuli consisted of simple foam-made 3D objects, such as stars and hearts along with 2D drawings of the same objects on cards (Figure 5). Children placed the cards in boxes containing a small opening on the top that could fit both 2D cards and 3D objects.
1.

Pre-switch (shape)  

(A)  

Visual Cue  

Post-switch (colour)  

Visual Cue

(B)  

Sorting Card  

Sorting Card
Figure 5. Examples of (1) 2D and (2) 3D stimuli used in Experiment 4

**Conditions and Procedure**

Children were presented with either 2D or 3D post-switch stimuli (between-subject) and the stimuli were either changed between the pre- and the post-switch phase or no changes were made (within-subject). This created four conditions of the study (Table 1): Zero-Change (3D),
One-Change (3D), Zero-Change (2D), and One-Change (2D) conditions, based on the stimuli children received in the post-switch phase (2D or 3D) and whether the stimuli were changed from the pre- to the post-switch (One-Change or Zero-Change). Accordingly, half of the children were assigned to both the Zero-Change (3D) and One-Change (3D) conditions and the others received Zero-Change (2D) and One-Change (2D) conditions. For instance, in the Zero-Change (3D) condition children were presented with 3D stimuli in both the pre- and post-switch phase such that no changes were made to the stimuli between the two phases, whereas in the One-Change (3D) condition 2D stimuli were used in the pre-switch phase, which were then changed to 3D stimuli in the post-switch. The procedure was similar to the previous experiments. The order of presentation of the conditions was counterbalanced with the order of presentation of colour and shape sorting rules randomized across participants.

Results

Preliminary analysis examined children’s performance on the pre-switch trials based on percentage of correct responses. A mixed-model ANOVA with the between-subjects factor of Post-switch Stimulus [2D versus 3D] and Order of Conditions [One-Change (2D) followed by Zero-Change (2D) versus Zero-Change (2D) followed by One-Change (2D) or One-Change (3D) followed by Zero-Change (3D) versus Zero-Change (3D) followed by One-Change (3D)] and within-subject factor of Change [One-Change versus Zero-Change] was conducted. Neither the effect of Change, $F(1,28) = 2.33$, $MSE = .002$, $ns$, nor any other interaction was found significant, all $p$’s > .13.

Children’s performance as the percentage of correct responses on the post-switch was first analyzed using a mixed-model ANOVA with the same variables. This analysis revealed a main effect of Post-switch Stimulus, $F(1,28) = 10.11$, $MSE = 2.37$, $p < .01$, $\eta^2_p = .27$, with better
performance in the 3D Post-switch conditions ($M = .83, SD = .67$) compared to 2D Post-switch conditions ($M = .45, SD = .67$). There was no main effect of Order of Conditions, $F(1,28) = .60$, $ns$, nor any effect of Change, $F(1,28) = .33, ns$. However, the experimentally critical two-way Post-switch stimulus X Change interaction was found significant, $F(1,28) = 5.75, MSE = .77, p < .025, \eta^2_p = .17$ (Figure 6). A series of paired-sample t tests demonstrated that changing the stimuli between the pre- and the post-switch phase affected performance in the 2D Post-switch condition, $t(15) = -2.29, p < .05, d = 0.57$, with better performance in the One-Change condition ($M = .58, SD = .48$) compared to the Zero-Change condition ($M = .31, SD = .48$). No difference was found in the 3D Post-switch condition between the One-Change and Zero-Change conditions, $t(15) = 1.25, ns$. Independent sample t tests further demonstrated that performance in the Zero-Change (3D) condition was better than performance in the One-Change (2D) condition, $t(28) = 3.17, p < .01, d = 1.15$, whereas performance in the One-Change (3D) condition was not found to be different than performance in the One-Change (2D) condition, $t(28) = 1.58, ns$.

Performance of children on the post-switch trials in each condition was also compared to performance at chance levels ($p = 0.5$). Performance on the Zero-Change (3D) condition, $t(15) = 6.63, p < .05$ and One-Change (3D) conditions, $t(15) = 2.24, p < .05$ were found to be significantly above chance, $d’s > 0.56$, whereas performance on the Zero-Change (2D), $t(15) = -1.6, p > .05$ and One-Change (2D) conditions, $t(15) = .70, ns$, were not different from chance levels.

In addition, performance of children in all conditions was compared to performance at 0% correct response (complete perseveration). All performances were greater than 0%, $t(15)’s > 2.6, p’s < 0.025, d’$s $> 0.65$. 
Figure 6. Percent of correct responses as a function of condition in Experiment 4
Discussion

Experiment 4 investigated the role of perceptual features of the task material by manipulating the degree of stimulus realism using three-dimensional objects and two-dimensional drawings of the same objects. The performance in the standard condition of Experiment 4 (Zero-Change (2D)) demonstrated the commonly observed poor performance of children in the DCCS task. However, interestingly and as a novel finding, such inflexibility was not seen when children were asked to sort the more salient 3D objects. High levels of perseverative errors observed while sorting 2D cards were significantly reduced when 3D objects were used instead. In addition, when a combination of 2D and 3D stimuli was employed, changing the stimulus dimensionality between the pre- and post-switch phases, performance was also improved, with this change resulting in greater improvement (as compared to the standard condition) when the 3D stimuli were present in the post-switch.

What do these findings suggest about children’s cognitive flexibility? First, the dramatic improvement in performance when 3D stimuli were employed in the post-switch emphasizes the importance of stimulus realism in children’s performance. This enhanced performance could thus suggest that perseveration only occurs in the presence of representations and not when real 3D objects are used. This finding is dramatic, given that no previous work has explored this phenomenon, and has important implications for theories of cognitive flexibility. The highly salient 3D stimuli attract children’s attention to the task and the current sorting dimensions, reducing the conflict that exists between pre- and post-switch sorting dimensions, resulting in reduced perseverative responding and improved performance.

The finding of enhanced performance with 3D objects is consistent with findings of previous investigations of children’s pictorial competence and demonstrates children’s difficulty
in using 2D objects. As suggested by the representational insight account, one of the primary accounts of children’s symbolic comprehension, children often have difficulty understanding the dual nature of pictures and other 2D images and often cannot understand that a picture can be an object and at the same time a representation of another entity (DeLoache, 1991, 1995a, 1995b). This difficulty combined with children’s problems in inhibiting previously-made representations has been shown to affect their performance on pictorial search task when they are asked to search for a hidden object using pictures or scale models (Jowkar-Baniani & Schmuckler, 2012; Kuhlmeier, 2005; Suddendorf, 2003). Such difficulty in using 2D images however, had not been previously investigated in the context of the DCCS task as all studies had employed 2D drawings or had presented images on a monitor. The findings of the present study thus suggest that difficulty in achieving representational insight can be generalized to other contexts and lead to difficulty in other domains.

In addition, and consistent with the findings of Experiments 1-3, when both 2D and 3D stimuli were used, the perceptual change in the task and more specifically in the degree of stimulus realism employed between the pre- and the post-switch invoked a novelty effect, resulting in improved performance.

Taken together, the joint effect of stimulus salience and stimulus novelty can be used to explain children’s performance. High stimulus salience on both the pre- and the post-switch phases (Zero-Change (3D)) leads to the best performance, whereas poorest performance is observed when such salience is low on both the pre- and the post-switch phases (Zero-Change (2D)). The performance on the two remaining conditions is seen along this continuum. Both of these conditions consist of a change between the pre- and post-switch phases of the task, however, in one condition (One-Change (3D)), the change requires switching from the less
salient stimuli in the pre-switch to the more salient stimuli in the post-switch, whereas in the other condition (One-Change (2D)), the change requires switching from the more salient stimuli in the pre-switch to the less salient stimuli in the post-switch. Although performance in both conditions was found better than performance on the standard condition, when compared to the performance at chance levels, only the performance of children in the Change-3D condition was found to be above the performance expected at chance levels. Thus, although changing the task stimuli (in this case a change in stimulus dimensionality) is important in improving performance, such a change is most effective when resulting in an increase in the salience of the post-switch stimuli (One-Change (3D)).

But how does employing a 3D stimulus impact performance? A large number of studies exploring children’s behaviour across 2D and 3D contexts (e.g., DeLoache, 1995a, 1995b; DeLoache et al., 1998; Enns & Rensink, 1991; Jansen, Onat, & Köing, 2009; Kasai, Morotomi, Katayama, & Kumada, 2003) have pointed to the differential treatment of 2D and 3D objects by children (DeLoache, 1995a, 1995b; DeLoache & Burns, 1994; DeLoache & Pierrou Takos, 2003; DeLoache et al., 1998), by exerting more manual manipulations (e.g., rubbing, touching or patting) towards the 3D objects (DeLoache et al., 1998) and towards the more realistic 2D pictures compared to the more abstract 2D line drawings (DeLoache & Pierrou Takos, 2003), as well as the picture-superiority effect demonstrated as a result of increased stimulus salience of 3D scale models (DeLoache, 1995a, 1995b). Although, this improvement in performance using 2D pictures might seem inconsistent with the findings of Experiment 4, the impact of salience and attractive nature of 3D objects can help account for these findings. In the context of symbolic search tasks in which success depends on children’s ability to understand the association between 2D and 3D objects, the salience of a symbol can be disruptive to children’s
ability to treat them as a symbol. However, in the context of a cognitive flexibility task in which attention to the correct sorting dimension is essential, such salience (especially in the post-switch) can facilitate attention towards the post-switch sorting dimension, resulting in improved performance.

Other work more directly exploring attention has also pointed to inherent differences in attentional mechanisms towards 2D and 3D objects (Enns & Rensink, 1991; Jansen et al., 2009). For instance, a number of studies have revealed the sensitivity of the visual system to process depth information from a very young age. In a visual search task, an item with a 3D orientation differing from the surroundings “pops out” indicating that the visual system has a “pre-attentive” process to analyze the 3D properties of a scene (Enns & Rensink, 1991). Similarly, a target can be searched for within a certain depth plane that is being selectively attended, suggesting that 3D depth information is important and processed early on (Holliday & Braddick, 1991).

Furthermore, Jansen et al. (2009) investigated the influence of disparity information on basic factors related to attention, such as saccadic rate, length and main sequence and the subjects’ explorative behaviour. The authors concluded that basic eye movement properties were different when participants explored images with binocular information compared to 2D images. Participants made more but shorter fixations on 3D images. The saccades were shorter and faster, with a wider region of the image being explored. The authors thus suggested that the greater amount of information available in 3D images (mainly disparity and depth cues) resulted in changes in the eye movement properties and increased explorations. The authors further claimed that since in most models of attention, salience is a determining factor for the selection of fixation points, it could be expected that changes in eye movement properties are also associated with changes in the properties of image salience, with disparity serving as a salient image feature.
with its effect comparable to the effect of a texture or luminance contrast in the first few seconds of image presentation (Jansen et al., 2009). Such findings are particularly interesting and revealing and provide relevant support for the findings of Experiment 4. For a long time, it was believed that the dynamics of saccades are insensitive to higher-level cognitive variables. However, these findings suggest that even basic eye movement properties are affected by the type of stimulus. In addition, these results suggest that the results of studies using 2D stimulus representations cannot be automatically generalized to 3D vision, consistent with the results of Experiment 4 in which significant variability in performance is observed across 2D and 3D conditions.

Additional line of work investigated the importance of active exploration of objects and its facilitative effects on performance. For instance, Meijer and Van der Lubbe (2011) investigated adults’ ability to recognize previously-studied objects while allowing either active versus passive explorations of objects. In the active exploration condition, the participants were allowed to manipulate the objects on the screen by moving the objects around. Improvement in recognition of objects was observed in the active exploration condition, which as the authors suggested could be due to strengthening of object representations via possible increases in allocation of attentional resources (although attention alone was not found to be the determining factor). It is thus possible that improved performance using 3D objects stems from additional tactile information received by children when manually manipulating the objects.

Moreover, the redundant tactile and visual input received while sorting might be impacting performance. A large literature on the role of intersensory redundancy has pointed to the highly salient nature of such information for infants (e.g., Bahrick, Flom, & Lickliter, 2002; Lewkowicz, 2000) and has demonstrated the facilitative effect of availability of such redundant
information (Bahrick et al., 2002; Bahrick & Lickliter, 2000; Flom & Bahrick, 2007; Lickliter, Bahrick, & Honeycutt, 2004). Intersensory redundancy refers to the temporally synchronous occurrence of the same information (e.g., rate, rhythm or duration) across two or more senses (Bahrick, Lickliter, Castellanos, & Vaillant-Molina, 2010). According to the intersensory hypothesis, multimodal stimulation selectively recruits attention and facilitates perceptual processing of redundant properties of events. For instance, properties such as rhythm, tempo and emotional expressions are more easily detected when they are presented redundantly through synchronous audiovisual stimulation rather than through visual or auditory stimulation alone (Bahrick et al., 2002; Bahrick & Lickliter, 2000; Flom & Bahrick, 2007; Lickliter et al., 2004).

It is thus possible that the redundant visual and tactile information received when sorting the 3D objects recruited children’s attention, leading to better performance and reduced perseveration. One way to examine this possibility would be to remove either the available visual or tactile information. For instance, 3D objects can be affixed to the cards to prevent children from directly manipulating them. This modification would thus remove the tactile information as well as the redundancy of both visual and tactile information. If better performance when sorting 3D objects can be attributed to availability of such extra information, then children’s performance would suffer upon removal of this information.

Alternatively, better performance of children while sorting 3D objects could be due to the greater familiarity of children with 3D objects compared to 2D cards. This explanation is consistent with the results of Yers and Munakata’s (2006) study demonstrating improved performance when employing novel shapes and colours. This enhanced performance is explained by the graded memory account as weaker latent representations of novel shape and colour dimensions on the pre-switch, making the switch from them easier. Similarly, greater familiarity
with 3D objects in the post-switch could help build stronger representations of the post-switch dimensions that can overcome latent representations of pre-switch sorting dimensions, resulting in improved performance and reduced perseverations.
Chapter 4

General Discussion

The goal of these four experiments was to investigate whether basic perceptual characteristics of the task materials can impact children’s performance in the dimensional change card sort task. Towards this end, four experiments demonstrated that such perceptual information is indeed critical in influencing performance, with this effect dependent on the salience of stimulus features. In addition, modifications of task information in terms of task-relevant parameters of the materials, such as the colour or the shape of the objects depicted on the cards, as well as task-irrelevant parameters, such as the background shape or colour of the cards themselves, or even the dimensionality of the stimuli enhanced children’s performance. Although the former result is not new (Müller et al., 2006; Zelazo et al., 2003), the latter result is highly novel, and provides an important challenge for current theories of children’s behaviour in this task, which assume that effects such as response perseveration are principally cognitive in nature (see Schmuckler, in press for a discussion of cognitive approaches to response perseveration).

As an alternative to these more cognitive based theories, the current findings are more in keeping with a framework that integrates, and potentially emphasizes, the importance of the perceptual characteristics of the overall task context in producing behaviour (Collimore, 2010; Collimore & Schmuckler, 2008, 2010; DeLoache, 1991; DeLoache & Sharon, 2005; Jowkar-Baniani & Schmuckler, 2012; Marzolf et al., 1999; Schmuckler, in press; Suddendorf, 2003).

Along these lines, any modifications to the perceptual information (or in some cases motor constraints) by either employing highly salient stimuli or changing the stimuli to increase
the salience of the post-switch phase can cause a dishabituation or a novelty effect in children which can potentially influence performance via an increase in attentional and cognitive resources. More importantly, these findings suggest that children treat the task, the stimuli and the context as a whole, attending to all aspects of the task, even those irrelevant for successful performance.

In addition to the perceptual factors, this account also makes predictions regarding manipulating the motor constraints of the task. If any salient changes to the task context can influence performance, then even modifying the motor components of the task, such as requiring children to produce a novel motor response on the post-switch should enhance dimensional switching. In fact, some studies have demonstrated improved performance and decreased perseverative responding as a result of manipulating such information. Moriguchi and colleagues (2010a; 2007) for instance, employed a modified DCCS task in which children were not required to respond on the pre-switch trials (i.e., they simply watched either an experimenter or a robot sort the cards by one dimension), but then had to physically sort the cards by the other dimension on the post-switch trials. Interestingly, children performed better after watching a robot sort the cards on the pre-switch compared to a baseline condition in which children actually sorted the cards during the pre-switch trials. This improvement was also observed after children watched a human model sorting the cards, but only in certain situations (e.g., when the model seemed uncertain about the accuracy of her sorting on the pre-switch). Although these latter results were explained by children’s sensitivity to social cues provided as part of the task (e.g., experimenters’ confidence in their sorting), given that the motor demands of the task were manipulated between the pre- and the post-switch phase, these findings are also in keeping with
the idea that manipulating salient perceptual-motor components of this task could lead to improved cognitive flexibility.

Why do such modifications influence cognitive flexibility? One possibility is that the increase in stimulus salience influences children’s performance by directing attention towards the task or the salient stimuli, facilitating children’s ability to allocate additional attentional resources to further analyze and explore the problem. This increase in stimulus salience can be achieved via a number of different means. One approach is to introduce a change in the stimuli across the pre- and the post-switch phases, based on the idea that children are attracted to novel objects (e.g., Berlyne, 1960; Valenti, 1985; Witryol & Wanich, 1983). When children are faced with a new problem their initial analysis of the situation is aimed at categorizing the task as either familiar or novel (Aguiar & Baillargeon, 2000). If the problem is perceived to be familiar, then children simply retrieve a previous solution to this problem. If it is perceived as novel, however, children allocate additional attentional and cognitive resources to further analyze and understand the problem. Alternatively, such an increase in attention can be also achieved by employing a highly salient stimulus in the post-switch. When highly salient stimuli are used in the task, such as employing 3D stimuli, high levels of attention are maintained across the two phases of the study, facilitating performance even in the absence of any other changes in the stimuli between the pre- and the post-switch phases. Taken together, and as demonstrated in the current studies, any task manipulation to increase the stimulus salience (via changing the stimuli across the two phases or using salient stimuli in the post-switch) that can increase attention can ultimately lead to improved performance.

Other research has also highlighted the role of the perceptual and contextual variables in affecting performance. Koechlin, Ody and Kouneiher (2003) for instance, proposed a cascade
model of cognitive control containing three nested levels of processing; sensory control involved in selection of the motor actions in response to stimuli; contextual control involved in selection of premotor representations according to the contextual information accompanying the stimulus; and temporal control involved in selection of stimulus-response associations according to the temporal episode in which the stimuli occurs. The findings of the present study are consistent with this cascade model, demonstrating the impact of contextual factors (e.g., background colour and shape of the cards, the shape of the sorting bin) on children’s dimensional switching.

Also in keeping with the general framework being proposed is the evidence that the processing of salient and/or unexpected stimuli differs qualitatively from the processing of more familiar stimuli. Corebetta and Shulman (2002), for instance, have found that while the intraparietal cortex is involved in the top-down detection of stimuli, another system in the temporoparietal cortex acts as a “circuit breaker” and shows increased activity in response to unexpected stimuli, such as a change in the colour of a visual stimulus or a change from croaking frogs to running water for an auditory stimulus (Downar, Crawley, Mikulis, & Davis, 2000). Interestingly, the regions activated by such stimuli are also those that typically respond when orienting towards unexpected spatial locations (Arrington, Carr, Mayer, & Rao, 2000; Kirino, Belger, Goldman-Rakic, & McCarthy, 2000). Thus, changes to the basic features of visual and auditory stimuli could have created a novelty effect reorienting attention towards these dimensions.

How well can the previously described theoretical frameworks explain the current findings? Generally, not well at all. In terms of the cognitive complexity and control theory (Zelazo & Frye, 1997, 1998) there is nothing about modifying aspects of the irrelevant task materials or the dimensionality of the stimuli that would necessitate a change in children’s
hierarchical rule representations. Hence, according to this account, modifications along these lines should have little or no impact on children’s performance. Similarly, both the attentional inertia theory (Kirkham et al., 2003) and the negative priming approach (Müller et al., 2006) face difficulties in explaining the current findings. In both cases, the principal mechanism underlying children’s inability to successfully complete the task involves changes and/or modifications to attention processes focused towards task-relevant dimensions; neither of these accounts assumes that dimensions totally irrelevant to the task (i.e., the background colour or shape of the cards themselves) or the degree of stimulus realism are either important to the task globally, or play a role in attention more specifically. Of course, it is possible that these theories could be modified in some form to also include irrelevant contextual features, but (1) it is not clear what such modifications would entail, and (2) such changes would dramatically restructure these approaches, altering the fundamental bases and premises on which these accounts operate.

Furthermore, the graded memory account explaining perseverations as a result of a competition between two memory systems, cannot fully account for the observed findings. This theory, which uses a Hebbian algorithm to model changes in the strength of latent representations formed by experience, cannot explain the immediate effects of changes in the stimulus salience in the absence of any additional modifications in children’s experience with the correct sorting rules.

Overall, the findings of the present four studies can be best explained by a joint function of the perceptual similarity (novelty) and the stimulus salience accounts. The fact that changes made to the task material, even those irrelevant to the task including changes to the stimulus dimensionality can enhance performance provides evidence for the role of the perceptual similarity account of performance, with greater dissimilarity leading to improved performance.
Additional attentional resources allocated to the task as a result of such changes act to reset behaviour, leading to enhanced performance. In addition, the role of stimulus salience is demonstrated by improved performance when the highly salient 3D stimuli are employed in the task, when the change in stimuli is salient enough to induce a novelty effect (e.g., changing background colour and not background shape), and when the change results in the more salient stimuli in the post-switch (e.g., 3D stimuli compared to 2D stimuli). Thus, the novelty account interacts with the salience account to explain behaviour when the stimulus salience is increased as a result of employing highly salient stimuli in the post-switch or modifying task parameters salient enough to induce a novelty effect.

Theoretically, these findings are also in line with the dynamic systems approach which explains children’s behaviour as a product of interaction among multiple elements such as the context, the stimuli, the task, the developmental history, and so on (Smith, Thelen, Titzer, & McLin, 1999; Spence et al., 2009; Spencer, Perone, & Buss, 2011; Thelen & Smith, 1994). One line of evidence for such an approach comes from a number of studies demonstrating the influence of a variety of contextual factors on children’s performance on the A-not-B task. For instance, modifying task-irrelevant parameters such as the infants’ posture between the A and B trials (by having children change their posture from sitting to standing) has been found to reduce errors in such tasks (Smith et al., 1999). In addition, Munakata (1997) demonstrated the effect of salience of the stimulus input on the A-not-B errors by presenting infants with lids only on the A trials, then presenting either a new toy or cueing the same lid on B trials. Perseverative errors were reduced when the toy was shown for the first time on the B trials. Similar effects of stimulus salience have been also demonstrated in other studies. In one task, the stimulus salience in the A-not-B task was manipulated by creating the objects ranging from low salience (plain
brown object) to medium salience (object with red, yellow and blue stripes and polka dots) to high salience (three multi-coloured flashing lights attached to the object). The authors also manipulated the memory demands of the task by modifying the delay between curing the object location and infants’ reaching on B trials. Infants perseverated more in the long delay condition compared to the short delay, but showed enhanced performance when high salient objects were used even in the presence of a long delay (Clearfield, Dineva, Smith, Diedrich, & Thelen, 2009). The presence of a highly salient cue attracted children’s attention, directing their attention away from the habitual response of searching at the A location. Moreover and in a more relevant vein, the visual cues available in the DCCS task have been associated with children’s ability to answer knowledge questions about the post-switch rules, such that removing visual cues hinders children’s ability to answer such questions (Buss & Spencer, 2012). Overall, all these findings emphasize the interactive nature of children’s behaviour, highlighting the role of all the available task and context information on performance.

In addition to providing evidence for the role of perceptual and contextual variables in the DCCS task, the present studies demonstrated that not all changes to the to-be-sorted materials necessarily improve performance. For example, changes to only a single feature of the cards, be they relevant to the task (e.g., the shape or colour of the depicted objects) or irrelevant to the task (e.g., change in the sorting bins) failed to facilitate performance. Moreover, in at least one case (Experiment 1) changes to two features of the to-be-sorted materials (change in a task-relevant parameter combined with a change in card shape) also failed to improve performance and in yet another case (Experiment 4), changes leading to the presentation of the less salient 2D stimuli in the post-switch phase resulted in smaller improvement.
Given such variability in children’s performance, the present findings suggest that the performance occurs along a continuum with only some modifications resulting in enhanced performance. In keeping with this idea, although the graded memory account cannot fully explain the findings of the present study, it is the only account to explain behaviour as graded rather than being all-or-nothing, based on the strength of active and latent representations (Munakata, 2001). According to this account, the strength of representations may vary based on a person’s state of development and prior experience as well as current environmental and task contexts, creating performance that is highly task dependent (Yerys and Munakata, 2006). In the DCCS task, weak representations might be sufficient for children to succeed on some tasks but not the others. For instance, despite children’s failure to correctly sort the cards, they can successfully answer knowledge questions pertaining to the task (where do trucks go in the shape game), but those representations might be too weak to allow them to correctly sort the cards based on the sorting rule. Similar knowledge-action dissociation is also seen in patients with pre-frontal damage in comparable contexts (Milner, 1963).

This explanation is also consistent with the findings of Yerys and Munakata’s (2006) study described previously in which the authors manipulated the strength of the latent representations of the pre-switch phase by employing objects with unfamiliar shapes and colours (dax or nust) or using uninformative labels for objects (e.g., instead of naming the objects by their shape or colour, they simply referred to all cards as “this”). Using objects of unfamiliar shape or colour or using uninformative labels is suggested to reduce the strength of latent representations formed on the pre-switch, making it easier to switch from the pre-switch sorting dimensions to the post-switch ones.
Although the manipulations made in the present study did not create stimuli completely novel for children (compared to Yerys and Munakata’s (2006) manipulation), the change in stimulus parameters and the resulting increase in salience, or employing highly salient 3D stimuli might have acted either as a resetting mechanism, preventing children to build strong latent representations of the pre-switch task or to carry such memory traces to the post-switch. Alternatively, the increase in salience and the resulting increase in attention could have facilitated children’s ability to form stronger active memory representations on the post-switch (an effect that is often seen by increase in age and experience), leading to less conflict among the active and latent task representations. Thus, the graded memory account can account for some of the current findings, but not all. It is possible that modifications to the structure of the model can accommodate more of the present findings, but this possibility awaits further investigation.

With regards to the role of perceptual similarly, the question still remains on the degree of change that must be incorporated into the task materials to induce a novelty effect, and thereby produce better performance by children. Unfortunately, these studies cannot, at this point, speak to this issue, given that other than the somewhat crude one- versus two-dimensional manipulations employed, these experiments did not attempt to more precisely vary or define the degree of contextual variation produced. Nevertheless, and with reference to other work, some conclusions regarding this issue can be drawn. First, it is clear that what classifies as sufficiently salient changes does not require modifications to information that is central to the task at hand. The principal finding of Experiment 3 was that changes made exclusively to parameters that have nothing to do with the sorting procedure *per se* can still induce a novelty effect and hence, facilitate performance. However, the fact that task-relevance is not a prerequisite to inducing a novelty effect does not mean that task-relevant versus task-irrelevant modifications are of equal
salience in facilitating performance; the specific weighting of changes along these two
dimensions (relevant versus irrelevant) has yet to be determined. Second, although the current
study cannot identify the degree of change necessary to induce a novelty effect, other
conceptually related work has attempted to determine a bit more of the scaling for this type of
effect. Specifically, in Jowkar-Baniani and Schmuckler’s (2012) previously discussed work on
the role of perceptual factors in symbolic search tasks, the authors found that changes to one-
third (2 of 6) of the potential hiding locations in a to-be-searched room was insufficient to induce
a novelty effect that led to improved search behaviour, whereas changes to two-thirds (4 of 6) of
the hiding locations did lead to better search accuracy. Interestingly, and in a fairly general (and
admittedly conceptually loose) fashion, these earlier findings converge with the present results in
that these studies observed that changes to only one of two possible relevant dimensions (i.e.,
colour or shape, but not both, of the objects depicted on the cards) were insufficient to increase
performance, whereas other research (Zelazo et al., 2003) has demonstrated that changes to both
critical dimensions (e.g., colour and shape simultaneously) does influence behaviour. Thus, in
different ways, both sets of studies imply that changes to over 50% of the critical information are
required to cause a novelty response in children. Of course, such considerations are highly
speculatively (although interesting), and clearly await more careful and controlled manipulations
of the degree and nature of the changes to the task materials, both contextual and task-relevant,
before any real conclusions can be drawn. In this regard it would be intriguing to modify Brace
and colleagues’ (2006) morphing procedure to the depicted objects in such a way that one can
systematically vary the degree of perceptual correspondence between the objects depicted on the
cards pre- and post-switch, in an attempt to more precisely answer this question.
Moreover, the proposed increase in attention as a result of manipulating such perceptual task information can be explored by comparing eye movement parameters across the pre- and the post-switch phases. More explorations of the post-switch stimuli compared to the pre-switch especially around the areas of change (e.g., background colour/shape) are expected as a result of the induced novelty effect. Using highly salient 3D stimuli in the post-switch is also expected to result in increased exploration pattern during the post-switch phase. However, less attention and fewer explorations is expected when the stimulus change is not as salient, such as manipulating the background shape of the cards in Experiment 1 or when sorting the less salient 2D stimuli in the post-switch.

In sum, these studies demonstrated that variation of perceptual characteristics of the task context influenced children’s ability to flexibly attend to dimensions of the task material. The fact that such perceptual and contextual modifications systematically influenced children’s performance underscores the idea that perceptual parameters of the global experimental context play a significant role in tasks that are presumed to fundamentally rely on more higher-level, cognitive factors. Findings such as these, then, highlight the need for future work investigating the role of perceptual constraints across an array of cognitive tasks and phenomena.
References


