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DOI
10.1016/j.jecp.2020.104809

Publication date
2020

Document Version
Final published version

Published in
Journal of Experimental Child Psychology

Journal of Experimental Child Psychology 193 (2020) 104809

Contents lists available at ScienceDirect

Journal of Experimental Child Psychology

journal homepage: www.elsevier.com/locate/jecp

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ARTICLE INFO

Article history:
Received 24 July 2019
Revised 13 January 2020
Available online 13 February 2020

Keywords:
Feedback
Cognitive flexibility
DCCS
Preschoolers
Transfer
Executive control

ABSTRACT

The current project studied the direct, near transfer, and far transfer effects of cognitive flexibility training in two experiments with 117 3-year-olds. In both Experiments 1 and 2, children performed three Dimensional Change Card Sorting (DCCS) tasks in a pre-training/training/post-training design. The training consisted of giving corrective feedback in the training DCCS task. In Experiment 2, in addition, three other executive control tasks were administered during pre-training and post-training. Results showed a direct effect of feedback in the training DCCS task and transfer of this effect to the post-training DCCS task after 1 week with different sorting rules and different stimuli. These findings show that preschoolers learned to switch sorting rules in the context of the DCCS task, independent of the specific sorting rules, and that this effect is not transient. No support was found for transfer to the other executive control tasks. A possible explanation is that the feedback mainly improved rule switching, an ability that is specifically required for performing a cognitive flexibility task but not the other executive control tasks.

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https://doi.org/10.1016/j.jecp.2020.104809
0022-0965/

Introduction

Young children are not good at controlling their behavior in a goal-directed way. For example, they find it difficult to wait for a larger reward if there is a small reward right in front of them. Adults sometimes find this difficult too. How often do you let yourself be tempted on your way home to buy a quick snack while you intended to eat healthier? What is needed in situations like this is executive control. Executive control allows the mind to override impulses and helps in making decisions based on goals rather than habits (Diamond, 2006, 2013; Garon, Bryson, & Smith, 2008).

Executive control is an umbrella term for a set of neurocognitive processes that include inhibitory control, working memory, and cognitive flexibility. These components are distinct but strongly correlated during adulthood (Friedman & Miyake, 2004; Miyake et al., 2000), adolescence (Friedman et al., 2007, 2008), and middle childhood (Huizinga, Dolan, & van der Molen, 2006; Lehto, Juujärvi, Kooistra, & Pulkkinen, 2003). During early childhood, however, the components are often described by a unitary, more domain-general process (Hughes, Ensor, Wilson, & Graham, 2010; Wiebe, Espy, & Charak, 2008; Wiebe et al., 2011).

Children's executive control develops markedly during the early childhood years (e.g., Carlson, 2005; Garon et al., 2008) and mirrors the development of the prefrontal cortex (e.g., Moriguchi & Hiraki, 2013). Working memory and inhibitory control, which are considered the core components of executive control, develop rapidly during the preschool years (Garon et al., 2008). Cognitive flexibility is generally conceptualized as a complex, later-developing component of executive control that is somehow built on, and acts on, the core components working memory and inhibitory control (Chevalier et al., 2012).

The establishment of strong executive control during early childhood is associated with success later in life (as indexed by, e.g., academic achievement, health, and income; Blair & Razza, 2007; Moffit et al., 2011; Titz & Karbach, 2014). On the other hand, weak executive control during early childhood is predictive of negative outcomes in health, wealth, and well-being later in life (Daly, Delaney, Egan, & Baumeister, 2015; Moffit et al., 2011). Interventions intended to improve executive control at this young age, therefore, serve an important goal. Quite a few studies on training the executive control of children have been carried out (for reviews, see Diamond, 2012; Karbach & Unger, 2014). These interventions range from school and curriculum-based programs (e.g., Raver et al., 2008, 2011) to physical and cognitive training approaches (e.g., Bergman Nutley et al., 2011; Lakes & Hoyt, 2004).

Most previous studies on training executive control in young children looked at the effect of training working memory (e.g., Blakey & Carroll, 2015; Karbach, Strobach, & Schubert, 2014; Thorell, Lindqvist, Bergman Nutley, Bohlin, & Klingberg, 2009; for reviews, see Kassai, Futo, Demetrovics, & Takacs, 2019; Sala & Gobet, 2017). These studies have shown that working memory training improved children's performance on trained and nontrained measures of working memory. Far transfer of the effect of working memory training to tasks measuring inhibitory control or cognitive flexibility was not found (Blakey & Carroll, 2015; Karbach et al., 2014; Kassai et al., 2019; Sala & Gobet, 2017; Thorell et al., 2009). Inhibitory control is often targeted in a combined training for multiple executive control components (e.g., Blakey & Carroll, 2015; Kassai et al., 2019; Thorell et al., 2009; Traverso, Viterbori, & Usai, 2015). Results of inhibitory control training programs are less successful than those of working memory training programs; improved performance on trained tasks has been shown, but no transfer to untrained tasks or tasks measuring working memory or cognitive flexibility has been shown (Blakey & Carroll, 2015; Kassai et al., 2019; Thorell et al., 2009; Traverso et al., 2015). It seems that working memory is more amenable to training than inhibitory control.

A number of studies looked at the effect of training the cognitive flexibility of preschool- or school-aged children and transfer of this effect to untrained tasks (for a review, see Buttelmann & Karbach, 2017). All studies with preschoolers used the Dimensional Change Card Sorting (DCCS) task (Zelazo, 2006). In the DCCS task, children are shown two stacks marked by target cards that vary along two dimensions (e.g., color and shape), and they are asked to sort two bivalent test cards repeatedly, first according to one dimension (e.g., color) and then according to the other dimension (e.g., shape). Each test card matches one target card on one dimension and matches the other target card on the other dimension. Although 3-year-olds have no problem in sorting test cards according to shape or color in the first phase of the task (the pre-switch phase), they do have problems in the post-switch phase of the task when they need to switch sorting dimensions. Typically, most 3-year-olds perseverate in the post-switch phase by sorting the test cards according to the dimension that was relevant in the pre-switch phase, whereas most 5-year-olds switch immediately to the new dimension when asked to do so (Doebel & Zelazo, 2015; Kirkham, Cruess, & Diamond, 2003; Morton & Munakata, 2002; Perner & Lang, 2002).

Previous training studies showed evidence of the trainability of cognitive flexibility during early and middle childhood (for a review, see Buttelmann & Karbach, 2017). All studies looking at the effect of training on the cognitive flexibility of preschoolers found a direct effect of their training procedure (Bohlman & Fenson, 2005; Espinet, Anderson, & Zelazo, 2013; Kloo & Perner, 2003; Moriguchi, Sakata, Ishibashi, & Ishikawa, 2015; van Bers, Visser, & Raijmakers, 2014). Regardless of whether the training consisted of providing feedback on children's sorting in the post-switch phase (Bohlman & Fenson, 2005; van Bers et al., 2014), emphasizing the need to redescribe the cards in terms of the new dimension (Kloo & Perner, 2003), having children reflect on the hierarchical structure of the sorting rules (Espinet et al., 2013), or having children explain the sorting rules to a puppet (Moriguchi et al., 2015), children's performance on the DCCS task at hand significantly improved.

In addition to the direct effect of cognitive flexibility training on performance on the task at hand, previous studies also looked at transfer of this effect to other tasks (Espinet et al., 2013; Kloo & Perner, 2003; van Bers et al., 2014). van Bers et al. (2014) found transfer of the effect of feedback in the post-switch phase of the DCCS task to a subsequent standard DCCS task with different stimuli (but the same sorting rules) after 5 min and after 1 week. They concluded that preschoolers learned to switch sorting rules and that the effects of feedback were not transient. However, the sorting rules of the subsequent standard DCCS task that van Bers and colleagues administered were the same as those of the training DCCS task (color and shape). Thus, children learned to switch between two specific sorting rules. Only improved performance on a subsequent standard DCCS task with different sorting rules would show that children learned to switch between any two sorting rules. Espinet et al. (2013) found transfer of the effects of a combination of feedback and reflection training to a subsequent standard DCCS task with different stimuli (but the same sorting rules) after 1 day. The improvements on the DCCS task were accompanied by changes in neural responses to conflict (a significant reduction in N2 amplitude of the event-related potential). Espinet et al. concluded that conflict monitoring and reflective reprocessing of information are key processes in the development of flexible rule use. Kloo and Perner (2003) studied transfer of the effects of a combination of feedback and explanations emphasizing the need to redescribe the stimuli in terms of the opposite dimension to a false belief task. Their study was based on earlier found correlations between executive control and theory of mind (for a review, see Perner & Lang, 1999). Their results showed mutual transfer of training; DCCS training improved performance on the false belief task, and false belief training improved performance on the DCCS task. According to Kloo and Perner (2003), these results reinforced the correlational evidence for a developmental link between cognitive flexibility and theory of mind. They suggested that the problem for children in both tasks lies in redescribing stimulus objects or situations. To conclude, previous research showed ample evidence of the direct effect of cognitive flexibility training in preschoolers and some evidence for near and far transfer of this effect to other tasks.

In the current project, we took the next steps in the study of cognitive flexibility training in preschoolers. Previous research looked only at the direct effect of training, transfer to a DCCS task with different stimuli, and far transfer to a false belief task. In the current project, we investigated the intermediate transfer steps. These were near transfer to a DCCS task with different sorting rules and different stimuli, far transfer to another cognitive flexibility task, and far transfer to an inhibitory control task and a working memory task, the other two components of executive control. In this study, we trained cognitive flexibility by providing feedback on children's sorting in the post-switch phase of the DCCS task, as Bohlman and Fenson (2005) and van Bers et al. (2014) did. Kloo and Perner (2003) and Espinet et al. (2013) used feedback in combination with another form of training, making it difficult to determine what exactly caused the effects found in these studies. The clear results of van Bers et al. (2014), and the fact that it is not clear what exactly caused the effects in the combined training sessions of Kloo and Perner (2003) and Espinet et al. (2013), led to our decision to use only feedback as our training method. We deliberately chose this pure form of feedback so that it would be clear what caused possible effects. An additional advantage of feedback training for young children was its short duration. Finally, we focused specifically on preschool-aged children. Considering the neural and behavioral plasticity of preschoolers, it was assumed that interventions at this age would be the most useful (Wass, 2015; Wass, Scerif, & Johnson, 2012). In addition, transfer from training is greater in younger children than in older children (Melby-Lervåg & Hulme, 2013).

In Experiment 1, we looked at the direct effect of feedback on the DCCS task at hand and near transfer of this effect to a subsequent standard DCCS task with different sorting rules and different stimuli. Children performed three DCCS tasks: a pre-training task, a training task, and a delayed post-training task. In the pre-training and delayed post-training task, children sorted according to shape in the pre-switch phase and sorted according to size in the post-switch phase. In the training task, children sorted according to color in the pre-switch phase and sorted according to number in the post-switch phase. Children in the *feedback* condition received feedback on their sorting in the post-switch phase of the training task only. Children in the *no-feedback* condition did not receive feedback in any of the tasks. We expected better performance on the training DCCS task and the delayed post-training DCCS task for children in the feedback condition compared with children in the no-feedback condition.

In Experiment 2, our first aim was to replicate the results of Experiment 1 by looking at the direct effect of feedback on the DCCS task at hand and near transfer of this effect to a subsequent standard DCCS task with different sorting rules and different stimuli. As in Experiment 1, children performed three DCCS tasks. The materials and procedure for the DCCS tasks were exactly the same as those in Experiment 1. We expected better performance in the training DCCS task and the delayed post-training DCCS task for children in the feedback condition compared with children in the no-feedback condition.

Our second aim of Experiment 2 was to look at far transfer of the effect of feedback on the DCCS task to another cognitive flexibility task, a working memory task, and an inhibitory control task. For a subgroup of children, during pre-training and delayed post-training, the administration of the DCCS task was followed by the administration of another cognitive flexibility task, an inhibitory control task, and a working memory task. Children in the feedback condition received feedback on their sorting in the post-switch phase of the training DCCS task only. Children in the no-feedback condition did not receive feedback in any of the tasks. Given the results of previous studies looking at the effect of training working memory (Blakey & Carroll, 2015; Karbach et al., 2014; Kassai et al., 2019; Sala & Gobet, 2017; Thorell et al., 2009), which found near transfer (i.e., improved performance on trained and non-trained measures of working memory), one would expect greater progress on the nontrained cognitive flexibility task from pre-training to delayed post-training in the feedback condition compared with the no-feedback condition. However, given the results of previous studies looking at the effect of training inhibitory control (Blakey & Carroll, 2015; Kassai et al., 2019; Thorell et al., 2009; Traverso et al., 2015), which did not find near transfer (i.e., improved performance on nontrained measures of inhibitory control), one would not expect greater progress on the nontrained cognitive flexibility task from pre-training to delayed post-training in the feedback condition compared with the no-feedback condition. Given these contrasting findings in the domains of working memory and inhibitory control, we investigated the transfer effects to a nontrained cognitive flexibility task in an explorative manner. In addition, both studies that looked at the effects of training working memory and studies that looked at the effects of training inhibitory control did not find far transfer to tasks measuring another component of executive control (Blakey & Carroll, 2015; Karbach et al., 2014; Kassai et al., 2019; Sala & Gobet, 2017; Thorell et al., 2009; Traverso et al., 2015). Given these results, we did not expect greater progress on the inhibitory control task and the working memory task from pre-training to delayed post-training in the feedback condition compared with the no-feedback condition. This may be seen as contrasting with the conceptualization of cognitive flexibility as a complex, later-developing component of executive control that is somehow built on, and acts on, the two core components working memory and inhibitory control (Chevalier et al., 2012).

Experiment 1

Method

Participants

A total of 51 3-year-olds participated in this experiment (M_{age} = 41.5 months, SD = 4.0; 28 girls). We tested another 5 children, but their data could not be used because they did not complete testing (n = 4) or did not pass the pre-switch phase (n = 1). Children needed to sort at least five of the six trials correctly to pass the pre-switch phase. In both experiments, children were recruited from day-care centers and preschools in The Netherlands. Informed consent was obtained from the parents of all children who participated, and ethical approval was obtained from the university's psychology ethics committee.

Design

Children were randomly assigned to one of two conditions: the *feedback* condition (n = 26, M_{age} = 40.7 months, SD = 3.8; 15 girls) or the *no-feedback* condition (n = 25, M_{age} = 42.3 months, SD = 4.1; 13 girls). The mean age and ratio of boys and girls did not differ significantly between the two conditions. In both conditions, children performed three DCCS tasks: a pre-training task, a training task, and a delayed post-training task. Each task consisted of six pre-switch trials and six post-switch trials. Children in the feedback condition received feedback on their sorting in the post-switch phase of the training task only. During the other two tasks, no feedback was provided. Children in the no-feedback condition did not receive feedback in any of the tasks. In the pre-training and delayed post-training tasks, children in both conditions sorted according to shape in the pre-switch phase and sorted according to size in the post-switch phase. In the training task, all children sorted according to color in the pre-switch phase and sorted according to number in the post-switch phase. We did not counterbalance the order of the sorting rules because we did find a difference in switching performance when using size as the pre-switch sorting dimension compared with color or shape as the pre-switch sorting dimension in an earlier study (van Bers et al., 2020). Children switched easier to the post-switch sorting dimension when they sorted according to size in the pre-switch phase. There was no difference in switching performance when using size as the post-switch sorting dimension.

Materials

The experiment was conducted using a laptop computer with a touch-screen monitor. Stimuli were presented against a dark gray background. Two light gray sorting stacks were present in the bottom left and bottom right corners of the screen. The target cards were depicted above them. A light gray card stack with closed test cards was present at the bottom center of the screen in between the two sorting stacks. A test card was turned around when the experimenter touched the stack of closed test cards. Children sorted the test card by touching the appropriate target card or sorting stack. The test card then moved to the chosen sorting stack and turned around. See Fig. 1 for an example of the computer screen.

Two different sets of target and test cards were used in the pre-training and delayed post-training tasks (where children sorted according to shape in the pre-switch phase and sorted according to size in the post-switch phase). Set A consisted of target cards depicting a big frog or a small snail and test cards depicting a small frog or a big snail. Set B consisted of target cards depicting a big rabbit or a small chicken and test cards depicting a small rabbit or a big chicken. Half of the children in each condition sorted with Set A in the pre-training task and sorted with Set B in the delayed post-training task, and the other half sorted with Set B in the pre-training task and sorted with Set A in the delayed post-training task. Two different sets of target and test cards were also used in the training task (where children sorted according to color in the pre-switch phase and sorted according to number in the post-switch phase). Set C consisted of target cards depicting one red dot or two blue dots and test cards depicting two red dots or one blue dot. Set D consisted of target cards depicting one green dot or two yellow dots and test cards depicting two yellow dots or one green dot. Half of the children in each condition sorted with Set C in the training task, and the other half sorted with Set D. The card sets in

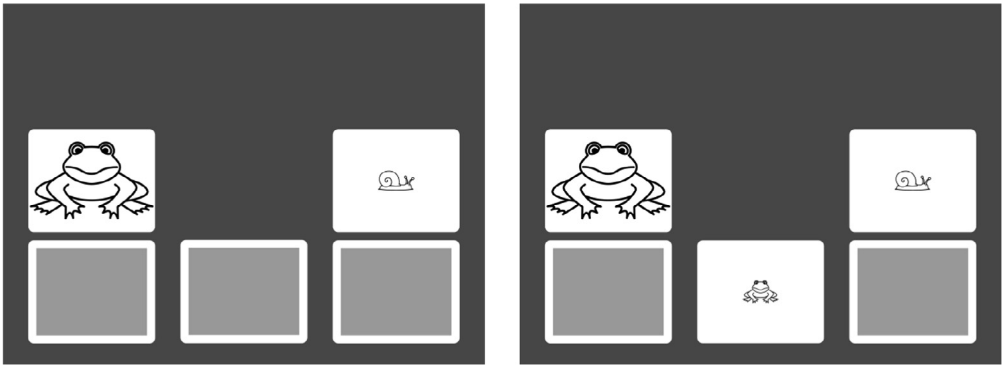

Fig. 1. Example of the computer screen in the DCCS tasks in Experiments 1 and 2. Left: A closed stack of test cards. Right: A flipped test card.

the training task were counterbalanced with the card sets in the pre-training and delayed post-training tasks in such a way that all four possible combinations of card sets were equally common. See Fig. 2 for the four different card sets used in the three DCCS tasks of Experiment 1.

Procedure

Children were tested individually in a quiet room in their day-care center or preschool. Once each child was comfortable with the experimenter, the touch-screen was introduced and the experimenter verified the child's knowledge of the shapes that were relevant in the pre-switch phase of the pre-training task. The experimenter explained the sorting rules of the pre-switch phase and demonstrated the correct way of sorting the two different test cards. The child was then asked to sort six test cards himself or herself. The two different test cards were presented in pseudorandom 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 frog"). The child was not given feedback on his or her sorting. At the start of the post-switch phase, the experimenter verified the child's knowledge of the sizes that were relevant in the post-switch phase of the pre-training DCCS task. The experimenter explained the sorting rules of the post-switch phase but did not demonstrate the correct way of sorting the two test cards. The child was then asked to sort six test cards himself or herself. As in the pre-switch phase, the two different test cards were presented in pseudorandom order, and the experimenter repeated the relevant sorting rules before every trial and labeled the test cards with the relevant dimension only (e.g., "This is a big one"). The administration of the delayed post-training DCCS task was exactly the same as the administration of the pre-training DCCS task.

The administration of the training DCCS task differed on two points from the administration of the other two DCCS tasks. First, children sorted according to color in the pre-switch phase and sorted according to number in the post-switch phase. Second, children in the feedback condition received feedback on their sorting of the post-switch trials in the training task. If the test card was sorted correctly, the experimenter gave enthusiastic verbal feedback (e.g., "Yes, well done. That is where the twos go in the number game"). If the test card was sorted incorrectly, the experimenter gave negative verbal feedback and demonstrated the correct way of sorting the test card (e.g., "No, that is not correct. In the number game, the twos go here"). The experimenter then touched the correct sorting stack, and the test card turned open, moved to the correct sorting stack, and turned around again. Children in the no-feedback condition were not given feedback on their sorting in the training task. The pre-training- and training tasks were administered on the same day with a 5-min break between them. The delayed post-training task was administered 1 week after the administration of the first two tasks.

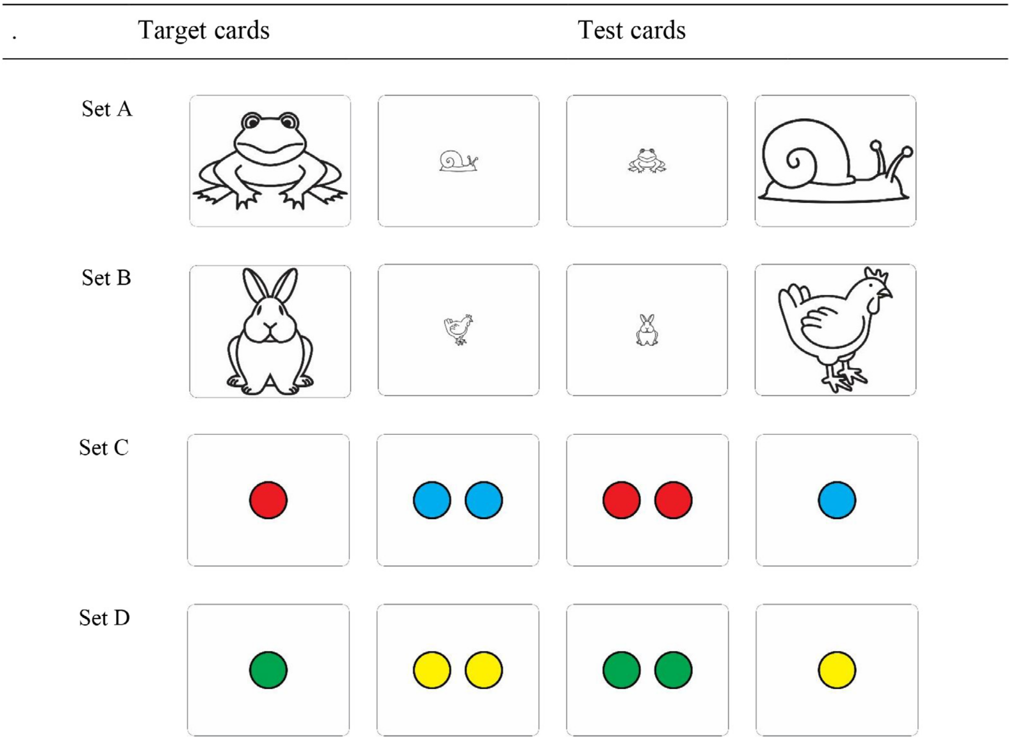

Fig. 2. Different card sets used in the three DCCS tasks of Experiments 1 and 2.

Results

In the post-switch phase of the three DCCS tasks, most children responded correctly on either zero trials or one trial (pre-training: 63%; training: 31%; post-training: 47%) or five or six trials (pre-training: 16%; training: 49%; post-training: 43%) of the six post-switch trials. Therefore, nonparametric tests were used to analyze the data. Children who sorted at least five of the six test cards correctly were considered to have passed the post-switch phase. No significant effects were found for the combination of card sets on performance in the post-switch phase of the three tasks. Therefore, all results were collapsed across this variable.

The percentages of children passing the post-switch phase of the pre-training, training, and delayed post-training DCCS tasks in the two conditions of Experiment 1 are shown in Fig. 3. As expected, performance of the children in the feedback condition and performance of the children in the no-feedback condition did not differ significantly in the post-switch phase of the pre-training DCCS task. This means that no preexisting differences between the two conditions in DCCS performance were present before the children in the feedback condition received feedback. According to expectations, more children passed the post-switch phase in the feedback condition compared to the no-feedback condition in the training DCCS task, $\chi^2(df = 1, N = 51) = 5.68$, $p < .05$, and in the delayed post-training DCCS task, $\chi^2(df = 1, N = 51) = 4.58$, $p < .05$. In addition, an exact McNemar test showed a significant difference in the proportions of switchers between the pre-training and delayed post-training DCCS tasks in the feedback condition ($p = .006$). There was no difference in the proportions of switchers between the pre-training and delayed post-training DCCS tasks in the no-feedback condition.

The 10 children who sorted all cards correctly in the post-switch phase of the training task did not receive any corrective feedback, so they were treated equally in the feedback and no-feedback conditions. If we excluded these children from the analyses, the results did not change. Again, more children

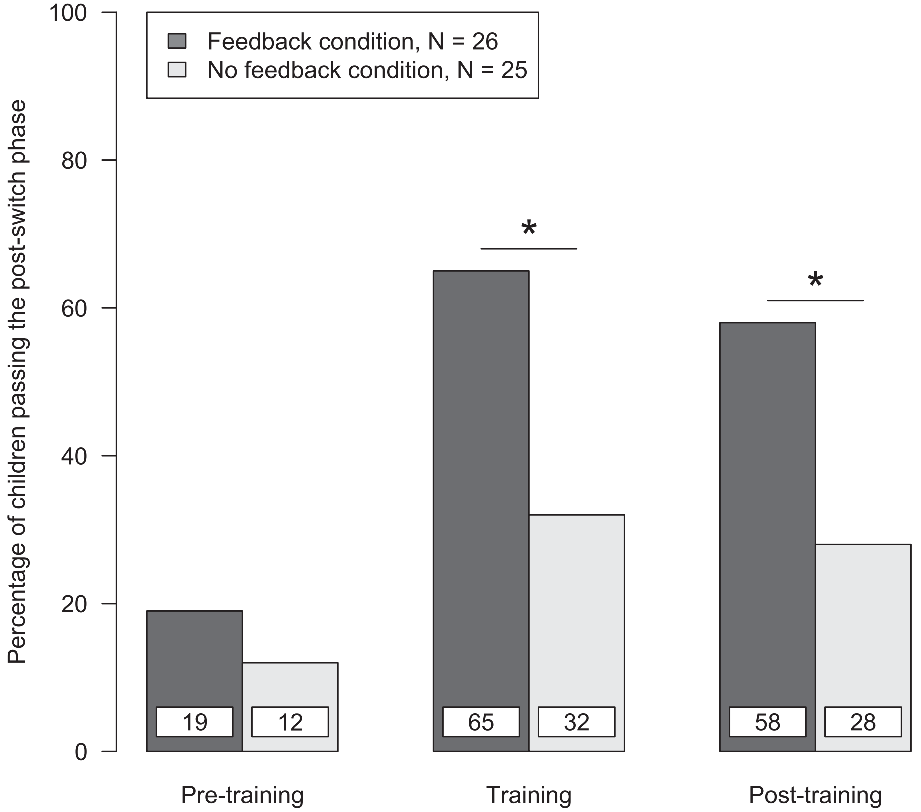

Fig. 3. Percentages of children passing the post-switch phase of the three DCCS tasks in the feedback and no-feedback conditions in Experiment 1. $^{*}p < .05$.

in the feedback condition compared with the no-feedback condition passed the post-switch phase of the training DCCS task, $\chi^2(df = 1, N = 41) = 5.71$, $p < .05$, and the delayed post-training DCCS task, $\chi^2(df = 1, N = 41) = 7.55$, $p < .01$. And again, an exact McNemar test showed a significant difference in the proportions of switchers between the pre-training and delayed post-training DCCS tasks in the feedback condition ($p = .004$) and not in the no-feedback condition.

Experiment 2

In Experiment 2, our first aim was to replicate the results of Experiment 1 by looking at the direct effect of feedback on the DCCS task at hand and near transfer of this effect to a subsequent standard DCCS task with different sorting rules and different stimuli. In addition, we looked at far transfer of the effect of feedback in the DCCS task to a different cognitive flexibility task, an inhibitory control task, and a working memory task.

Method

Participants

A total of 62 3-year-olds participated in the three DCCS tasks of this experiment ($M_{age} = 41.7$ months, $SD = 3.4$; 34 girls). We tested another 14 children, but their data could not be used because they did not complete testing (n = 8) or did not pass the pre-switch phase of the pre-training DCCS task (n = 6). As in Experiment 1, children needed to sort at least five of the six trials correctly to pass the pre-switch phase. A subgroup of 32 children performed three other executive control tasks in addition to the three DCCS tasks (M_{age} = 41.1 months, SD = 3.1; 17 girls). With the remaining 30 children, we piloted the other executive control tasks and adjusted them when needed based on the first results.

Design

Children were randomly assigned to one of two conditions: the *feedback* condition (n = 35, M_{age} = 42.2 months, SD = 3.3; 18 girls) or the *no-feedback* condition (n = 27, M_{age} = 41.2 months, SD = 3.5; 16 girls). The mean age and ratio of boys and girls did not differ significantly between the two conditions. Of the subgroup of 32 children, 18 were in the feedback condition (M_{age} = 40.5 months, SD = 3.0; 9 girls) and 14 were in the no-feedback condition (M_{age} = 41.5 months, SD = 3.2; 8 girls). The mean age and ratio of boys and girls did not differ significantly between the two conditions in this subgroup.

Materials and procedure

Children were tested individually in a quiet room in their day-care center or preschool. As in Experiment 1, children in both conditions performed three DCCS tasks: a pre-training task, a training task, and a delayed post-training task. The DCCS tasks used in Experiment 2 were the same as in Experiment 1 (see Fig. 1), including the target and test cards (see Fig. 2). The procedure for the administration of the three DCCS tasks in Experiment 2 was also the same as in Experiment 1. For a subgroup of 32 children in Experiment 2, the administration of the pre-training and delayed post-training DCCS tasks was followed by the administration of three other executive control tasks: another cognitive flexibility task, an inhibition task, and a working memory task. The choice of the specific tasks was based on earlier research into the executive control of preschoolers (Carlson, 2005; Hughes & Ensor, 2005, 2007; Smidts, Jacobs, & Anderson, 2004).

Cognitive flexibility: Object Classification Task for Children. The Object Classification Task for Children (OCTC; Smidts et al., 2004) is a measure of concept generation and mental flexibility. In this task, children were asked to divide four toys into two groups. Children received two practice trials. The toys in the practice trials were two sets of two identical bath toys. One set needed to be placed on one side of the table, and the other set needed to be placed on the other side of the table. The toys in the test trials were padded geometrical figures made of felt (see Fig. 4). During pre-training, children needed to categorize a red triangle, a blue circle, a blue triangle, and a red circle. During delayed post-training, children needed to categorize a yellow square, a green cross, a green square, and a yellow cross. These toys could be categorized according to shape or color. The task included three performance levels, providing increasing levels of structure for children. On the first level, the *free generation* level, children were not told the groupings; they needed to generate them themselves. Children were given 3 points when they sorted the toys in two groups correctly (by either shape or color) and were given 1 extra point when they could label the groups. After this, the test leader put the toys back on one heap and asked children to divide them into two different groups. Again, children could earn 3 points for any correct way of sorting (by either shape or color) and could earn 1 extra point for labeling. If children could not sort the toys correctly in one or both ways, they moved to a more structured level, the *identification* level. On this level, the experimenter sorted the toys into two groups and asked children to label the groups. Children could earn 2 points for each correct label (either shape or color). When children could not label one or both ways of sorting by the experimenter, they moved to the most structured level, the *explicit instruction* level. On this level, children were asked to sort the toys according to shape or color. Children could earn 1 point for a correct sort at this level. The total score for this task ranged from 0 to 8 points. The administration of this task took approximately 10 min.

Inhibition: Day/Night Stroop task. The Day/Night Stroop task (Gerstadt, Hong, & Diamond, 1994) is a measure of inhibitory control. In this task, children were presented a white card with a yellow sun and a black card with a yellow moon and stars repeatedly (see Fig. 5). The same cards were used during pre-training and delayed post-training. Children were asked to say “moon” to the white card with

Fig. 4. Toys children were asked to categorize in the pre-training (top) and delayed post-training (bottom) OCTC in Experiment 2.

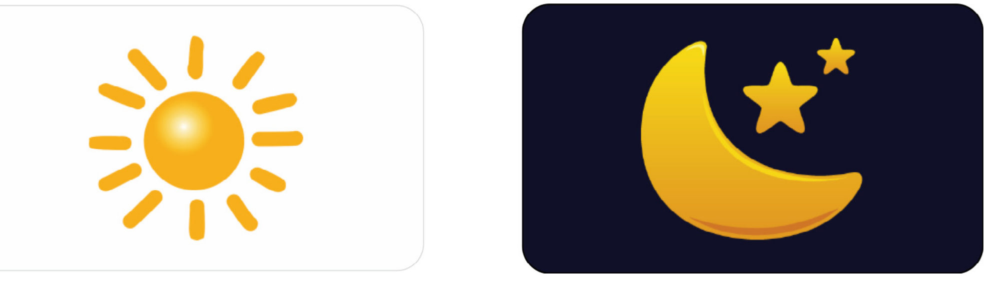

Fig. 5. Cards used in the Day/Night Stroop task in Experiment 2.

the sun and to say "sun" to the black card with the moon. Up to six practice trials were administered (three white cards and three black cards). Children received verbal feedback during these practice trials. Children needed to label one white card and one black card correctly in order to continue to the test phase. Children received 2 points when passing the practice phase. The 14 test trials were administered without feedback. The white and black cards were presented in the same pseudorandom order to all children. The score of this task ranged from 0 to 16 points (1 point for each correctly labeled card). The administration of this task took approximately 5 min.

Working memory: Spin the Pots task. The Spin the Pots task (Hughes & Ensor, 2005, 2007) is a measure of both maintenance and updating functions of spatial working memory. In this task, children were presented eight visually distinct opaque pots (e.g., candy tins, jewelry boxes with different colors, shapes, and textures) on a rotatable disc (see Fig. 6). The same pots were used during pre-training and delayed post-training. At the start of the task, children put a sticker in six of the eight pots. At the start of each trial, the pots were covered with a cloth and the disc was rotated to ensure that children did not know where the stickers were based on their location. After the cloth was removed, children were asked to indicate one pot in which they thought there was a sticker. If there was indeed a sticker in that pot, it was taken out. Then the next trial started. The pots were covered again, the disc was rotated, the cloth was removed, and children were asked again to indicate in which pot they

Fig. 6. Pots used in the Spin the Pots task in Experiment 2.

thought there was a sticker. Therefore, children needed to remember in which six pots they put a sticker at the start of the task and from which pots they already had taken a sticker in previous trials. The task ended when children found all six stickers. There was a maximum number of 16 trials, and the score was 16 minus the number of mistakes made. The administration of this task took approximately 5 min.

The three other executive control tasks were presented in the same order to all children—first the inhibitory control task, then the cognitive flexibility task, and finally the working memory task—because we did not want to administer the two cognitive flexibility tasks (DCCS and OCTC) immediately after each other. As in Experiment 1, the pre-training and training tasks were administered on the same day with a 5-min break between them. So, the last task administered on the first day of testing was the training DCCS. The administration of this task took approximately 10 min, bringing the total time of testing on Day 1 to approximately 40 min. The complete procedure of pre-training was repeated during post-training 1 week later. The total time of testing on Day 2 was approximately 30 min because the training DCCS task was not administered on this day. Finally, children were thanked for their participation and brought back to their group.

Results

DCCS task

In the post-switch phase of the three DCCS tasks, most children responded correctly on either zero trials or one trial (pre-training: 82%; training: 32%; delayed post-training: 47%) or five or six trials (pre-training: 8%; training: 37%; delayed post-training: 37%) of the six post-switch trials. Therefore, nonparametric tests were used to analyze the data. Children who sorted at least five of the six test cards correctly were considered to have passed the post-switch phase. No significant effects were found for the combination of card sets on performance in the post-switch phase of the three tasks. Therefore, all results were collapsed across this variable.

The percentages of children passing the post-switch phase of the pre-training, training, and delayed post-training DCCS tasks in the two conditions of Experiment 2 are shown in Fig. 7. As expected, performance of the children in the feedback condition and performance of the children in the no-feedback condition did not differ significantly in the post-switch phase of the pre-training DCCS task. This means that no preexisting differences between the two conditions in DCCS performance were present before the children in the feedback condition received feedback. According to expectations, and replicating the results of Experiment 1, more children passed the post-switch phase in the feedback condition compared with the no-feedback condition in the training DCCS task, $\chi^2(df = 1, N = 62) = 10.18$, $p = .001$, and in the delayed post-training DCCS task, $\chi^2(df = 1, N = 62) = 7.07$, $p < .01$. In addition, an exact McNemar test showed a significant difference in the proportions of switchers between the pre-training and delayed post-training DCCS tasks in the feedback condition ($p < .001$). There was no difference in the proportions of switchers between the pre-training and delayed post-training DCCS tasks in the no-feedback condition.

If we excluded the 14 children who sorted all post-switch cards correctly in the training DCCS task, and so did not receive any corrective feedback, the results did not change. Again, more children in the feedback condition compared to the no-feedback condition passed the post-switch phase of the training DCCS task, $\chi^2(df = 1, N = 48) = 3.96$, $p < .05$, and the delayed post-training DCCS task, $\chi^2(df = 1, N = 48) = 7.44$, $p < .01$. And again, an exact McNemar test showed a significant difference in the proportions of switchers between the pre-training and delayed post-training DCCS tasks in the feedback condition ($p = .001$) and not in the no-feedback condition.

Transfer tasks

Mean scores on the pre-training and delayed post-training OCTC, Day/night Stroop task, and Spin the Pots task in both conditions are shown in Table 1. Correlations among the pre-training DCCS task, OCTC, Day/Night Stroop task, and Spin the Pots task and correlations among the delayed post-training DCCS task, OCTC, Day/Night Stroop task, and Spin the Pots task are shown in Table 2. First, we checked for baseline differences between the two conditions. As expected, performance on the OCTC, Day/Night Stroop task, and Spin the Pots task of children in the feedback condition and children in the no-feedback condition did not differ significantly during pre-training. This means that no preexisting differences between the two conditions were present before the children in the feedback condition received feedback in the training DCCS task.

Three executive control tasks separately. To test whether the effect of feedback in the training DCCS task transferred to the delayed post-training OCTC, Day/Night Stroop task, and Spin the Pots task, general linear models were performed with time as a within-participants factor (pre-training vs. delayed post-

Table 1
Mean scores on the pre-training and delayed post-training OCTC, Day/Night Stroop task, and Spin the Pots task in the feedback condition and no-feedback condition in Experiment 2.

	Feedback condition (n = 18)		No-feedback condition (n = 14)	
Task	Pre-training	Post-training	Pre-training	Post-training
OCTC	5.56 (1.76)	6.72 (1.41)	5.14 (1.56)	5.79 (1.53)
Day/Night Stroop	8.56 (5.22)	9.50 (5.38)	7.86 (6.11)	9.71 (5.92)
Spin the Pots	14.72 (1.49)	15.17 (0.92)	14.00 (2.25)	14.36 (2.17)

Note. Standard deviations are in parentheses.

Table 2
Correlations among the DCCS task, OCTC, Day/Night Stroop task, and Spin the Pots task in Experiment 2.

	1	2	3	4
1. DCCS		.43*	.21	.37*
2. OCTC	.25		.52**	.38*
3. Day/Night Stroop	.22	.51**		.58**
4. Spin the Pots	.33	.53**	.68**	

Note. $N = 32$. To the right above the diagonal are the correlations during pre-training, and to the left below the diagonal are the correlations during delayed post-training. For the DCCS task, we used the number of correct post-switch trials.

* $p < .05$.

** $p < .01$.

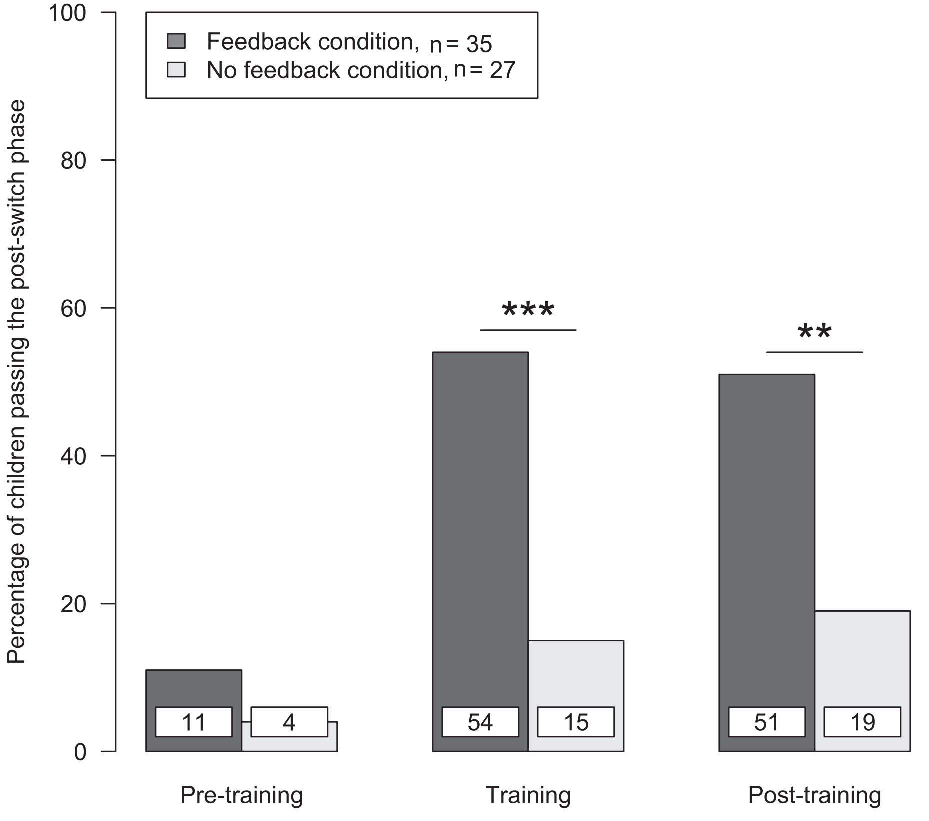

Fig. 7. Percentages of children passing the post-switch phase of the three DCCS tasks in the feedback and no-feedback conditions in Experiment 2. $^{**}p < .01$, $^{***}p \leq .001$.

training) and condition as a between-participants factor (feedback vs. no feedback) on the task scores. For the OCTC, there was a significant main effect of time, $F(1, 30) = 8.82$, $p = .006$, $\eta_p^2 = .23$, no main effect of condition, and no significant interaction between time and condition. Children in both conditions performed better on the OCTC during delayed post-training compared with pre-training. For the Day/Night Stroop task, there were no significant effects. Finally, for the Spin the Pots task, there was a significant main effect of time, $F(1, 30) = 7.01$, $p = .013$, $\eta_p^2 = .19$, no main effect of condition, and no significant interaction between time and condition. Children in both conditions performed better on the Spin the Pots task during delayed post-training compared with pre-training.

Three executive control tasks together. Given the fairly high correlations among the OCTC, Day/Night Stroop task, and Spin the Pots task, and the conclusion of Hughes et al. (2010) and Wiebe et al. (2008, 2011) that the three components of executive control can best be described by a unitary more domain-general process, we performed principal component analyses (PCAs) on the scores of these three tasks for the pre-training and delayed post-training tasks separately. The Kaiser–Meyer–Olkin (KMO) test showed that the sample size was sufficient to perform PCAs (KMO pre-training = 0.65, KMO post-training = 0,689). Bartlett's test of sphericity was significant at both time points, showing sufficiently high correlations between the task scores to perform a PCA. During both pre-training and delayed post-training, one component had an eigenvalue above Kaiser's criterion of 1. During pre-training this component explained 66.3% of the variance, and during post-training this component explained 71.6% of the variance. We used the pre-training and delayed post-training component scores extracted from the PCAs to test the effects of feedback. The pre-training component scores in the feedback condition and the no-feedback condition did not differ significantly. This means that no preexisting differences between the two conditions were present before children in the feedback condition received feedback in the training DCCS task. To test whether the effect of feedback in the training DCCS task transferred to the delayed post-training component scores, general linear models were performed with time as a within-participants factor (pre-training vs. delayed post-training) and condition as a between-participants factor (feedback vs. no feedback) on component scores. There was no significant main effect of time, no main effect of condition, and no significant interaction between time and condition.

Discussion

In two experiments with preschoolers, we studied the direct, near transfer, and far transfer effects of feedback in the DCCS task using a pre-training/training/post-training design. In both experiments, there was a direct effect of feedback on children's performance on the task at hand. Children in the feedback condition performed better on the training DCCS task compared with children in the no-feedback condition. These findings show that children understood the feedback we provided and were able to immediately adjust their behavior based on that feedback. These results are in line with the results of previous studies (Bohlman & Fenson, 2005; Espinet et al., 2013; Kloo & Perner, 2003; Moriguchi et al., 2015; van Bers et al., 2014).

In both experiments, we also found near transfer of the effect of feedback to a subsequent standard DCCS task with not only different stimuli but also different sorting rules. Notably, this delayed post-training test took place 1 week after the training. Children in the feedback condition received feedback in the training DCCS task, in which they needed to switch from color to number. They then performed better, compared to children in the no-feedback condition, in the delayed post-training DCCS task (without feedback), in which they needed to switch from shape to size. These findings show that children, in the context of the DCCS task, learned to switch sorting rules in general and not just in the case of specific sorting rules. This is an important follow-up to earlier research that looked at transfer of the effect to a subsequent standard DCCS task with different stimuli (Bohlman & Fenson, 2005; Espinet et al., 2013; van Bers et al., 2014). Moreover, these results show that the effect of feedback is not transient. The delayed post-training DCCS task was administered 1 week after the training DCCS task, which is a longer delay than in most previous studies. Bohlman and Fenson (2005) administered the subsequent standard DCCS task immediately after the training DCCS task, Espinet et al. (2013) administered it after 1 day, and van Bers et al. (2014) administered it after 5 min and 1 week. Future research should investigate whether the effect remains visible over an even longer period of time, for example, with a follow-up measurement after 3 months. Future research should also counterbalance the different sorting rules among the pre-training, training, and delayed post-training DCCS tasks. This is something that we did not do in the current project and that would make the conclusion even stronger.

Even though performance on the DCCS task was significantly correlated to performance on the OCTC during pre-training, we did not find far transfer of feedback in the training DCCS task to the not-trained cognitive flexibility task. Improvement of performance between pre-training and delayed post-training on the OCTC did not differ between the feedback condition and the no-feedback condition. This is not in line with previous studies looking at the effects of training working memory (e.g., Blakey & Carroll, 2015; Karbach et al., 2014; Kassai et al., 2019; Sala & Gobet, 2017; Thorell et al., 2009). These studies have shown that working memory training improved children's performance on trained and nontrained measures of working memory. However, the current result is in line with previous studies looking at the effects of training inhibitory control (e.g., Blakey & Carroll, 2015; Kassai et al., 2019; Thorell et al., 2009; Traverso et al., 2015). These studies showed improved performance on trained inhibitory control tasks but no transfer to untrained measures of inhibitory control.

Despite the fact that we chose the other cognitive flexibility task very carefully based on earlier research (Smidts et al., 2004) and pilot-tested it before final selection, the choice of this task can nevertheless be a reason for not finding a far transfer effect. Our findings with the DCCS task in Experiments 1 and 2 showed that children learned to switch sorting rules in general and not just in the case of specific sorting rules. This is a skill that is also needed in the OCTC. In this task, children first need to sort the toys according to one dimension and then make a switch to sorting according to the other dimension. However, a number of other skills are also needed to correctly perform the OCTC. In the two most difficult levels of the OCTC (the free generation level and the identification level), for example, children need to generate the groups themselves and label these groups besides making a switch between the dimension on which they base these groups. This may make the OCTC slightly more difficult than the DCSS task and can possibly explain why we did not find far transfer from the effect of feedback in the training DCCS task to the delayed post-training OCTC. Future research could investigate far transfer of the effect of feedback in the DCCS task to other untrained cognitive flexibility tasks that more closely match the DCCS task.

We did not find far transfer of feedback in the training DCCS task to a working memory task or an inhibitory control task. Improvement of performance between pre-training and delayed post-training on the Spin the Pots task and the Day/Night Stroop task did not differ between the feedback condition and the no-feedback condition. This is in line with previous studies looking at the effects of training working memory (e.g., Blakey & Carroll, 2015; Karbach et al., 2014; Kassai et al., 2019; Sala & Gobet, 2017; Thorell et al., 2009) and studies looking at the effects of training inhibitory control (e.g., Blakey & Carroll, 2015; Kassai et al., 2019; Thorell et al., 2009; Traverso et al., 2015). These studies did not find far transfer of training to tasks measuring another component of executive control. However, these results might not match the idea that cognitive flexibility is a complex, later-developing component of executive control, which is somehow built on, and acts on, the core components working memory and inhibitory control (Chevalier et al., 2012). Perhaps the skill that we have trained, switching sorting rules, is specific for cognitive flexibility and less relevant for performance on a working memory or inhibitory control task.

Conclusion

In the current project, we studied the direct, near transfer, and far transfer effects of cognitive flexibility training in preschoolers. We trained children by providing corrective feedback in the post-switch phase of the DCCS task. It is striking that children learned to switch sorting rules with such a short intervention. Children not only learned to switch between two specific sorting rules but also learned the general principle of switching between any two sorting rules in the context of the DCCS task. Moreover, after 1 week this ability was still present. We did not find support for far transfer of this effect to another cognitive flexibility task, an inhibitory control task, or a working memory task. Two possible explanations for these results are the choice of the other cognitive flexibility task (OCTC) and training of an ability that is specific for cognitive flexibility (switching sorting rules). Considering that the establishment of strong executive control during early childhood is associated with success later in life (Blair & Razza, 2007; Moffit et al., 2011; Titz & Karbach, 2014), interventions to improve the executive control at this young age serve an important role. The current study provides important insights that contribute to the development of such interventions.

Acknowledgments

We thank participating children, parents, preschools, and day-care centers. Thanks also go to Stella Balci, Milena Cnossen, Eline Erdmann, Ghita Gosling, Eline ter Haar, Anne Leijen, and Sasha Yablonska for assisting with data collection. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for profit sectors.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jecp.2020.104809.

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