Dynamics, models, and mechanisms of the cognitive flexibility of preschoolers
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Stimulus novelty weakens children’s pre-switch rule in rule switching

This chapter is based on:
Abstract
Cognitive flexibility is an ability that develops importantly in early childhood. Different factors influence children’s ability to switch between card sorting rules. The current study tests how novel features of existing stimulus dimensions, influences the performance of 4- and 5-year-old children (N = 299) on the Dimensional Change Card Sorting (DCCS, Zelazo, 2006) task. To this end, we designed a DCCS task with three stimulus dimensions, color, shape and size that vary between target and test cards. The introduction of a third stimulus dimension made it possible to observe whether children direct attention to a dimension with novel stimulus features. Remarkably, results showed that it is relatively easy to switch sorting rule when sorting to size in the pre-switch phase. The current study shows clear evidence, based on both accuracy and speed of DCCS performance, for a non-directional hypothesis about the effect of stimulus novelty on switching performance: the introduction of stimulus novelty together with a rule switch only weakens the strength of the pre-switch rule. The results oppose the idea that stimulus novelty in the DCCS task functions as an exogenous stimulus factor that directs attention towards a particular dimension (analogous to Fisher, Thiessen, Godwin, Kloos, & Dickerson, 2013). Current results are consistent with the competing memory systems account (Munakata, 1998), which assumes that latent memory of the pre-switch rule is dependent on all stimulus features that were correlated to the sorting location.

5.1 Introduction
Cognitive flexibility is the ability to flexibly adapt behavior in relevant ways to the environment. Cognitive flexibility is regarded as one of the executive functions but also involves other executive functions: working memory to remember what is needed in the new situation and inhibition to suppress the tendency to direct attention and to act according to the old situation or any external lure (Diamond, 2013). A common way to investigate cognitive flexibility is by using task-switching or set-shifting tasks, such as the Wisconsin Card Sorting Task (Milner, 1964; Huizinga, Dolan & van der Molen, 2006). A remarkable improvement in cognitive flexibility occurs between three and five
years of age (Carlson, 2005; Diamond, 2013). Children of this age improve on a wide range of tasks, such as Luria’s tapping task (Diamond & Taylor, 1996), appearance reality tasks (Flavell, Flavell, & Green, 1986), and the Dimensional Change Card Sorting (DCCS) task (Zelazo, 2006; Zelazo, Frye & Rapus, 1996). The DCCS task is the simplest paradigm to measure cognitive flexibility in preschoolers, mostly used between 3- and 5 years of age. The DCCS is a rule-switching task in which the experimenter explains the sorting rules to the preschooler. Target cards that differ on two dimensions, usually shape and color (e.g., a red boat and a blue rabbit), mark two sorting locations. Children are asked to sort test cards with novel pictures composed of the same dimensional features (e.g., a blue boat and a red rabbit). After a few trials sorting according to one rule, the pre-switch rule (e.g., matching color), the experimenter introduces a new rule, the post-switch rule (e.g., matching shape). Most 3- and 4-year-olds are able to sort according to the pre-switch rule, but a large proportion of 3- and 4-year-olds cannot make the rule switch and hence perseverate in sorting according to the pre-switch rule.

Many different perspectives have been introduced to explain cognitive inflexibility in children (Cognitive Complexity & Control (CCC) theory, Zelazo & Frye, 1997; Learning and Response-Conflict Resolution, Ramscar; Dye, Gustafson, & Klein, 2013; Attentional inertia account, Kirkham, Cruess & Diamond, 2003; Activation-deficit or negative priming hypothesis, Chevalier & Blaye, 2008; Müller, Dick, Gela, Overton, & Zelazo, 2006; Re-description theory, Perner and Lang, 2002; Competing memory systems account, Morton & Munakata, 2002; Munakata, 1998). Several of these theoretical perspectives assume that a necessary switch in attention from one to another stimulus dimension is the limiting factor of children’s cognitive flexibility. According to the attentional inertia theory (Diamond, Carlson & Beck, 2005; Diamond & Kirkham, 2005; Kirkham, Cruess & Diamond, 2003), children have the tendency to continue to focus attention on what had previously been relevant and they need inhibitory control to direct attention to a different stimulus dimension. According to the activation-deficit or negative priming account important factors for perseverative behavior are representation maintenance and activation of previously inhibited information (Chevalier & Blaye, 2008; Müller; Dick, Gela, Overton, & Zelazo, 2006).
Fischer, Thiessen, Godwin, Kloos, & Dickerson (2013) describe how, in a paradigm comparable to the DCCS, selective sustained attention in young preschoolers depends on both endogenous and exogenous factors. Exogenous factors are characteristics of the stimuli, mainly their salience to the child. Endogenous factors are those factors that are under cognitive control of the individual. With development, the relative impact of endogenous factors on children’s behavior increases (Fisher et al., 2013; Snyder & Munakata, 2010; Smith & Yu, 2012). If exogenous factors limit performance in sustained attention tasks, in rule-switching tasks, such as the DCCS task, these exogenous factors may help to switch attention (Snyder & Munakata, 2010). The reverse may be true as well. Exogenous factors could also hamper rule switching by increasing attention to the pre-switch rule. The assumption of this approach is that exogenous factors could draw attention to specific aspects of the stimuli. For example, the introduction of stimulus novelty could direct attention to the dimension with novel features in a similar way as novel objects attract attention (Fischer et al., 2013). The aim of the current study is to test this specific hypothesis: that an exogenous factor, stimulus novelty, directs attention to the novel stimulus features and thus affects preschoolers’ performance on the DCCS task.

Several studies report on the effects of experimental manipulations in the DCCS task that introduce novel stimulus features together with the rule switch (Zelazo, Müller, Frye & Marcovitch, 2003; Yerys & Munakata, 2006). In case only features of one dimension changed (the pre-switch relevant dimension, also called the negative priming version, or the post-switch relevant dimension, also called the partial change version) the effects on switching behavior are not conclusive. In particular, Zelazo et al. (2003) report a trend towards more children switching in case the post-switch relevant dimension changed and a trend towards more children perseverating in case features of the pre-switch relevant dimension changed. In contrast, in their negative priming condition, Yerys and Munakata (2006) report more children switching, albeit with a slightly different version of the DCCS. The most convincing effect is that novel features for both stimulus dimensions (color and shape; total change version) result in a positive effect on switching behavior (two out of three experiments in Zelazo et al., 2003).
Van Bers, Visser, and Raijmakers (2014, Chapter 4) studied the effect of exogenous factors that are not related to the sorting rules, i.e. card shapes (outlines) and card position on the screen, on 3-year olds’ switching behavior, in comparison with changes in stimulus features that are related to the sorting rules. In this study it was found that changes of card shape and changes of card position improve DCCS performance. In addition, they replicated earlier findings that a total change of related stimulus features results in improved performance. In contrast to conclusions of earlier studies, however, the found effect was not an increase of the number of participants who switch but a decrease of the number of errors perseverators make. That is, the average success rate of perseverators was not around zero, which it was in the control condition, but was around .2. Changes of card shape also resulted in perseverators showing more correct trials (success rate is around .1). An explanation of this dissimilar finding is that earlier studies could not reliably distinguish between these two interpretations of improved performance on a group level.

Stimulus novelty has effect on children’s DCCS performance, but how is not clear. Yerys and Munakata (2006) suggest that such exogenous factors disturb the sustained attention to the pre-switch relevant features, and thus result in improved DCCS performance. However, according to Yerys and Munakata there are at least two possible ways in which stimulus novelty could cause a disturbance in sustained attention. On the one hand, the introduction of stimulus novelty could attract attention to the dimension with novel features in a similar way as novel objects attract attention (Fischer et al., 2013). According to this hypothesis, it is important for which stimulus dimension novel features are introduced. We call this the directional hypothesis. On the other hand, the introduction of stimulus novelty could also have a non-directional effect on the sustained attention to the pre-switch rule. According to this hypothesis, novelty only acts as a distractor for the attention to the pre-switch relevant dimension. Only the salience and total amount of novelty is hence important. The discussed effect of a total change of related stimulus features that is consistently found (Zelazo et al., 2003; Van Bers et al 2013b, Chapter 4) supports this hypothesis. The current study aims at disentangling these possible effects of stimulus novelty on children’s DCCS performance.
With a standard DCCS task that has two stimulus dimensions that vary between cards, the different hypotheses cannot be distinguished very well. For example, if stimulus novelty is introduced in the post-switch relevant dimension and improves performance, do children use the post-switch rule due to attraction of attention to the post-switch relevant dimension or do they use the post-switch sorting rule because novelty diverts attention away from the pre-switch relevant dimension, and the post-switch relevant dimension is the only alternative there is? To distinguish these hypotheses about the influence of stimulus novelty on switching performance, for the present study we designed a DCCS task with three stimulus dimensions that vary between target and test cards resulting in three possible sorting rules: a pre-switch sorting rule, a post-switch sorting rule, and a third dimension sorting rule that is never relevant for the task (cf. Déak, 2003). We designed four experimental conditions by introducing new stimulus features in one or two stimulus dimensions. See the methods section for the complete design of the study. Introduction of novelty in the third stimulus dimension provides a strong test for the directional hypothesis: it is predicted that children make more sorts based on the third dimension, while the non-directional hypothesis predicts that children make fewer sorts based on the pre-switch relevant dimension (in comparison with the standard condition). Table 5.1 shows hypothesized attention change according to the two hypotheses for all conditions. The predictions could be translated in predictions about DCCS performance. An increased attention to the pre-switch relevant dimension (+ pre) would result in fewer children switching. An increased attention to the post-switch relevant dimension (+ post) would result in more children switching or perseverators making more occasional correct sorts. An increased attention to the 3rd dimension (+ 3rd) would result in more children sorting according to the 3rd dimension or more occasional sorts to the 3rd dimension. Less attention to the pre-switch relevant dimension (- pre) would result in more children switching or more occasional correct sorts by the perseverators. The predictions in Table 5.1 could also be translated into predictions for the reaction times of responses from switchers (Diamond & Kirkham, 2005). It is predicted that less attention for the pre-switch relevant dimension (- pre) and more attention to the post-switch relevant dimension (+ post) would result in a faster post-switch response. More attention to the pre-
Table 5.1 | Predicted attention change for the four task conditions.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Directional hypothesis</th>
<th>Non-directional hypothesis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-switch relevant change</td>
<td>+ pre</td>
<td>-pre</td>
</tr>
<tr>
<td>Post-switch relevant change</td>
<td>+ post</td>
<td>-pre</td>
</tr>
<tr>
<td>3rd dimension change</td>
<td>+ 3rd</td>
<td>-pre</td>
</tr>
<tr>
<td>Pre-switch + Post-switch relevant change</td>
<td>+ pre + post</td>
<td>--pre</td>
</tr>
</tbody>
</table>

Note. Pre denotes change of features of the pre-switch relevant dimension, post denotes post-switch relevant dimension, 3rd means the stimulus dimension that is never relevant, pre+post means both the pre-switch and the post-switch relevant dimensions. Hence, ‘+ pre’ means that in the post-switch phase there is more attention for the pre-switch relevant stimulus dimension (compared to the standard condition).

In the experiment presented below, a 3-dimensional version of the DCCS task was used with shape, color, and size as stimulus dimensions that vary between test cards and target cards. Shape and color are the prevailing dimensions for DCCS tasks; size was used before in only a few experiments (e.g. Déak, 2003). In addition to the standard condition, keeping all stimulus features equal in the post-switch phase, we constructed four experimental conditions in which for one or two stimulus dimensions novel features were presented in the post-switch phase of the task. Features of size as stimulus dimension never changed because size differences could not be made large enough to create six different values. For this reason we did not construct a condition with all stimulus features changing. The expectation is that the introduction of novel stimulus features influences children’s sorting behavior according to one of the hypotheses depicted in Table 5.1.
5.2 Method

Participants

A total of 299 children participated in this study: 135 4-year-olds (\(M = 53.3\) months, \(SD = 3.2\), range = 48 - 59, 81 boys and 54 girls), and 164 5-year-olds (\(M = 65.7\) months, \(SD = 3.4\), range = 60 - 71, 66 boys and 98 girls). We tested another 30 children but their data could not be used because they did not pass the pre-switch phase (\(n = 22\)), refused to complete testing (\(n = 1\)), or due to experimenter error (\(n = 7\)). Children were recruited from primary schools in the Netherlands. Informed consent was obtained from the parents of all children who participated.

Design

Within each age group, children were randomly assigned to one of five conditions: the standard condition (\(n = 78\), 36 four-year-olds and 42 five-year-olds, \(M = 59.9\) months, \(SD = 7.5\), range = 48 - 71, 40 boys and 38 girls), the pre-switch relevant change condition (\(n = 54\), 26 four-year-olds and 28 five-year-olds, \(M = 59.9\) months, \(SD = 7.2\), range = 48 - 71, 25 boys and 29 girls), the post-switch relevant change condition (\(n = 62\), 24 four-year-olds, 38 five-year-olds, \(M = 60.4\) months, \(SD = 7.1\), range = 48 - 71, 30 boys and 32 girls), the 3rd dimension change condition (\(n = 53\), 27 four-year-olds and 26 five-year-olds, \(M = 59.8\) months, \(SD = 6.1\), range = 48 - 70, 28 boys and 25 girls), and the pre-switch + post-switch relevant change condition (\(n = 52\), 22 four-year-olds, 30 five-year-olds, \(M = 60.3\) months, \(SD = 6.9\), range = 49 - 71, 24 boys and 28 girls).

The conditions differed in which dimension of the stimuli changed between the pre-switch and the post-switch phase of the task. In the standard condition test cards and target cards in the pre-switch phase were equivalent to the test and target cards in the post-switch phase. In the pre-switch relevant change condition the values of the stimulus dimension that is relevant during the pre-switch phase changed, both in the test and the target cards. In the post-switch relevant change condition the values of the dimension that is relevant in the post-switch phase changed. In the 3rd dimension change condition the values of the dimension that is irrelevant in both the pre-switch and post-switch phase changed. And finally in the pre-switch + post-switch relevant change
condition the values of both the dimension that is relevant in the pre-switch phase and the dimension that is relevant in the post-switch phase changed. The combinations of the three different sorting rules and the order of the sorting rules were counterbalanced and crossed within each age x gender cell. With the exception that size was never the changing dimension, because it was too difficult to distinguish six levels of size and to label all these sizes. The three used sizes were labeled small, middle, and large.

Materials
The experiment was conducted using a laptop computer with a separate touch-screen monitor. The task was programmed using the software package Authorware version 7.0. Stimuli were presented against a dark grey background (1024 x 768 pixels). Three target cards (270 x 220 pixels) were depicted in the bottom of the screen. A test card (270 x 220 pixels) appeared in the top center of the screen when the experimenter pressed a key on the laptop computer. Children sorted the test cards by touching the appropriate target card. The test card then moved to the chosen target card and disappeared. See Figure 5.1 for an example of the computer screen.

![Figure 5.1](image_url)

**Figure 5.1** Example of the computer screen during a trial: the left panel depicts the screen before the test card is presented and the right panel when the test card is presented.
For the pre-switch phase target- and test cards were the same in all conditions. The target cards depicted a big yellow rabbit, a small red fish and a medium size blue pig. The test cards depicted a small blue rabbit, a medium size yellow fish and a big red pig. Each test card matched one target card on the dimension color, one target card on the dimension shape and one target card on the dimension size. Therefore, the correct answer when sorting by color was the wrong answer when sorting by shape or size. For the post-switch phase the target- and test cards depended on the condition and relevant sorting rules. Shapes could change to frog, snail or cat. Colors could change to orange, green or purple. As in the pre-switch phase, each test card matched one target card on the dimension color, one target card on the dimension shape and one target card on the dimension size. See Figure 5.2 for examples of the stimuli used in the pre-switch phase and the post-switch phase of the task in the five conditions.
### Condition

<table>
<thead>
<tr>
<th>Standard</th>
<th>Pre-switch</th>
<th>Post-switch</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Target cards</strong></td>
<td>![Color](Image 139x116 to 175x146) ![Shape](Image 178x158 to 214x188)</td>
<td>![Color](Image 178x229 to 214x259) ![Shape](Image 216x496 to 252x526)</td>
</tr>
<tr>
<td><strong>Test cards</strong></td>
<td>![Color](Image 178x116 to 214x146) ![Shape](Image 216x158 to 252x188)</td>
<td>![Color](Image 216x229 to 252x259) ![Shape](Image 254x272 to 290x301)</td>
</tr>
</tbody>
</table>

**Pre-switch relevant**

| **Target cards** | ![Color](Image 139x158 to 175x188) ![Shape](Image 178x272 to 214x301) | ![Color](Image 178x341 to 214x370) ![Shape](Image 216x455 to 252x485) |
| **Test cards** | ![Color](Image 178x229 to 214x259) ![Shape](Image 216x496 to 252x526) | ![Color](Image 216x229 to 252x259) ![Shape](Image 254x272 to 290x301) |

**Post-switch relevant**

| **Target cards** | ![Color](Image 139x158 to 175x188) ![Shape](Image 178x272 to 214x301) | ![Color](Image 178x341 to 214x370) ![Shape](Image 216x455 to 252x485) |
| **Test cards** | ![Color](Image 178x229 to 214x259) ![Shape](Image 216x496 to 252x526) | ![Color](Image 216x229 to 252x259) ![Shape](Image 254x272 to 290x301) |

**Never relevant**

| **Target cards** | ![Color](Image 139x158 to 175x188) ![Shape](Image 178x272 to 214x301) | ![Color](Image 178x341 to 214x370) ![Shape](Image 216x455 to 252x485) |
| **Test cards** | ![Color](Image 178x229 to 214x259) ![Shape](Image 216x496 to 252x526) | ![Color](Image 216x229 to 252x259) ![Shape](Image 254x272 to 290x301) |

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Condition | Pre-switch | Post-switch
--- | --- | ---
Pre-switch + post-switch relevant | Target cards: | Test cards: |
| Color | | |
| | | |
| Shape | | |

**Figure 5.2** Examples of target cards and test cards used during the pre-switch phase and post-switch phase of the task in the five conditions.

**Procedure**

Children were tested individually in a quiet room in their primary school. Once the child was comfortable with the experimenter, the touch screen was introduced and the experimenter verified the child’s knowledge of the shapes, colors or sizes that were present in the pre-switch phase of the task.

The experimenter then explained the sorting rules of the pre-switch phase and demonstrated the sorting of the three different test cards. The child was then asked to sort six test cards him- or herself. The three different test cards were presented in pseudo-random order, so that no test card was presented more than twice in a row. On every trial the experimenter repeated the relevant sorting rules. Immediately after the repetition of the rules a test card was presented. The experimenter labeled the test card with the relevant dimension only (e.g. “This is a red one.”). Children were not given feedback on their sorting. A child had to sort at least five of the six test cards correctly to pass the pre-switch phase.

At the start of the post-switch phase the experimenter verified the child’s knowledge of the shapes, colors or sizes that were relevant in the post-switch phase of the task. The experimenter then explained the sorting rules of the post-switch phase, but did not demonstrate the sorting of the three different test cards. The child was then asked to sort nine test cards him- or herself. As in

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the pre-switch phase, the three different test cards were presented in pseudorandom order, the experimenter repeated the relevant sorting rules before every trial, labeled the test card with the relevant dimension only, and children were not given feedback on their sorting.

**Statistical approach**

Most experimental DCCS studies with preschoolers show that the number of correct post-switch trials is bimodally distributed. Therefore, performance is usually reported dichotomously: switching (5 or 6 trials correct, out of 6 post-switch trials) or perseverating (1 to 4 trials correct). For a standard DCCS task the threshold of 5 correct trials (i.e., 83%) can be statistically motivated (Van Bers, Visser, van Schijndel, Mandell, & Raijmakers, 2011, Chapter 2). This is not necessarily true for a non-standard DCCS task (Van der Maas & Straatemeier, 2008): in case the accuracies of switchers and perseverators change a threshold of 5 could be no longer appropriate, resulting in an incorrect conclusion about the number of switchers. Determining an appropriate threshold is even less straightforward in the case of 9 post-switch trials as used in the current study. For example, in 9 trials sequential effects might be expected, such as perseverating a few trials before switching to the post-switch rule.

Hence, improved performance on a group level by experimental manipulations could have completely different interpretations: one interpretation is that stimulus novelty facilitates switching, as for example Yerys and Munakata (2006) conclude. Alternatively, stimulus novelty may affect the accuracy of a sorting strategy. An increase in the occurrence of scores 3 and 4 in the post-switch trials could be an indicator of such changes in accuracy of sorting strategies. To resolve this interpretation problem we used latent Markov models (Visser, 2011) for statistical analysis. The methods section of Chapter 4 of this thesis provides a detailed description of the statistical approach. Here, we will only give a short summary.

As in Van Bers et al. (2011, Chapter 2) we modeled trial-by-trial accuracy data of post-switch trials with latent Markov models. For each condition separately we selected the optimal number of latent states (i.e., behavioral modes) on basis of the Bayesian Information Criterion (BIC; Schwarz, 1978). We expected to find two or three modes representing switching,
perseverating, and (in some conditions) sorting according to the third
dimension. By the application of latent Markov models we estimated for each
condition multiple parameters: a) the probabilities of responses (i.e., switch,
perseverate, 3rd dimension) in each behavioral mode; b) the probabilities of
responding according to the behavioral modes at the first post-switch trial; c)
the probabilities of a transition between behavioral modes at each post-switch
trial.

Differences between experimental conditions were tested by
comparing parameters of respective models. To this end, we formulated multi-
group models and we compared model fits of multi group models with and
without parameter equalities by means of likelihood-ratio tests (Azzalini,
1996). In the case specific parameters differences were found between
conditions, we made pair-wise comparisons between each condition and the
standard (control) condition. The alfa level for these comparisons was divided
by the number of comparisons made (4) and hence adjusted to .012.

5.3
Results
Preliminaries
In the post-switch phase of the task, most children either responded correctly
on at most 2 trials (22%) or at least 7 trials (71%) of the 9 post-switch trials.
Hence, for the standard analyses we dichotomized the data in children passing
(> 6 correct post-switch trials) and failing (< 7 correct post-switch trials). A
chi-square test on the number of children passing and failing did not reveal a
gender difference, but it did reveal an age difference, $\chi^2(df = 1, N = 299) = 14.19,$
$p < .001$; fewer 4-year-old children were passing the post-switch phase (60%)
than 5-year-olds (80%). Each of the five experimental conditions consisted of
several sub-conditions depending on the pre-switch and post-switch rule that
was relevant. Comparing the sub-conditions based on the pre-switch relevant
dimension, we found that the sub-conditions with size being the relevant
pre-switch dimension were easier than the other sub-conditions, $\chi^2(df = 1, N
= 193) = 24.92,$ $p < .001$; Here, only the conditions are included that include
a sub-condition with size as the pre-switch relevant dimension. There was
no systematic difference between sub-conditions based on the post-switch
relevant sorting rules.

Standard analyses
To analyze differences between conditions in a standard way we collapsed over gender and we disregarded the sub-conditions with size being the pre-switch relevant rule (see Figure 5.3). There is a difference between conditions, $\chi^2(df = 4, N = 216) = 13.16, p = .01$. Planned comparisons (all conditions compared with the standard condition) show that only the pre-switch + post-switch relevant change condition differs from the standard condition, $\chi^2(df = 2, N = 103) = 11.56, p < .001$.

Model-based analyses
To test differences between conditions and sub-conditions in more detail we modeled the trial-by-trial three-valued nominal responses of the post-switch phase by Latent Markov Models (see Methods section). The first step of the procedure was to determine the optimal number of states per condition (separating also sub-conditions with size as the pre-switch relevant dimension). For all conditions, three-state models did not result in stable solutions of the parameters because the estimations of multiple parameters were on boundaries (zero or one). Hence, we prefer to present the two-state models, which were always more optimal than the one-state models (using BIC as model selection criterion). The two states in all conditions were a switch state (high probability of switching) and a perseveration state (high probability of perseverating). The next step was to combine the models for separate conditions in a multi-group model and test for differences between conditions in parameter estimates. As an additional constraint, we set all parameters but the initial parameters equal between the sub-conditions within a condition (e.g., the standard condition with and without size as the pre-switch relevant dimension). In total, the multi-group model consisted of eight groups. Comparisons of conditions with the standard condition were always made such that size and non-size sub-conditions were tested simultaneously. Model comparison by means of a likelihood ratio test showed that the transition probabilities were not significantly different between conditions, $\chi^2(df = 8) = 8.74, p = .36$.

The probability of a transition from the switch state to the perseveration state equaled .01 and the probability of a transition from the perseveration state to the switch state equaled .05. The subsequent step was to test for differences in response probabilities between conditions, representing the error rates of switching and perseverating. The response probabilities of the switch state were not significantly different between conditions, $\chi^2(df = 8) = 9.32, p = .32$; these probabilities were .97, .02, and .01 for the correct response, the perseverating response, and the 3rd response option respectively. There were significant differences between the conditions in the response probabilities of the perseverating state indicating that for perseverators the response options (correct response, perseverating response, and the 3rd response option) differed between conditions, $\chi^2(df = 8) = 27.84, p < .001$. 

Figure 5.3  Percentage of children (with standard errors) passing the pre-switch phase of DCCS task. Black (grey) bars denote conditions without (with) size being the relevant pre-switch dimension. Numbers below bars is N for each condition.
parameters because the estimations of multiple parameters were on boundaries (zero or one). Hence, we prefer to present the two-state models, which were always more optimal than the one-state models (using BIC as model selection criterion). The two states in all conditions were a switch state (high probability of switching) and a perseveration state (high probability of perseverating). The next step was to combine the models for separate conditions in a multi-group model and test for differences between conditions in parameter estimates. As an additional constraint, we set all parameters but the initial parameters equal between the sub-conditions within a condition (e.g., the standard condition with and without size as the pre-switch relevant dimension). In total, the multi-group model consisted of eight groups. Comparisons of conditions with the standard condition were always made such that size and non-size sub-conditions were tested simultaneously. Model comparison by means of a likelihood ratio test showed that the transition probabilities were not significantly different between conditions, $\chi^2(df=8) = 8.74, p = .36$. The probability of a transition from the switch state to the perseveration state equaled .01 and the probability of a transition from the perseveration state to the switch state equaled .05. The subsequent step was to test for differences in response probabilities between conditions, representing the error rates of switching and perseverating. The response probabilities of the switch state were not significantly different between conditions, $\chi^2(df=8) = 9.32, p = .32$; these probabilities were .97, .02, and .01 for the correct response, the perseverating response, and the 3rd response option respectively. There were significant differences between the conditions in the response probabilities of the perseverating state indicating that for perseverators the response options (correct response, perseverating response, and the 3rd response option) differed between conditions, $\chi^2(df=8) = 27.84, p < .001$. Planned paired comparisons (with $\alpha = .013$ correcting for multiple comparisons) showed that the response probabilities of the perseverating state in the 3rd dimension change condition marginally differed from the standard condition, $\chi^2(df=2) = 7.96, p < .018$ (with an alfa-level of .012, see methods section). Finally, we tested for differences between the initial probabilities (i.e., the probability of being in the perseverator and switcher state at the first post-switch trial). There were significant differences between conditions in the initial parameters, denoting the proportion of switchers
and perseverators, $\chi^2(df = 8) = 27.84, p < .001$. Planned comparisons showed that only the 3rd dimension change condition and the pre-switch + post-switch change condition differed from the standard condition (3rd dimension change condition: $\chi^2(df = 2) = 13.75, p = .001$; pre-switch + post-switch change condition: $\chi^2(df = 1) = 13.85, p < .001$). Table 5.2 shows the estimated parameter values for all conditions.

**Table 5.2** Parameter values of the constrained multi-group latent Markov model for the five conditions.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Response probabilities</th>
<th>Initial probability</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>perseverance state</td>
<td>switch state</td>
<td></td>
</tr>
<tr>
<td></td>
<td>correct pers. 3rd</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standard</td>
<td>.04 .1 .05 .43</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standard - size</td>
<td>.04 .91 .05 .94</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-switch relevant change</td>
<td>.1 .94 .06 .56</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post-switch relevant change</td>
<td>.00 .9 .10 .67</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post-switch relevant change - size</td>
<td>.00 .90 .10 .91</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3rd dimension change</td>
<td>.04 .8 .16 ° .49 *</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3rd dimension change - size</td>
<td>.04 .8 .16 ° .10 *</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-switch + post-switch relevant change</td>
<td>.04 .96 .00 .83 *</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note. ° denotes a marginal difference with the control condition at the .05 level; * denotes a significant difference with the control condition at the .013 level. The response probabilities in the switch state are .97, .02, .01 for correct, perseverating and the 3rd response option respectively; the probability of a transition from the switch state to the perseveration state and the switch state is .010, and the probability of a transition from the perseveration state to the switch state is .05 in all conditions.

By assigning individuals to the model states based on posterior probabilities (see Visser, 2011 and Methods section Chapter 4) we could classify their performance as switching (only in the switch state), perseverating (only...
in the perseveration state), or being in transition (shifting between the switch state and the perseveration state or vice versa). Age differences were found in the number of children perseverating, switching and being in transition, \( \chi^2(\text{df} = 2, N = 299) = 9.87, p = .007 \). Table 5.3 (left 2 columns) shows the percentages \((N)\) of 4- and 5-year-olds with different DCCS performance over all conditions.

<table>
<thead>
<tr>
<th>Age</th>
<th>4</th>
<th>5</th>
<th>4</th>
<th>5</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Switching</td>
<td>59 (80)</td>
<td>76 (124)</td>
<td>36 (9)</td>
<td>42 (11)</td>
<td>48 (13)</td>
<td>96 (26)</td>
</tr>
<tr>
<td>Perseverating</td>
<td>29 (39)</td>
<td>15 (25)</td>
<td>48 (12)</td>
<td>35 (9)</td>
<td>7 (2)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>In transition</td>
<td>12 (16)</td>
<td>9 (15)</td>
<td>16 (4)</td>
<td>23 (6)</td>
<td>44 (12)</td>
<td>4 (1)</td>
</tr>
</tbody>
</table>

Based on this assignment, the differences between conditions were also tested in the relative speed of the first post-switch trials when novel stimulus features have only just been introduced and are expected to have their largest impact. As discussed in the introduction clear predictions about differences between conditions were only made for the children eventually switching. To this end, we calculated the difference in RT between the first four post-switch trials and the pre-switch trials for the children who eventually managed to switch. This subgroup consists of the children who switch and the children in transition. There is a main effect of condition on RTs, \( F(4, 145) = 3.37, p = .01 \). Contrast analysis shows that the pre-switch relevant change \((p = .012)\), the post-switch relevant change \((p = .003)\), and the pre-switch + post-switch relevant change condition \((p = .02)\) differ from the standard condition. See Table 5.4 for the difference in RT between the pre-switch trials and the post-switch trials in the five conditions.

Table 5.3  

DCCS performance within age groups (percentages and N).
Table 5.4  Difference in RT between pre-switch and post-switch trials.

<table>
<thead>
<tr>
<th>Condition</th>
<th>ΔRT sec (se)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard</td>
<td>1.56 (.40)</td>
</tr>
<tr>
<td>Pre-Switch relevant change</td>
<td>0.77 (.16)</td>
</tr>
<tr>
<td>Post-Switch relevant change</td>
<td>0.47 (.30)</td>
</tr>
<tr>
<td>3rd dimension change</td>
<td>1.10 (.24)</td>
</tr>
<tr>
<td>Pre-switch + post-switch relevant change</td>
<td>0.74 (.19)</td>
</tr>
</tbody>
</table>

Note. results are only for the participants who switched at the last trial. * indicates a significant difference with the standard condition.

5.4 Discussion

The present large scale DCCS experiment (N = 299) was set up to study the question how children’s DCCS performance was affected by exogenous factors, in particular stimulus novelty. We compared predictions from two hypotheses: attention is directed to the dimension with novel features (the directional hypothesis) or attention to the pre-switch relevant dimension is decreased due to any stimulus novelty (the non-directional hypothesis). To this end, we adapted the standard version of the DCCS task in two ways: First, we varied stimuli in three dimensions: color, shape and size resulting in a 3D-DCCS task. Second, we introduced stimulus novelty in several stimulus dimensions at the start of the post-switch phase.

Modeling the post-switch trial-by-trial behavior showed that 3D-DCCS post-switch behavior could best be described as switching (following the post-switch rule), perseverating (following the pre-switch rule), or shifting between these two behavioral modes during the nine post-switch trials. Sorting according to the third dimension did occur, but was not found as a systematic behavior. The addition of a third dimension made the task more difficult compared to the (classical; Zelazo et al., 1996) DCCS task with 2 dimensions as reported in Van Bers et al. (2011, Chapter 2), $\chi^2(df = 2, N = 105) = 22.14, p < .001$ (see Table 5.3, last 4 columns). Remarkably, taking size as the pre-switch relevant stimulus dimension simplified the task considerably.
Apparently, it was easier to switch selective sustained attention away from the size dimension, compared to the shape and color dimensions. Maybe, because size was only a relative value and not an absolute value where one could focus on. We are not aware of any card-switching studies that report on size as the relevant pre-switch dimension (cf. Déak, 2003).

Likewise earlier findings with a standard 2D-DCCS task, introducing novel features for only the pre-switch relevant dimension or the post-switch relevant dimension did not have a significant effect on 3D-DCCS performances. A null result could still be consistent with both the directional and the non-directional hypotheses, but parameter estimates are in the direction of the non-directional hypothesis. The introduction of stimulus novelty in the third, never relevant dimension shows some, marginal evidence for the directional hypothesis: Model-based analyses showed that perseverating children made marginally more occasional sorts to the third dimension. A second effect of stimulus novelty in the 3rd dimension shows some evidence for the non-directional hypothesis, more children were switching. However, differences between the standard condition and the 3rd dimension change condition were small.

A large difference was found between the standard condition and the pre-switch + post-switch relevant change condition, where stimulus novelty was introduced for both the shape and the color dimension: More participants were switching. Although the pre-switch + post-switch relevant change condition was easier than the standard condition, this particular finding differs from the effect found in Van Bers et al. (2014, Chapter 4). In the latter study, the effect of stimulus novelty in both the pre- and post-switch relevant dimensions was that perseverating children were making more occasional correct sorts. Nevertheless, both effects are supporting the non-directional hypothesis, which would indicate that selective sustained attention to the pre-switch relevant dimension was weakened by the introduction of stimulus novelty, without necessarily directing selective attention towards the dimension with the novel features.

Analysis of reaction times of the switchers, analogous to Diamond and Kirkham (2005), shows that responses were faster in the pre-switch relevant change condition, the post-switch relevant change condition, and the pre-
switch + post-switch relevant change condition than in the standard condition. These results, and especially from the pre-switch relevant change condition, support the non-directional hypothesis.

Results of the current study show clear evidence for the non-directional hypothesis about the effect of stimulus novelty on switching performance. In the introduction we discussed card-switching performance from the perspective that exogenous and endogenous factors affect sustained attention (Fischer et al., 2013). However, not all theoretical perspectives on card switching consider switching attention to be the limiting factor of cognitive flexibility. The competing memory systems account (Morton & Munakata, 2002; Munakata, 1998) provides an alternative explanation for most of the current results. According to this account perseverative behavior is due to weak active (short-term) memory that cannot overrule the learned habit to sort according to the first rule, stored in latent memory. Latent memory stores associations between specific stimuli and sorting locations. Consequently, changing any stimulus feature that was correlated to a specific location weakens the latent memory for the pre-switch rule (Yerys & Munakata, 2006). Hence, the competing memory systems account makes the same predictions about the introduction of stimulus novelty as the non-directional hypothesis and is consistent with the present results.

Another different aspect of DCCS performance might be difficult to explain by the competing memory systems account. In the current study (see also van Bers et al., 2011 (Chapter 2), and other chapters of this thesis) we observed a considerable number of children perseverating the first rule only for a few trials after which they finally switch. Since actually executing the rule strengthens latent memory for it in the competing memory systems account (as in most computational models; van Bers et al., 2011, Chapter 2), this observation requires additional assumptions about the dynamics of DCCS performance. One possible assumption would be that repeating the rule each post-switch trial strengthens active memory for the post-switch rule more than latent memory for the executed pre-switch rule. With this additional assumption, children could also switch after perseverating for a few trials (but see Morton & Munakata, 2002).
Conclusion

Results of the current study show clear evidence for the non-directional hypothesis about the effect of stimulus novelty on switching performance. That is, the introduction of stimulus novelty at the moment of a rule switch weakens the strength of the pre-switch rule. These results oppose the idea that stimulus novelty is mainly an exogenous stimulus factor that directs attention (Fischer et al., 2013). In contrast, stimulus novelty might disrupt attention in a non-directional way. Current results are also consistent with the competing memory systems account, which assumes that latent memory is dependent on all stimulus features that are correlated to the sorting location. According to this perspective stimulus novelty of any dimension correlated with a sorting location would weaken the effect of latent memory in favor of active memory.

Acknowledgements

We would like to thank participating children, parents, and preschools. Thanks to Saskia Visser for assisting with data collection.

Footnote

1 The original motivation for most of these studies was to assess the representation of sorting rules among preschoolers: abstract representations (same colors go together), feature-based representations (e.g., red goes with red and blue with blue) or stimulus-based representations (e.g., red truck goes with red fish and blue fish goes with blue truck). A later study (Van Bers, Visser, & Raijmakers, in press, Chapter 3) shows that all children who learn the pre-switch rule have an abstract rule representation, suggesting perseveration on dimension rather than on dimensional features. Hence, rule representations do not seem to be a valid explanation of the perseverative performance for the DCCS.