Dynamics, models, and mechanisms of the cognitive flexibility of preschoolers

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7

General discussion

The main goal of this thesis is to gain insight into the cognitive flexibility of preschoolers. In five empirical chapters we made novel contributions on three important issues in this field. First, we investigated the dynamics of development concerning this important ability. Secondly, we empirically tested key questions about the mechanisms underlying performance and development on the Dimensional Change Card Sorting (DCCS) task (Zelazo, 2006). Finally, we introduced an analysis method that is more developmentally appropriate than standard ways of analyzing DCCS task data. This general discussion starts with a summary of the main findings of the five empirical studies in this thesis, and then continues with the discussion of a number of issues that are key to furthering insights in this field. First, we discuss a methodological issue that concerns all studies in this thesis, namely exclusion of children who did not pass the pre-switch phase of the task. Next, we discuss the implications of our results for the main theoretical frameworks and computational models that have been proposed to explain preschoolers' behavior and development on the DCCS task. We then return to the conflict cusp model introduced in Chapter 2. In this model the dynamics of the developmental process on the DCCS task is formalized without specifying a mechanism of change in terms of neural or cognitive systems. We propose a substantive interpretation of the variables controlling development in this model based on the results of the empirical studies in this thesis. Finally, we discuss directions for future research.

7.1
Summary of main findings

In **Chapter 2** the dynamics of development on the DCCS task were investigated in 3- to 5-year-old children using a computerized version of the task. Model-based analysis showed that development on the DCCS task could best be described as a discontinuous change in performance for the post-switch phase of the task. In addition to a perseveration group and a switch group, a transitional group that showed transitions between perseverating and switching during the post-switch trials could be distinguished. However, additional empirical research is needed to get a more complete picture of the developmental dynamics and test specific hypotheses about the variables controlling the developmental process. Computational models of performance and development on the DCCS task proposed in literature cannot, in their current forms, explain our results. In the discussion of Chapter 2 a conflict cusp model for the transition from perseverating to switching on the post-switch phase of the DCCS task is proposed that could serve as a starting point for future studies about the dynamics of DCCS performance development. This model is further elaborated below.

The abstractness of children's rule representation in the pre-switch phase of the DCCS task is studied in **Chapter 3** by letting 3- and 4-year-old children perform a standard DCCS task and a separate generalization task. In the generalization task children were asked to generalize their sorting rules to novel stimuli in one of three conditions. In the relevant change condition the values of the relevant sorting dimension changed, in the irrelevant change condition the values of the irrelevant dimension changed, and in the total change condition the values of both dimensions changed. All children showed high performance in the relevant change condition, which implies an abstract rule representation at the level of dimensions ('same colors go together') of the pre-switch rules. Performance in the relevant change condition was significantly better (and faster) than performance in the other two conditions. Children with higher cognitive flexibility (switchers on the DCCS task) more often switched their attention to the irrelevant dimension in the generalization task when only the values of the irrelevant dimension changed. Children with lower cognitive flexibility (perseverators on the DCCS task) were more often inconsistent in their sorting on the generalization task if values of both dimensions changed. These findings support the idea that DCCS perseverators suffer from attentional inertia at the level of dimensions and that differences between switchers and perseverators at the standard DCCS task are not due to differences in the representations of sorting rules.

The studies described in Chapter 4 and 5 investigated the influence of exogenous factors on the performance of preschoolers on the DCCS task. Exogenous factors are stimulus driven, bottom-up, and not under the voluntary control of the child (Fisher et al., 2013). The exogenous factors investigated in **Chapter 4** were related to the sorting rules (changes in the values of one or more sorting dimensions), or unrelated to the sorting rules (changes in the outline shape of the stimuli or the position of the stimuli on the screen). By fitting latent Markov models we could test for differences in the consistency of switching or perseverating between the conditions, in addition to differences in the proportion of switchers and perseverators. Marginally fewer children switched sorting rules in the card shape change condition compared to the control condition. Children in the total change condition (values of both sorting dimensions color and shape changed), and perseverating children in both conditions with changes that were not related to the sorting rules made more occasional correct sorts than children in the control condition. The hypothesis of Yerys and Munakata (2006) that changes in values of a sorting dimension would draw attention towards that dimension leading to more sorting according to that dimension could not be confirmed. The conclusion from this study is that exogenous factors can distract attention from the pre-switch relevant sorting dimension, but not necessarily direct attention towards the post-switch relevant sorting dimension.

In **Chapter 5** the influence of changing the values of one or more sorting dimensions on the performance of 4- and 5-year-old children is investigated with a DCCS task with three stimulus dimensions, color, shape, and size, that varied between target- and test cards. The introduction of a third dimension made it possible to test whether children's attention was directed to the stimulus with novel values of sorting dimensions. Results agree with the idea that changes in the values of a dimension distract attention from the dimension children were focusing on, but do not direct the attention towards the dimension with changed values. The results in Chapter 5 are consistent with the competing memory systems theory, which assumes that latent memory of the pre-switch rules is dependent on all stimulus values that were correlated to the sorting location (hence also the values of the irrelevant dimension).

The study described in **Chapter 6** investigated the direct and long-term effect of feedback on 3-year-old children's switch behavior in three experiments with a computerized version of the DCCS task. The task was designed such that feedback was connected to the stimulus and causally related to the child's behavior. Whether children learned from the feedback was assessed with the administration of two subsequent standard DCCS tasks (without feedback) with different stimuli, one after five minutes and one after one week. Experiment 1 and 2 showed that children receiving feedback on their post-switch behavior performed better compared to children administered a standard DCCS task. This effect transferred to a subsequent standard DCCS task after five minutes and also after one week. Experiment 3 showed that children switched to the new post-switch rules and not to rules that oppose the pre-switch sorting rules (e.g. from 'same colors go together' to 'different colors go together'). These results highlight preschoolers' sensitivity for the design of feedback in learning an abstract rule.

7.2
Drop out

A total of 959 children participated in the studies in this thesis: 520 3-year-olds, 252 4-year-olds, and 187 5-year-olds. We tested another 210 children but their data could not be used because they did not pass the pre-switch phase (n = 152), did not complete testing (n = 39), or due to experimenter error (n = 19). In analyzing post-switch performance on the DCCS task it is common practice to use only the data of children who passed the pre-switch phase (i.e. who sorted at least five of the six pre-switch trials correctly, a criterion which is set beforehand). The reason for this practice is that it is impossible to determine if a child can switch between rules when he or she cannot consistently sort according to the first rule. In the studies presented in this thesis approximately 13% of the total number of children tested did not pass the pre-switch phase. A number of different explanations can be given for this seemingly high drop out rate compared to earlier studies with the DCCS task (e.g. Kharitonova et al., 2009: 20%; Hanania, 2010: 1.4% and 3.2%; Bohlman & Fenson, 2006: 13%). First, in the studies in this thesis no feedback was provided on children's sorting during the pre-switch phase. The sorting rules were repeated before every trial, and the test card was labeled by the relevant dimension only. When the child has sorted the test card, the experimenter responds neutrally by saying "Let's play another one". The drop out rate of studies that do not provide feedback in the pre-switch phase are comparable to ours (e.g. Diamond, Carlson & Beck, 2005; drop out rate = 42%). Secondly, in studies with more than one task (Chapter 3: DCCS task and generalization task; Chapter 6: 3 DCCS tasks) we only included children that passed the first phase of all tasks. In Chapter 3 children had to pass both the pre-switch phase of the DCCS task and the base-line phase of the generalization task. In Experiments 1 and 2 of Chapter 6 children had to pass the pre-switch phases of all three DCCS tasks administered. The percentage of children failing the first phase of the first task in these studies was comparable to the percentage of children failing the pre-switch phase in our studies with only one task, except for Experiment 2 of Chapter 6. Finally, the studies in this thesis were carried out on day-care centers, preschools and primary schools. Although we tried to test in as quiet a room as possible, this is probably not as quiet as a test situation in a university lab, which is a typical location used in many other studies.

As in almost all the other studies with the DCCS task, we only included the data of children that passed the pre-switch phase of the task in our analyses of post-switch performance. Not being able to consistently sort according to the first rule is probably caused by a problem with sustained attention, i.e. set maintenance (Diamond, 2013). This could be due to poor executive functions, but also task unrelated issues could play an important role with preschoolers. For example, there were also children who just refused to finish a task, which was rarely observed in older children. With the post-switch DCCS data we wanted to investigate the cognitive flexibility of preschoolers. Naturally, the exclusion of children that did not pass the pre-switch phase does limit the generalizability of the results of the studies to all 3-year-olds that learned to execute the pre-switch rules consistently. We do not think that excluding the children who did not pass the pre-switch phase importantly influenced the results on the post-switch phase of the task. Since we always compare performance in the experimental conditions with performance in a standard control condition of the same experiment.

7.3
Implications of our results for theoretical frameworks and computational models

The results of the studies presented in this thesis have implications for the theoretical frameworks and computational models proposed in literature to explain preschoolers' behavior and development on the DCCS task. The most commonly discussed theoretical frameworks are the Cognitive Complexity and Control theory-revised (CCC-r; Zelazo et al., 2003), the attentional inertia theory (Kirkham, Cruess, & Diamond, 2003), the activation-deficit account (Chevalier & Blaye, 2008; Müller et al., 2006), and the competing memory systems theory (Morton & Munakata, 2002; Munakata, 1998).

The *Cognitive Complexity and Control theory-Revised* (CCC-r) assumes that perseverators have difficulties in reflecting on their rule representations, that is formulating and using a higher order rule for selecting which pair of rules (color rules or shape rules) must be used on a particular trial (Zelazo et al., 2003). According to the *attentional inertia* theory inhibitory control plays a primary role in switching. Perseverators may know the new rules they should be following during the post-switch phase, but fail to inhibit attention to the pre-switch relevant information (Kirkham et al., 2003). Diamond and Kirkham (2005) interpret their results with adults on the DCCS task as attentional inertia that does not completely disappear with age. The *activation-deficit* or *negative priming* account assumes that in the post-switch phase perseverators fail to activate information that was automatically inhibited in the pre-switch phase, because it was irrelevant at that time (Chevalier & Blaye, 2008; Müller, Dick, Gela, Overton, & Zelazo, 2006). Finally, the *competing memory systems* theory supposes that flexible behavior depends on the competition between active and latent memory traces. Perseveration occurs when an active memory trace of the post-switch relevant sorting rules is not strong enough to compete against a latent memory trace of the pre-switch relevant sorting rules (Morton & Munakata, 2002; Munakata, 1998). These accounts do not necessarily contradict each other. The competing memory systems theory, for example, can be seen as a lower level mechanism for the attentional inertia account (Yerys & Munakata, 2006).

To explain the results of empirical studies, three computational models of behavior and development on the DCCS task have been proposed as well (Buss & Spencer, 2008; Morton & Munakata, 2002; Marcovitch & Zelazo, 2000). These computational models specify mechanisms underlying the development of flexible behavior. In these models, developmental change is formalized in terms of one or more parameters of the model, such as the strength of working memory relative to the strength of latent memory (Buss & Spencer, 2008; Morton & Munakata, 2002), or the impact of the length of training on performance (Marcovitch & Zelazo, 2000). Consequently, these models relate to cognitive and or neural systems in the brain that play a crucial role in the development of flexible behavior. The computational model of Marcovitch and Zelazo (2000) is an implementation of the Cognitive Complexity and Control (CCC) theory (Zelazo & Frye, 1997), and the computational model of Morton and Munakata (2002) is an implementation of the competing memory systems theory (Munakata, 1998).

The results of Chapter 2 on the dynamics of development on the DCCS task do not so much have implications for the theoretical frameworks described above, but so much the more for the computational models. The two most important characteristics of the optimal latent Markov model for discontinuous development in Chapter 2 are: first, the existence of two modes of behavior characterized by a high and a low probability of a correct response, and, second, the possible occurrence of reciprocal transitions between these two modes over the course of the post-switch trials. One way of implementing these dynamics in a computational system is by a model consisting of at least two subsystems that have a competitive interaction. All three computational models mentioned earlier incorporate two separate states: a perseveration state and a switch state, but not all of them incorporate competitive interaction. In particular, the computational model of Marcovitch and Zelazo (2000) does not provide competition between the subsystems, and is therefore not consistent with the results of Chapter 2. In contrast, the computational models of Buss and Spencer (2008) and Morton and Munakata (2002) are composed of competitive subsystems or subprocesses. However, those two models do not predict the occurrence of reciprocal transitions between the two states over the course of the post-switch trials, because the stability of the initial behavioral mode after the switch is always increased during the post-switch trials. There are at least two ways in which the computational models, which do incorporate competition can be adapted such that they do predict reciprocal transitions. First, adding noise to the internal system might be a possible solution to incorporate transitions over the course of the post-switch trials into the conflict models of Buss and Spencer (2008) and Morton and Munakata (2002). Note, however, that due to the nonlinear dynamics of these models, adding noise could importantly affect the equilibrium dynamics of the model importantly (e.g., Katada & Nishimura, 2009). Moreover, it is also unclear whether adding noise would lead to the typical asymmetry in transition probabilities that we have found consistently. A second possible adaptation of these models with the aim generating transitions could be the added assumption that the repetition of the post-switch sorting rules by the experimenter during the post-switch phase strengthens the active memory of these rules. In this way the active memory of the post-switch rules could outcompete the latent memory of the pre-switch rules during the post-switch trials. This might be testable by varying the verbal instructions of the experimenter during the post-switch phase.

The results of Chapter 3 on the abstractness of rule representations in the pre-switch phase of the DCCS task is most consistent with attentional inertia at the level of dimensions (Kirkham, Cruess, and Diamond, 2003). Perseverators may know the new rules they should be following, but the automatic rule factor driving attention towards the old dimension is too strong. The competing memory systems account (Morton & Munakata, 2002) also fits very well with the theoretical idea of competing endogenous and automatic rule factors proposed in the discussion section of Chapter 3. However, the interpretation of the competing memory systems theory that Kharitonova et al. (2009) present seems to conflict with the results of Chapter 3. We come back to this issue in the next section (paragraph 7.4). The Cognitive Complexity and Control (CCC) theory (Zelazo et al., 2003) predicts that when children perseverate, they are perseverating on specific lower order rules (e.g. if red then here; if blue then here). This prediction does not match with the results of chapter 3 as those indicate abstract representations in both perseverators and switchers.

The results of Chapter 4 and 5 on the effects of exogenous factors on preschoolers' DCCS performance are most consistent with the competing memory systems theory (Morton & Munakata, 2002; Yerys & Munakata, 2006), which assumes that latent memory of the pre-switch rules is dependent on all stimulus features that are correlated with the sorting location (this means both relevant and irrelevant stimulus features). According to this perspective then, stimulus novelty of any dimension correlated with a sorting location would weaken the strength of latent memory of the pre-switch rules, and hence operates in favor of active memory of the post-switch rules. Note that it is not necessary to assume that stimulus novelty increases the strength of active memory, only that it decreases the strength of latent memory.

The result of Chapter 6 on the influence of causally related feedback on DCCS performance is especially interesting in the light of the results of Espinet, Anderson and Zelazo (2013). Based on the Cognitive Complexity and Control theory (Zelazo et al., 2003), Espinet et al. compared two experimental conditions: one condition in which children received a training that made children reflect on their rule representations combined with corrective feedback, and a second condition in which children only received corrective feedback. The combination of corrective feedback and reflection training resulted in improved performance on a post-training DCCS task after one day, whereas corrective feedback alone or mere practice with the DCCS task alone did not. From this contrast Espinet et al. concluded that reflection training was the effective aspect of their manipulation. The corrective feedback provided in the study presented in Chapter 6 is slightly different from the corrective feedback provided in the study of Espinet et al. The unique feature of the feedback in our study might have been the causal relation between the feedback the child received and the stimulus, without intervention of the experimenter. Hence, the strong argument about reflection that Espinet et al. make based on the CCC-r theory might not completely hold.

Overall attentional inertia at the level of dimensions and the competing memory systems account (Morton & Munakata, 2002; Munakata, 1998) seem to be most consistent with the results of the five empirical studies presented in this thesis.

7.4
Competing memory systems

Based on the results of the studies in this thesis we would frame the competing memory systems account a little bit different from other discussions in literature (Kharitonova et al., 2009). Kharitonova et al. state that "a striking qualitative distinction between switchers' and perseverators' representations of rules, which affect not only the ability to update flexibly when rules change, but also the ability to generalize behavior to new stimuli" (page 6). According to our interpretation of the competing memory systems account, all children (who passed the pre-switch phase) have an active, abstract representation of the pre-switch rules based on the sorting rules the experimenter repeats before every trial in the pre-switch phase. In addition, during the pre-switch phase all children build a latent representation of the pre-switch rules, which strengthens with each trial due to repeatedly sorting test cards according to the pre-switch rules. This latent representation of the sorting rules is less abstract than the active representation of the pre-switch sorting rules (As is implicit or procedural memory; Ashby, Alfonso-Reese, Turken, & Waldron(1998)). More specifically, the representation in latent memory is related to all stimulus features that are correlated to the sorting locations (this means both relevant and irrelevant stimulus features). In the post-switch phase the active, abstract representation of the pre-switch rules is replaced by the active and abstract representation of the post-switch rules based on the verbal explanation of the experimenter of the post-switch relevant sorting rules. Moreover, the strength of the active representation of the post-switch sorting rules needs to build up in a few trials, which might be stimulated by the repetition of the post-switch relevant sorting rules by the experimenter before every trial. The latent memory of the pre-switch rules, however, is only dependent on the actual sorting behavior. Hence, perseverators increase the strength of the latent memory of the pre-switch rules and switchers decrease the strength of the latent memory of the pre-switch rules.

The difference between the results of the study in Chapter 3 and the results of Kharitonova et al. (2009) can be explained by the difference in the moment children were asked to generalize their sorting rules. In the study in Chapter 3 we asked the children directly after the pre-switch phase to generalize their sorting rules to new stimuli. Both perseverators and switchers have an active abstract representation of the pre-switch sorting rules. In the study of Kharitonova et al., on the other hand, children were asked to generalize their sorting rules to new stimuli after the post-switch phase. This resulted in a difference found between the consistency of generalization between switchers and perseverators. For perseverators sorting in the post-switch phase is based on the latent representation of the pre-switch relevant sorting rules, which is more stimulus-specific. For switchers sorting in the post-switch phase is based on the active representation of the post-switch relevant sorting rules, which is abstract. Hence, in our interpretation of the model switchers and perseverators do not construct qualitatively different representations of the pre-switch and post-switch sorting rules. The part of the mechanism that differs between perseverators and switchers is the relative strength of the latent and active rule representations of the pre-switch and post-switch sorting rules. Consequently for the two groups of children different memory systems control their sorting behavior after the rule switch.

The competing memory systems model (Morton & Munakata, 2002; Munakata, 1998) is specified in terms of a computational model, which, for example, specifies the details of the interaction between the two systems. The level of detail is not necessary in order to generate some predictions about the dynamics of the system. The next paragraph specifies the competitive interaction in terms of a conflict cusp model.

7.5
Conflict cusp model revisited

In the discussion section of Chapter 2 we introduced a conflict cusp model (Zeeman, 1976; Van der Maas & Molenaar, 1992) for the transition from perseverating to switching in the post-switch phase of the DCCS task. A conflict cusp model is an example of a formal mathematical model. Formal models could provide insight into the variables that control the developmental process without making detailed assumptions about a possible mechanism, such as in computational models. In order to test specific hypotheses about the variables that control development on the DCCS task, we return to the conflict cusp model of Chapter 2 and expand this model with an interpretation of the variables controlling the developmental process based on the results of the empirical studies presented in this thesis and the ideas about the competing memory systems account described above.

In the conflict cusp model, which is displayed in Figure 7.1, the change in the dependent variable depends on continuous variation in two independent variables. The interpretation of the dependent variable and independent variables in our cusp model is based on the competing memory systems account presented in the previous section based on the results of the studies in this thesis. The dependent variable in our conflict cusp model of DCCS development is the probability of a correct response on a post-switch trial, and it is represented by the z-axis in Figure 7.1. The first independent variable in our conflict cusp model is the strength of the latent representation of the pre-switch relevant sorting rules, and is represented by the a-axis in Figure 7.1. The second independent variable in our conflict cusp model is the strength of the active representation of the post-switch relevant sorting rules, and is represented by the b-axis in Figure 7.1. Consequently, as can be read of from figure 7.1, strong latent memory of the pre-switch rules (high values on the a-axis) combined with weak active memory of the post-switch rules (low value on b-axis) results in a low probability of correct post-switch performance, hence perseverative behavior. In contrast, weak latent memory of the pre-switch rules (low value on the a-axis), combined with strong active memory of the post-switch rules (high value on the b-axis) leads to a high probability of correct post-switch performance, hence switching. According to this model, when during the post-switch phase of the DCCS task, the strength of the latent memory of the pre-switch rules is roughly equal to the strength of the active memory of the post-switch rules, the rules are in competition with one another and the child is in transition. This means that both correct and incorrect performance is part of the behavioral repertoire, and the child can oscillate between these behaviors (Van der Maas & Molenaar, 1992). Which rules such a child actually applies depends on the history of performance (did the child apply the pre-switch rules on former trials), a bias for a particular stimulus dimension or value, and perturbations of his or her behavior.

A perturbation can be anything that influences the strength of the latent representation of the pre-switch relevant sorting rules or the strength of the active representation of the post-switch relevant sorting rules. Perturbations can cause a transition from perseverating to switching, a transition from switching to perseverating, or less inconsistent behavior. The manipulations we applied in the studies in this thesis can be seen as perturbations as well. The exogenous factors of the studies in Chapter 4 and 5 resulted in less consistent behavior. And the causally related feedback provided in the experiments of Chapter 6 is a perturbation that strengthens the active representation of the post-switch relevant sorting rules and weakens the latent representation of the (applied incorrect) pre-switch rules. Feedback learning can both affect active memory and latent, procedural memory (Ashby et al., 1998). Hence, the positive feedback strengthens active memory and the negative feedback weakens latent memory.

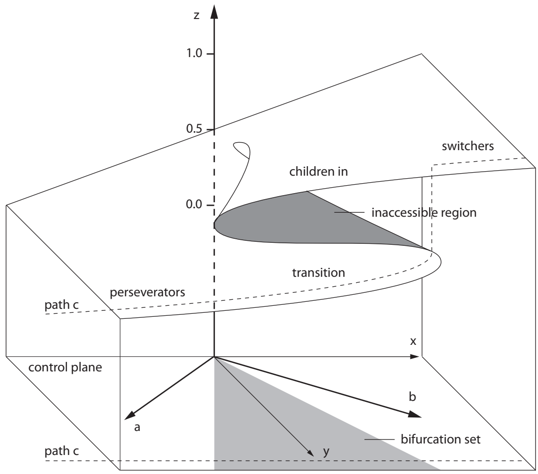

Figure 7.1 *Conflict cusp model for the transition from perseverating to switching on the post-switch phase of the DCCS task. z = dependent variable; probability of a correct response on a post-switch trial, a = independent variable 1: strength of the latent memory of the pre-switch rules, b = independent variable 2: strength of the active memory of the post-switch rules.*

The variable represented on the y-axis in Figure 7.1 is called the splitting variable. This variable is the total strength of the representations of the pre-switch and the post-switch rules. When the splitting variable is increased, the jump between perseverating and switching becomes more extreme. When the splitting variable is decreased the jump between perseverating and switching becomes smaller. This phenomenon is called divergence. Hence it is predicted that decreasing the strength of the latent memory of the pre-switch rules is more effective for letting children switch than only increasing the strength of the active memory of the post-switch rules. Based on the first conflict cusp model presented in Chapter 2, we designed a first pilot study to test this hypothesis. The aim was to decrease the splitting variable by repeating before every post-switch trial that the pre-switch rules were no longer relevant. This way we wanted to decrease the strength of the pre-switch rules. We compared this pre-switch rules condition with a post-switch rules condition in which we repeated the post-switch relevant sorting rules before every post-switch trial (which is the standard procedure in the DCCS task), with a condition in which no rules were repeated, and with a condition in which both rules were repeated. Although the percentage of children passing the post-switch phase suggested better performance in the both rules condition and worse performance in the no rules condition compared to the post-switch rules condition and the pre-switch rules condition, there was no significant difference in the percentage of switchers between the four conditions, $\chi 2(df = 3, N = 98) = 5.75$, $p = .12$. Naturally, we aim to analyze these results with latent Markov models in order to test for more detailed differences, but due to time constrains we did not do this yet. Now, with a more detailed interpretation of the cusp model we could understand why this manipulation did not work as initially expected. In this experiment the manipulation of the pre-switch sorting rules was at an active/explicit level, while the representation of the pre-switch rules according to the revised cusp model is at a latent/implicit level. In the next section we point out directions for further research, partly based on the conflict cusp model.

7.6
Directions for future research

The studies presented in this thesis all use the Dimensional Change Card Sorting (DCCS) task (Zelazo, 2006). The DCCS task is a widely used paradigm to study cognitive flexibility in preschoolers. A wide variety of experimental manipulations have been investigated in this task. But the consistency of all these results is difficult to see, because they are all driven from the different theoretical frameworks proposed to explain behavior and development on the DCCS task. It may seem that the scope of this thesis is rather limited: we only studied cognitive flexibility by DCCS performance. However, Focusing on one paradigm also has advantages. The results of the empirical studies with the DCCS task presented in this thesis are consistent and robust. Found results are replicated in different studies or in different experiments of the same study. A two state latent Markov model with reciprocal transitions between the two states is found as optimal model in Chapter 2, 3, 4, and 5. The effects of exogenous factors on preschoolers' DCCS performance found in Chapter 4 match the results of Chapter 5. And the effect of causally related feedback is replicated in the three experiments of Chapter 6. The proposed analysis method ensures that variations of manipulations can be expressed in the same consistent manner.

The results on the dynamics of development on the DCCS task presented in Chapter 2 come together with the results of the empirical studies presented in Chapter 3 through to 6 in the revised conflict cusp model. This conflict cusp model is an excellent starting point for future studies on the dynamics of DCCS performance development. Specific predictions can be derived from catastrophe flags. Catastrophe flags are typical properties of behavior that indicate, and sometimes predict the occurrence of a discontinuous transition (Gilmore, 1982; Scheffer et al., 2009; Van der Maas & Molenaar, 1992). Examples of catastrophe flags that can be studied in future research are sudden jumps, hysteresis and divergence. Sudden jumps from perseverating to switching or from switching to perseverating are the result of changes in the normal variable.

The normal variable is represented on the x-axis in Figure 7.1, and can be interpreted as the difference between the strength of the active representation of the post-switch rules and the strength of the latent representation of the pre-switch rules, a measure of conflict. Increasing the normal variable results in a sudden jump from perseverating to switching and decreasing the normal variable results in a sudden jump from switching to perseverating. The phenomenon that the jump from perseverating to switching takes place at a higher value of the normal variable than the jump from switching to perseverating, is called hysteresis. The presence of sudden jumps and hysteresis can be studied by continuously manipulating the normal variable in both directions.

As mentioned earlier, the variable represented on the y-axis in Figure 7.1 is called the splitting variable. This variable is the total strength of the representations of the pre-switch and the post-switch rules. When the splitting variable is increased, the jump between perseverating and switching becomes more extreme and hence more difficult to accomplish. When the splitting variable is decreased, the jump between perseverating and switching becomes smaller. This is called divergence. A possible way of weakening the splitting variable is reducing the number of pre-switch trials (which weakens the latent representation of the pre-switch relevant sorting rules). It is predicted that with fewer pre-switch trials fewer children will perseverate. These future studies would further our understanding of the dynamics of development on the DCCS task and test specific developmental hypotheses about the variables controlling the developmental process.

Another interesting direction for future research is application of the knowledge we have gained on the performance and development on the DCCS task to other paradigms. One possibility consists of other cognitive flexibility tasks that are related to changing perspectives, such as Luria's tapping task (Diamond & Taylor, 1996), appearance reality tasks (Flavell, Flavell, & Green, 1986), or theory of mind tasks (Premack & Woodruff, 1978; Wimmer & Perner, 1983). Performance on these tasks improves importantly between the ages of three and five years, as in the DCCS task. The question would be whether they share the same dynamical process of development.

Research in the field of executive control is very relevant, because the development of executive control in early childhood is predictive of success later in life (as indexed by e.g., academic achievement, health and income; Blair & Razza, 2007; Moffit et al., 2011). It is important to perform that research in a systematic way. This thesis introduces a conflict cusp model, which can serve as an excellent starting point for future studies on the dynamics of performance development. With the developmentally more appropriate analysis method presented in this thesis this can be done in a robust way.