Setting Goals to Switch Between Tasks: Effect of Cue Transparency on Children’s Cognitive Flexibility

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Three experiments examined the difficulty of translating cues into verbal representations of task goals by varying the degree of cue transparency (auditory transparent cues, visual transparent cues, visual arbitrary cues) in the Advanced Dimensional Change Card Sort, which requires switching between color- and shape-sorting rules on the basis of cues. Experiment 1 showed that 5- and 6-year-old children’s performance improved as a function of cue transparency. Experiment 2 yielded the same pattern of results and showed that cue transparency effects cannot be accounted for by cue format only. Finally, Experiment 3 examined the effect of cue transparency in 7- and 9-year-olds and adults. The effect decreased over age for accuracy performance but not for latencies, suggesting that under some conditions, the difficulty of cue translation can still be observed in individuals whose inner speech is efficient. Overall, these findings showed that goal setting substantially contributes to children’s flexible behaviors and continues to influence adults’ performance.

Keywords: cognitive flexibility, goal setting, preschoolers, task switching, cue transparency
in action control, see, e.g., Altmann & Trafton, 2002). Indeed, measures of flexibility are differently demanding in terms of task goal setting. In measures such as the standard DCCS or the PAST (Chevalier & Blaye, 2008), goal setting is ensured by the experimenter, who explicitly announces when a switch occurs and reminds children of the relevant task (sorting criterion) and related rules on every trial. In contrast, tasks that have been found particularly difficult for older preschoolers require children to decide on their own when and what to switch to on the basis of, often arbitrary, cues (e.g., Advanced DCCS, Shape School, FIM) or with no external support (e.g., OCTC, FIST). Furthermore, to set specific task goals according to arbitrary cues, one must actively maintain specific cue–task associations (e.g., star color, no star means shape) in working memory, which probably increases the difficulty of goal setting. Goal setting may thus be an important contributor to diverging performance across flexibility measures in preschoolers, though other variables, such as the requirement to switch either once or back and forth, probably also influence performance (e.g., Diamond, 2006). Similarly, goal setting improvement may partly account for development of flexibility later in childhood. The present study investigated the potential role of goal setting in preschoolers’ performance on the Advanced DCCS and whether this role changes as children grow older.

Many models of adults’ flexibility include an intentional goal-setting component along with a switching process (Baddeley, Chincotta, & Adlam, 2001; Emerson & Miyake, 2003; Gruber & Goschke, 2004; Rubinstein, Meyer, & Evans, 2001; Schuch & Koch, 2003). According to these models, to switch among multiple tasks, one must first determine which task is to be performed next, that is, to set the relevant task goal. This is thought to be achieved through retrieval, maintenance, and updating of verbal representations of the tasks to be performed. Once the goal is set, one can implement the switch per se (i.e., re-orient attention by inhibiting irrelevant information and activating relevant information and, in turn, select a response) if necessary. Consistently, a model involving two factors (goal setting and switching) has been found to better fit performance in the task-switching paradigm than a single-factor model (Kray & Lindenberger, 2000), and functional magnetic resonance imaging results suggest that goal setting and switching are subserved by different brain areas (Crone, Donohue, Honomichl, Wendelken, & Bunge, 2006; Crone, Wendelken, Donohue, & Bunge, 2006).

The task-switching paradigm used with adults (e.g., Allport, Styles, & Hsieh, 1994; Meiran, 1996; Rogers & Monsell, 1995), in which goal setting has been revealed as a critical component of flexibility, requires participants to alternate between two or more tasks on the basis of cues. In this paradigm, goal setting is achieved by translating cues into task goals in the exact same way as must be done by older preschoolers in the Advanced DCCS. Previous studies in adults showed that switching performance is greatly impaired when participants are asked to simultaneously perform a verbal dual task that disrupts articulatory rehearsal (e.g., continuously repeating “the”), whereas switching performance is unaffected by a nonverbal dual task (e.g., putting marbles into a receptacle) with no articulatory suppression effect (Miyake, Emerson, Padilla, & Ahn, 2004; see also Baddeley et al., 2001; Emerson & Miyake, 2003; Kray, Eber, & Lindenberger, 2004; Saeki & Saito, 2004). Complementarily, verbalizing relevant task names enhances switching performance, whereas irrelevant verbalizations have a deleterious effect (Goschke, 2000; Miyake et al., 2004). These results suggest that the phonological loop is involved in setting verbal representations of task goals, allegedly through inner speech, and that goal setting is disrupted by articulatory suppression.

Remarkably, the detrimental effect of articulatory suppression on switching performance is modulated by cue transparency (Baddeley et al., 2001; Emerson & Miyake, 2003; Kray & Eber, 2003; Miyake et al., 2004; Van Loy, Liefooghe, & Vandierendonck, 2007). For instance, Miyake et al. (2004) asked participants to perform color- or shape-matching tasks based on either highly transparent cues (“SHAPE” or “COLOR”) or less transparent cues (“S” or “C”). With concomitant articulatory suppression, switching performance was higher for highly transparent cues than for less transparent ones. According to Emerson and Miyake (2003; Miyake et al., 2004), well-learned, transparent (explicit) task cues automatically trigger related verbal task goals and, hence, greatly reduce (or even suppress) the need to rely on inner speech. On the contrary, arbitrary cues are less efficient at signaling the next task goal and thus must be translated through inner speech. Similarly, Logan and Schneider (2006; Schneider & Logan, 2007) assumed that task goals are automatically triggered by transparent cues, whereas verbal mediators (i.e., task names; Arrington, Logan, & Schneider, 2007) are required in the case of arbitrary cues.

The task-switching paradigm offers specific measures to investigate the process of goal setting. Traditionally, different switch-cost measures (mixing costs and local costs) can be distinguished. Mixing costs compare performance on simple blocks (only one relevant task across trials) and no-switch trials (trials on which the relevant task is the same as in the previous trial) from mixed blocks in which two relevant tasks alternate (they are also termed “global cost” when computed as contrasting simple blocks to all mixed-block trials). Local costs compare no-switch and switch trials (in which the relevant task differs from that of the previous trial) within mixed blocks only. Mixing and local costs have been shown to be sensitive to different variables (e.g., Bryck & Mayr, 2005; Mayr, 2001). Rubin and Meiran (2005) argued that mixing costs primarily reflect goal setting (which they also termed “task decision”) because goal setting, but not switching, is present in no-switch trials, and neither goal-setting demand nor switching demand is present in simple blocks.1 Local costs may primarily reflect the switching process per se because both switch and no-switch trials require goal setting but only the former need to implement a switch. Consistently, some studies found a cue transparency effect on mixing costs (e.g., Baddeley et al., 2001; Kray & Eber, 2003) but not on local costs (Kray & Eber, 2003).

However, other studies did find such an effect on local costs (Miyake et al., 2004; Van Loy et al., 2007). Those findings may be reconciled by the mediator-retrieval hypothesis (Logan & Schneider,

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1 Mixing costs are also thought to reflect the difficulty of maintaining two task sets active in working memory. Task set maintenance and goal setting are intrinsically related because it is easier to set the goal of a task that is highly activated in memory and, conversely, it is easier to actively maintain a task for which the goal is regularly set than a task that is quite infrequent because a task level of activation is renewed each time its goal is set (see Kane & Engle, 2003, for a study on task frequency in the Stroop test).
2006), which assumes that when the task repeats, task name retrieval (necessary for nontransparent cues) goes faster than when the task changes because the relevant task name matches that of the previous trial still present in short-term memory, which facilitates its re-activation as compared with task switch trials for which the task name to be retrieved is less activated. Goal setting may be slightly more difficult in switch than in no-switch trials, thus affecting local costs, although mixing costs primarily capture it. Although mixing and local costs may reflect partially overlapping processes, differentiating goal setting and the switching process through the computation of these indices offers a new methodology to investigate potential sources of preschoolers’ difficulties on the Advanced DCCS.

Previous research on cognitive flexibility in preschoolers has not directly addressed goal setting, although there are reasons to suspect that inefficient goal setting may be a critical aspect of older preschoolers’ lack of flexibility. Indeed, it is now well documented that children do not spontaneously (or efficiently) resort to verbal rehearsal before 7 or 8 years of age when performing memory tasks, such as serial recall tasks (e.g., Flavell, Beach, & Chinsky, 1966; Gathercole, 1998; Halliday, Hitch, Lemon, & Petipher, 1990; Pressley & Hilden, 2006; Thor & Gathercole, 2000). Therefore, while performing tasks that tap flexibility, preschool-age children may encounter difficulty in efficiently setting goals, even without concomitant articulatory suppression. This seems all the more probable as the tasks on which older preschoolers still perform relatively poorly (e.g., Advanced DCCS, Shape School) involve arbitrary cues. As previously mentioned, such cues are difficult to translate and require rehearsing cue–task associations to permit translation. These two sources of difficulty are intertwined as they tap into the phonological loop and, thus, concomitantly lead to high goal-setting demands. Finally, consistent with the claim that goal setting may contribute to children’s flexibility, verbal labeling has been found to enhance children’s performance on some flexibility measures. For instance, 3-year-olds are better at switching sorting dimensions on the DCCS when they must label the relevant feature of the stimuli than when it has been labeled by the experimenter (Kirkham, Crnue, & Diamond, 2003). Similarly, 3- and 4-year-olds’ performance on a rule use task requiring children to inhibit a prepotent response and switch to an alternative rule improves when children spontaneously verbalize or are instructed to verbalize relevant stimulus information (Müller, Zelazo, Leone, Hood, & Roehr, 2004). Later in childhood, 7- and 8-year-olds’ switching performance can be improved by verbalizations related to task-relevant information and hampered by task-irrelevant verbalizations (Kray, Eber, & Karbach, 2008).

The present study aimed to investigate, in two different ways, whether children have difficulties setting goals on the basis of arbitrary cues. First, if preschoolers encounter difficulties in translating arbitrary cues into task goals because they do not efficiently recruit inner speech and because of the additional demand of cue–task association maintenance, then varying the degree of cue transparency should affect their performance in the Advanced DCCS (without the concomitant articulatory suppression task). This was tested in Experiments 1 and 2. Second, previous studies showed that adults’ performance is mediated by cue transparency when articulatory rehearsal is prevented. If preschoolers’ alleged difficulty in goal setting is primarily bound to inefficient use of inner speech, then the effect of cue transparency should progressively disappear as children’s inner speech increases in efficiency. This was tested in Experiment 3 with school-age children and adults. As we used a situation without articulatory suppression, we expected any effect of cue transparency to decrease with age.

Experiment 1

Experiment 1 aimed to graduate the difficulty of goal setting in the Advanced DCCS. In this task, preschool children must repeatedly switch between color and shape-matching rules on the basis of arbitrary cues, which, we assumed, imposes high demands on goal setting. To vary the difficulty of goal setting, we manipulated the degree of transparency of task cues. In the auditory transparent cues condition, the relevant task name was explicitly announced on every trial (children heard “color” or “shape” on each trial). In this condition, there was no cue–goal translation, as task goals were communicated to children in the final transparent phonological format, which imposed few goal-setting demands. In the visual transparent cues condition, children had to set task goals on the basis of transparent visual cues (a string a multiple colors for the color task and a black square for the shape task). The cues had to be translated. However, the cues were strongly associated with task goals, hence imposing intermediate demands on goal setting (moderate difficulty of cue–goal translation). Finally, in the visual arbitrary cues condition, task cues were arbitrarily associated with task goals (a gray background and a black background). The task allegedly required a difficult cue–goal translation and was assumed to impose heavy demands on goal setting. If, as hypothesized, preschoolers experience difficulty in setting task goals, then performance should evolve as a function of cue transparency. In particular, auditory transparent cues should lead to better performance than visual transparent cues, which, in turn, should lead to better performance than visual arbitrary cues.

Method

Participants

Sixty-nine 5- and 6-year-old children (M = 70.8 months, SD = 3.3 months, range = 65–77 months), of whom 34 were girls and 35 were boys, participated in this experiment. Data from 12 additional children were eliminated because children either completed only one session, decided to stop the experiment while in progress, or failed to understand experimental instructions. Children were recruited from two preschools located in a small town in the south of France. Most participants were Caucasian and came from middle-class backgrounds, although race and socioeconomic status data were not collected. Parental consent was received for all participants. Participants were tested individually in a quiet room in their preschools.

Apparatus and Materials

The Advanced DCCS was administered on a laptop computer (15-in. [38-cm] HP Compaq nx9000 Notebook PC monitor; Hewlett-Packard, Geneva, Switzerland and Palo Alto, California). The experiment was run with E-Prime software (Psychology Software Tools, Inc., 2007). Children had to respond by pressing one of two keys (corresponding to the “q” and “p” keys of a QWERTY computer keyboard). The remaining keys were masked.
The Advanced DCCS required children to match, on the basis of task cues, a stimulus picture with one of two response pictures on either color (Color Game) or shape (Shape Game) on every trial. Stimulus pictures were two pictures of different colors and shapes (e.g., a blue boat and a red rabbit) and were displayed at the top of the screen (Figure 1). Each response picture matched each stimulus on either color or shape (e.g., a red boat and a blue rabbit). Both response pictures remained visible throughout the task and were displayed on the two bottom corners of the screen in correspondence with the “q” and “p” keys, respectively. Pictures were about 6 cm × 6 cm. Each participant saw a different pair of colors (blue–red, yellow–green, brown–pink, orange–violet) and shapes (boat–rabbit, flower–cat, car–dog, teddy bear–seat) on each cue condition. Picture pairs and locations were counterbalanced across cue conditions and participants (12 different versions, 6 different orders).

In the auditory transparent cue condition, cues were the words couleur (French for color) for the Color Game and forme (French for shape) for the Shape Game. Auditory cues were recorded by a male voice and were 380 ms in duration. In the visual transparent cue condition, a string of multiple colors (Color Game) or a black outline of a square introduced as a shape (Shape Game) surrounded the stimulus picture (Figure 1). Finally, in the visual arbitrary cues condition, a black square or a gray circle (of the same dimensions as visual transparent cues) were used as backgrounds for the stimuli. For half of the participants, the black-squared background indicated color and the gray-circled background indicated shape, and conversely for the other half of the participants.

On every trial, the cue and the stimulus were simultaneously presented at the top of the screen (auditory cues started at stimulus onset). Visual cues remained visible until a response was entered. Then the stimulus (without the cue) moved onto the side of the given response for 500 ms. This procedure was designed to make button-press responses concrete for children, just as putting cards into boxes serves this purpose on the traditional card version of the Advanced DCCS. Cues and stimuli were simultaneously displayed as they are in the card versions of the Advanced DCCS and the Shape School. Response pictures were displayed without interruption. In Experiment 1, each trial was triggered by the experimenter in order to maintain control over the unfolding of the experiment.2

Procedure

All participants were tested on all three cue conditions (with order counterbalanced across participants). The participants were tested in two sessions 1 or 2 days apart. They completed two cue conditions in the first session (about 20 min total) and the third condition in the second session (about 10 min).

At the beginning of each cue condition, children were told that they would see pictures and would be asked to play either the Color Game or the Shape Game on the basis of cues. In the Color Game, they were instructed to press the key under the bottom picture of the same color as the top picture. In the Shape Game, they were instructed to press the key under the bottom picture of the same shape as the top picture. Children were asked to respond as quickly and accurately as possible. Each cue condition started with two simple blocks in which children had to constantly play either the Color Game or the Shape Game (the order was counterbalanced). Each simple block consisted of 5 training trials (which were replayed if children committed more than two errors) and 10 test trials. The experimenter helped children on training

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2 The duration of intertrial intervals has been shown to affect switching performance (e.g., Allport et al., 1994). One might therefore argue that any cue condition effect could relate to this factor. Yet, this seems highly unlikely, as intertrial intervals did not significantly vary across conditions (p > .91). Nevertheless, to fully discard this possibility, trials were automatically triggered in Experiments 2 and 3.
trials if necessary, but not on test trials. Children were told that they would then play the two games at the same time and proceeded to the mixed block. The mixed block started with a training phase of 6 trials (which were repeated if children committed more than two errors). Children were guided by the experimenter on these trials (“Which cue is it?” “Which game does it mean?” “So which color/shape is it [stimulus]?” “Which one [response picture] is of the same color/shape?”). Children were then administered 20 test trials with no help from the experimenter. They were incited to take a short break, were reminded of cue meanings, and again completed 20 trials. Except for training trials, no feedback was delivered. At the end of visual transparent and visual arbitrary conditions, children were asked to recall which task was associated with each cue (cue questions). These cue questions were used to ensure that children were not confused about cue meanings and thus succeeded in maintaining cue–task associations. The mixed block contained equal numbers of each stimulus and each correct response, as well as equal numbers of color and shape trials, and 20 no-switch trials (i.e., the relevant game repeats), 18 switch trials (i.e., the relevant game changes), and 2 start trials. In Experiment 1 (contrary to the subsequent experiments), color and shape games were not randomly ordered but alternated on every second trial.

Results

In this experiment and the subsequent ones, the analyses were run after discarding the first trial of each block because they were neither switch nor no-switch trials. Only reaction times (RTs) for correct responses immediately preceded by a correct response were analyzed. Outliers (<200 ms or >10,000 ms) and times greater than two standard deviations above the mean of each participant (computed separately for simple blocks, switch, and no-switch trials of mixed blocks) were also discarded. On the remaining data, we ran two 3 (cue transparency) × 3 (trial type) repeated measures analyses of variance (ANOVA; one for accuracy rates and one for RTs). Significant effects were further examined with planned contrasts. Local costs were examined, contrasting switch and no-switch trials of the mixed block. We evaluated mixing costs, contrasting simple trials and no-switch trials of the mixed block, as this computation mode has been shown to be particularly sensitive to goal setting (Rubin & Meiran, 2005), and it avoids including costs due to the switching process. Analyses comparing single-block trials with all mixed-block trials (global costs) led to similar results as mixing costs and thus are not reported. When appropriate (as evidenced by Mauchly’s tests), the Greenhouse–Geisser (Greenhouse & Geisser, 1959) correction was applied for violation of the assumption of sphericity. Preliminary results showed no significant differences in either accuracy or RTs between the two single blocks, which were collapsed for further analyses. In the present experiment, the trimming procedure resulted in the suppression of 5.1% trials. Children with missing data for some trial type were excluded from RT analyses (n = 6). Six children failed the cue questions for visual arbitrary cues. Accuracy and RT analyses were computed for the remaining 63 children (M = 70.8 months, SD = 3.3 months), of whom 34 were girls and 29 were boys. Data are shown in Table 1 and Figure 2.

Two 3 (cue transparency: auditory transparent, visual transparent, visual arbitrary) × 3 (trial type: simple block, no switch, switch) repeated measures ANOVAs were performed, one on accuracy and one on RTs. Both ANOVAs revealed a significant main effect of cue transparency, F(2, 124) = 21.61, MSE = 187, p < .0001, partial eta squared (ηp2) = .26, and F(2, 112) = 31.96, MSE = 439.635, p < .0001, ηp2 = .36, for accuracy and RTs, respectively, and a significant main effect of trial type, F(2, 124) = 90.58, MSE = 106, p < .0001, ηp2 = .59, and F(2, 112) = 427.93, MSE = 230.225, p < .0001, ηp2 = .88, for accuracy and RTs, respectively. These main effects were qualified by significant Cue Transparency × Trial Type interactions, F(4, 248) = 12.88, MSE = 77, p < .0001, ηp2 = .17, and F(4, 224) = 16.34, MSE = 143.027, p < .0001, ηp2 = .23, for accuracy and RTs, respectively. The interactions were further examined with planned contrasts.

Mixing Costs

Mixing costs on accuracy rates were significant, F(1, 62) = 65.93, MSE = 711, p < .0001, ηp2 = .52. Most important, they were significantly lower with auditory transparent cues (3.1%) than with visual transparent cues (7.3%), F(1, 62) = 5.02, MSE = 220, p < .05, ηp2 = .08. In turn, mixing costs increased from visual transparent cues to visual arbitrary cues (16.9%), F(1, 62) = 12.29, MSE = 480, p < .001, ηp2 = .17.

Mixing costs on RTs were also significant, F(1, 56) = 345.67, MSE = 1,689,050, p < .0001, ηp2 = .86. Mixing costs were significantly lower with auditory transparent cues (676 ms) than with visual transparent cues (1,228 ms), F(1, 56) = 34.62, MSE = 501.942, p < .0001, ηp2 = .38. However, local costs did not significantly differ between visual transparent cues and visual arbitrary cues (1,297 ms; F < 1).

Local Costs

Whether computed on accuracy rates or RTs, local costs were significant, F(1, 62) = 42.67, MSE = 330, p < .0001, ηp2 = .41, and F(1, 56) = 90.53, MSE = 915,333, p < .0001, ηp2 = .62, for accuracy and RTs, respectively. Overall, children performed better for no-switch trials (86.3%) than for switch trials (81.4%) similarly, they responded faster to no-switch trials (2,323 ms) than to

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3 We also analyzed percentages of children passing each cue condition to facilitate comparison between our data and previous studies using the Advanced DCCS (Carlson, 2005; Hongwanishkul et al., 2005). Children were considered to have passed a simple block if they correctly responded to at least 8 trials (out of 10) and to at least 30 trials (out of 40) in the mixed block, which matched the criterion of 75% correct responses (9 out of 12) used in Hongwanishkul et al. (2005). Percentages of children passing the first simple block (100% in auditory transparent, 98% in visual transparent, 100% in visual arbitrary) and of those passing the second simple block (95% in auditory transparent, 100% in visual transparent, 95% in visual arbitrary) were very close to ceiling with all three cue types. In contrast, success rates significantly increased in the mixed block as a function of cue transparency, with 66% (n = 42) of children passing with visual arbitrary cues, 86% (n = 54) passing with visual transparent cues, and 97% (n = 61) passing with auditory transparent cues, χ2(2, N = 63) = 23.08, p < .0001. Although performance with visual arbitrary cues was somewhat higher than in Hongwanishkul et al. (nearly 50%), probably because our sample included children who were about 6 months older, the present study confirmed that an important proportion of 5- and 6-year-olds still failed the Advanced DCCS with such cues. Performance increased with more transparent cues and even reached ceiling with auditory transparent cues (97% success).
Table 1
Mean Accuracy Rates and Reaction Times for Each Trial Type and Cue Type and for Mixing Costs (MC) and Local Costs (LC) in Experiments 1–3

<table>
<thead>
<tr>
<th>Cue</th>
<th>Accuracy (%)</th>
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<th>Reaction times (ms)</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Simple</td>
<td>No switch</td>
<td>Switch</td>
<td>MC</td>
<td>LC</td>
<td>Simple</td>
<td>No switch</td>
<td>Switch</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>block</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>block</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Auditory transparent</td>
<td>63</td>
<td>95.9 (5.3)</td>
<td>92.8 (8.3)</td>
<td>87.9 (11.4)</td>
<td>3.1 (8.6)</td>
<td>4.9 (9.1)</td>
<td>57</td>
<td>1,195 (337)</td>
<td>1,871 (475)</td>
</tr>
<tr>
<td>Visual transparent</td>
<td>63</td>
<td>94.9 (6.4)</td>
<td>87.6 (13.4)</td>
<td>81.6 (15.9)</td>
<td>7.3 (14.5)</td>
<td>6.1 (9.6)</td>
<td>57</td>
<td>1,270 (368)</td>
<td>2,498 (799)</td>
</tr>
<tr>
<td>Visual arbitrary</td>
<td>63</td>
<td>95.6 (5.5)</td>
<td>78.7 (17.6)</td>
<td>74.6 (17.6)</td>
<td>16.9 (18.1)</td>
<td>4.1 (10.9)</td>
<td>57</td>
<td>1,304 (416)</td>
<td>2,601 (765)</td>
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Experiment 2: Children, ages 5 to 6 years (first series of analyses)

<table>
<thead>
<tr>
<th>Cue</th>
<th>Accuracy (%)</th>
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<th></th>
<th></th>
<th></th>
<th>Reaction times (ms)</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Simple</td>
<td>No switch</td>
<td>Switch</td>
<td>MC</td>
<td>LC</td>
<td>Simple</td>
<td>No switch</td>
<td>Switch</td>
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<tr>
<td></td>
<td>N</td>
<td>block</td>
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<td></td>
<td></td>
<td></td>
<td>block</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Auditory transparent</td>
<td>31</td>
<td>95.6 (4.9)</td>
<td>88.9 (14.9)</td>
<td>84.8 (14.5)</td>
<td>6.8 (14.6)</td>
<td>4.0 (10.8)</td>
<td>25</td>
<td>1,170 (257)</td>
<td>1,752 (462)</td>
</tr>
<tr>
<td>Visual transparent</td>
<td>31</td>
<td>95.0 (5.5)</td>
<td>80.0 (18.8)</td>
<td>73.7 (19.1)</td>
<td>15.0 (19.2)</td>
<td>6.3 (10.6)</td>
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<td>1,170 (257)</td>
<td>2,110 (626)</td>
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<tr>
<td>Visual arbitrary</td>
<td>31</td>
<td>95.3 (5.9)</td>
<td>75.0 (21.3)</td>
<td>68.7 (30.9)</td>
<td>20.3 (21.3)</td>
<td>6.3 (24.2)</td>
<td>25</td>
<td>1,154 (241)</td>
<td>2,143 (811)</td>
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Experiment 2: Children, ages 5 to 6 years (second series of analyses)

<table>
<thead>
<tr>
<th>Cue</th>
<th>Accuracy (%)</th>
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<th>Reaction times (ms)</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Simple</td>
<td>No switch</td>
<td>Switch</td>
<td>MC</td>
<td>LC</td>
<td>Simple</td>
<td>No switch</td>
<td>Switch</td>
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<tr>
<td></td>
<td>N</td>
<td>block</td>
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<td></td>
<td></td>
<td></td>
<td>block</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Auditory transparent</td>
<td>19</td>
<td>95.5 (4.7)</td>
<td>93.9 (8.4)</td>
<td>86.8 (13.5)</td>
<td>1.6 (8.3)</td>
<td>7.1 (10.5)</td>
<td>18</td>
<td>1,133 (267)</td>
<td>1,730 (463)</td>
</tr>
<tr>
<td>Visual arbitrary</td>
<td>19</td>
<td>95.8 (4.7)</td>
<td>83.4 (17.3)</td>
<td>73.7 (24.3)</td>
<td>12.4 (17.4)</td>
<td>9.7 (20.0)</td>
<td>18</td>
<td>1,174 (226)</td>
<td>2,209 (818)</td>
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Experiment 3: Children, age 7 years

<table>
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<tr>
<th>Cue</th>
<th>Accuracy (%)</th>
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<th></th>
<th></th>
<th>Reaction times (ms)</th>
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<tr>
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<td>Simple</td>
<td>No switch</td>
<td>Switch</td>
<td>MC</td>
<td>LC</td>
<td>Simple</td>
<td>No switch</td>
<td>Switch</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>block</td>
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<td></td>
<td></td>
<td></td>
<td>block</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Auditory transparent</td>
<td>29</td>
<td>94.0 (9.2)</td>
<td>92.6 (7.2)</td>
<td>87.4 (9.6)</td>
<td>1.4 (12.2)</td>
<td>5.3 (9.6)</td>
<td>29</td>
<td>934 (252)</td>
<td>1,583 (347)</td>
</tr>
<tr>
<td>Visual transparent</td>
<td>29</td>
<td>96.8 (6.1)</td>
<td>90.7 (12.1)</td>
<td>82.8 (12.7)</td>
<td>6.1 (14.5)</td>
<td>7.9 (7.7)</td>
<td>29</td>
<td>1,075 (298)</td>
<td>1,876 (475)</td>
</tr>
<tr>
<td>Visual arbitrary</td>
<td>29</td>
<td>96.6 (4.4)</td>
<td>85.4 (16.5)</td>
<td>82.2 (13.6)</td>
<td>11.2 (16.5)</td>
<td>3.2 (10.3)</td>
<td>29</td>
<td>1,032 (266)</td>
<td>1,979 (590)</td>
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</table>

Experiment 3: Children, age 9 years

<table>
<thead>
<tr>
<th>Cue</th>
<th>Accuracy (%)</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th>Reaction times (ms)</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Simple</td>
<td>No switch</td>
<td>Switch</td>
<td>MC</td>
<td>LC</td>
<td>Simple</td>
<td>No switch</td>
<td>Switch</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>block</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>block</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Auditory transparent</td>
<td>29</td>
<td>95.6 (5.9)</td>
<td>95.4 (6.2)</td>
<td>87.9 (8.6)</td>
<td>2.8 (8.1)</td>
<td>5.8 (8.4)</td>
<td>29</td>
<td>737 (218)</td>
<td>1,170 (209)</td>
</tr>
<tr>
<td>Visual transparent</td>
<td>29</td>
<td>96.4 (3.4)</td>
<td>92.9 (7.8)</td>
<td>86.7 (11.7)</td>
<td>3.6 (6.7)</td>
<td>6.2 (7.3)</td>
<td>29</td>
<td>779 (157)</td>
<td>1,488 (321)</td>
</tr>
<tr>
<td>Visual arbitrary</td>
<td>29</td>
<td>95.7 (4.8)</td>
<td>85.9 (12.7)</td>
<td>81.8 (14.2)</td>
<td>10.0 (12.9)</td>
<td>4.0 (9.9)</td>
<td>29</td>
<td>809 (253)</td>
<td>1,659 (358)</td>
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</table>

Experiment 3: Adults

<table>
<thead>
<tr>
<th>Cue</th>
<th>Accuracy (%)</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th>Reaction times (ms)</th>
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<tr>
<td></td>
<td></td>
<td>Simple</td>
<td>No switch</td>
<td>Switch</td>
<td>MC</td>
<td>LC</td>
<td>Simple</td>
<td>No switch</td>
<td>Switch</td>
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<tr>
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<td>N</td>
<td>block</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>block</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Auditory transparent</td>
<td>10</td>
<td>98.7 (2.3)</td>
<td>96.4 (3.9)</td>
<td>94.2 (6.8)</td>
<td>2.3 (4.1)</td>
<td>2.2 (6.6)</td>
<td>26</td>
<td>511 (104)</td>
<td>786 (154)</td>
</tr>
<tr>
<td>Visual transparent</td>
<td>10</td>
<td>96.8 (1.9)</td>
<td>96.4 (4.5)</td>
<td>92.7 (6.6)</td>
<td>2.4 (4.2)</td>
<td>3.7 (6.2)</td>
<td>26</td>
<td>566 (177)</td>
<td>1,061 (370)</td>
</tr>
</tbody>
</table>

Note. Standard deviations are presented in parentheses.
switch trials (2,725 ms). However, local costs did not significantly differ across cue types (all ps > .22).

Discussion

Experiment 1 investigated the role of goal setting in preschoolers by manipulating cue transparency on the Advanced DCCS. Almost all children perfectly recalled meanings of visual cues, suggesting that they succeeded in maintaining cue–task associations for both visual transparent and arbitrary cues. Analyses of accuracy revealed the expected gradation of mixing costs across auditory transparent, visual transparent, and visual arbitrary cues (but the difference between the latter two types of cue was not significant for RTs, which is discussed in the General Discussion section), whereas cue types did not significantly affect local costs. This pattern of results further confirmed the interest of dissociating mixing and local cost in the Advanced DCCS. It is in line with the claim that mixing costs primarily capture goal setting (Rubin & Meiran, 2005), whereas local-cost sensitivity to goal setting is much smaller and not conspicuous in the present experiment.

These findings suggest that older preschoolers encountered difficulty translating arbitrary cues into task goals, as compared with more transparent cues, even without concomitant articulatory suppression. This difficulty could not relate to a failure to memorize cue meanings because almost all children succeeded in responding to cue questions, and the few children who failed were excluded from the analyses. However, the cue translation difficulty may be strengthened by the requirement of maintaining cue–task associations. Overall, these findings suggest that a goal-setting deficit partly accounts for poor performance on the Advanced DCCS (Carlson, 2005; Hongwanishkul et al., 2005).

Alternative interpretations need to be ruled out before reaching further conclusions on the role of goal setting in older preschoolers’ flexibility. One could argue that cue format (auditory vs. visual) rather than transparency accounts for the cue type effect because visual cues are processed through the same channel as visual stimuli, whereas auditory cues and visual stimuli can be simultaneously processed through separate channels (see Monsell & Mizon, 2006, for a similar argument; see also Wickens, 2002). The cue transparency effect on RTs may be even more affected by cue format, as cues and stimuli were simultaneously displayed, and auditory and visual cues may need unequal perceptual encoding times. Indeed, cue format lies at the core of the cue translation hypothesis. The goal-setting difficulty is assumed to be greatly attenuated with auditory transparent cues because such cues are both auditory and transparent, that is, they match the verbal phonological representation of task names that is recruited to guide responses (Arrington et al., 2007; Gruber & Goschke, 2004). Furthermore, a processing-channel hypothesis does not tell the whole story, as it cannot account for the difference between transparent and arbitrary visual cues given that both require the same processing channel. Nonetheless, this issue was further investigated in Experiment 2.

Experiment 2

Experiment 2 was designed to address two main goals. First, we aimed to replicate the effect of cue transparency on preschoolers’ performance on the Advanced DCCS. As the task-switching paradigm in adults mainly involves unpredictable sequences of switch and no-switch trials, such sequences were used here. Second, a new condition with auditory arbitrary cues was introduced to determine whether the cue-transparency effect was due to the difficulty of cue translation or to the capacity (or lack thereof) of processing cues and stimuli through separate channels. If better performance with auditory transparent cues was related to the difference in cue format, which allowed children to perceptually encode cues more quickly and/or process cues and stimuli simultaneously through separate channels, then children should perform better with auditory arbitrary than with visual arbitrary cues. In contrast, if better performance with auditory transparent cues reflected the conjunction of both the auditory format and transparency, which greatly attenuated any need for cue translation (cues were already task names), then auditory arbitrary cues, which are supposedly difficult to translate, should lead to lower performance than auditory transparent cues.

Method

Participants

Thirty-one 5- and 6-year-old children (M = 69.9 months, SD = 3.7 months, range = 65–76 months) of whom 18 were girls and 13
were boys, participated. Data from one additional child were eliminated because this child did not seem to understand the task instructions. Children were recruited from a preschool located in a small town in the south of France. Most participants were Caucasian and came from middle-class backgrounds, although race and socioeconomic status data were not collected. Parental consent was received for all participants, none of whom had participated in Experiment 1. Participants were tested individually in a quiet room in their preschools.

Procedure

Apparatus, materials, and procedure were strictly the same as in Experiment 1, except for the following changes. Trials were automatically triggered as follows: They started with a fixation point at the top center of the screen (800 ms), which was then replaced with the simultaneous presentation of the cue and the stimulus (until a response was entered). Next, the stimulus (without the cue) was moved to the side of the selected response (500 ms). Each trial ended with a refresh screen (200 ms). In the mixed blocks, switch and no-switch trials were randomly ordered. There were $2 \times 11$ single-block trials and 42 mixed-block trials (2 start trials, 20 no-switch trials, 20 switch trials). Finally, to further equalize visual encoding times between arbitrary and transparent cues, we designed visual arbitrary cues as outlines of a gray circle or a brown square, associated with either color or shape (see Figure 1). In addition to auditory transparent, visual transparent, and visual arbitrary conditions, children were tested in a fourth condition with auditory arbitrary cues in which cues were the French pseudowords *timo* and *ralu* recorded by the same male voice as for the auditory transparent cues and with the same duration (380 ms). For half of the participants, *timo* signaled the Color Game and *ralu* signaled the Shape Game, and conversely for the other half of participants. As for visual transparent and visual arbitrary cues, children were asked cue questions at the end of the task. All four conditions (auditory transparent, auditory arbitrary, visual transparent, visual arbitrary cues) were administered to each participant in two 20-min sessions (two conditions per session) 1 or 2 days apart (with order counterbalanced across participants).

Results

The trimming procedure was the same as in Experiment 1 and resulted in the exclusion of 5.4% trials from RT analyses. All participants correctly answered cue questions in visual transparent and visual arbitrary conditions, but 12 children (39%) failed these questions in the auditory arbitrary condition. This relatively high failure rate for these cue questions jeopardized the achievement of the two main purposes of Experiment 2 within a single set of analyses. The remaining 19 children who passed the cue questions probably constitute a selected subsample whose goal-setting ability might be higher than that in the general population. To determine whether the gradation among cue types observed in Experiment 1 holds with unpredictable trial sequences, it is important to compare performance of a sample of children comparable to that in Experiment 1. Therefore, this was tested including all participants ($N = 31$ for accuracy, $N = 25$, for RTs) in the first series of repeated measures ANOVAs, with cue transparency and trial type as variables on auditory transparent, visual transparent, and visual arbitrary cues (Table 1, Figure 3). Then, because it was essential that children memorize the meaning of auditory arbitrary cues for further investigation of the role of cue format (i.e., including the children who failed cue questions might have led to overestimating the difficulty of this condition), a second series of analyses was conducted on auditory transparent, auditory arbitrary, and visual arbitrary cues including only children who correctly answered cue questions for all cue types ($N = 19$, $M = 69.8$ months, $SD = 3.7$ months, 12 girls and 7 boys; $N = 18$ for RTs; Table 1, Figure 4).

Effect of Cue Transparency With Unpredictable Sequences

To examine whether results from Experiment 1 could be replicated using unpredictable trial sequences, we analyzed performance with auditory transparent, visual transparent, and visual arbitrary cues including all participants. The two 3 (cue transparency: auditory transparent, visual transparent, visual arbitrary) $\times$ 3 (trial type: simple block, no switch, switch) repeated measures ANOVA, performed on accuracy and RTs, showed significant main effects of cue transparency, $F(2, 60) = 7.22$, $MSE = 343,$
Local costs. Local costs were significant for both accuracy rates and RTs, \(F(1, 30) = 6.96, \text{MSE} = 205, p < .05, \eta^2_p = .19; F(1, 24) = 27, \text{MSE} = 244.072, p < .0001, \eta^2_p = .53, \) respectively. Children performed better on no-switch (81.3%) than on switch (75.8%) trials. Responses were also faster for no-switch (2,002 ms) than for switch (2,421 ms) trials. However, local costs did not significantly differ across cue types (all \(p > .19\)).

Effect of Cue Format

Analyses were conducted with auditory transparent, visual arbitrary, and auditory arbitrary cues, including only participants who correctly answered all cue questions to test the cue translation and processing channel hypotheses. The two cues (cue transparency: auditory transparent, visual arbitrary, auditory arbitrary) \(\times 3\) trial type: simple block, no switch, switch) repeated measures ANOVA, performed on accuracy and RTs, showed significant main effects of cue transparency, \(F(2, 36) = 10.67, \text{MSE} = 238, p < .0001, \eta^2_p = .37; F(2, 34) = 7.00, \text{MSE} = 337.308, p < .01, \eta^2_p = .29, \) respectively, and of trial type, \(F(2, 36) = 27.90, \text{MSE} = 193, p < .0001, \eta^2_p = .61; F(2, 34) = 57.86, \text{MSE} = 369.417, p < .0001, \eta^2_p = .77, \) respectively. These main effects were qualified by significant Cue Transparency \(\times\) Trial Type interactions, \(F(4, 72) = 7.87, \text{MSE} = 97, p < .0001, \eta^2_p = .30; F(4, 68) = 2.84, \text{MSE} = 195.563, p < .05, \eta^2_p = .14, \) respectively, which are further explored in the subsequent sections.

Mixing costs. Mixing costs on accuracy were significant, \(F(1, 18) = 29.26, \text{MSE} = 164, p < .0001, \eta^2_p = .62.\) Mixing costs significantly increased from auditory transparent cues (1.6%) to visual arbitrary cues (12.4%), \(F(1, 18) = 10.17, \text{MSE} = 54, p < .01, \eta^2_p = .36, \) and again from visual arbitrary cues to auditory arbitrary cues (25%), \(F(1, 18) = 7.21, \text{MSE} = 105, p < .05, \eta^2_p = .27.\) Mixing costs were also significant for RTs, \(F(1, 17) = 67.52, \text{MSE} = 301.609, p < .0001, \eta^2_p = .80.\) Mixing costs were significantly lower with auditory transparent cues (597 ms) than with visual arbitrary cues (1,035 ms), \(F(1, 17) = 5.68, \text{MSE} = 152.159, p < .05, \eta^2_p = .25, \) and auditory arbitrary cues (974 ms), \(F(1, 17) = 4.29, \text{MSE} = 149.132, p < .05, \eta^2_p = .20, \) whereas visual and auditory arbitrary cues did not significantly differ \((F < 1)\).

Local costs. Local costs were significant (all \(p > .13\)).

Discussion

Experiment 2 aimed to (a) replicate the effect of cue transparency on preschoolers’ performance with unpredictable trial sequences in the mixed block and (b) further investigate the issue of cue format. Because many children failed to correctly recall cue-task associations for auditory arbitrary cues, analyses were first conducted for all children in order to compare auditory transparent, visual transparent, and visual arbitrary conditions. The results replicated those from Experiment 1, except that the difference between visual transparent and visual arbitrary cues for mixing costs on accuracy rates did not reach significance. This nonsignificant difference between visual cues could relate either to the new
pair of visual arbitrary cues that are more like visual transparent cues or to a lack of statistical power, given that the sample in Experiment 1 was twice as large as the one here. This issue is further addressed in the General Discussion. Overall, the present findings further suggest that children encounter difficulty in translating nontransparent cues into task goals.

The high proportion of failures to cue questions for auditory arbitrary cues suggests that cue–task associations are particularly difficult to maintain when cues are both transient and arbitrary, hence, first hinting at the difficulty of setting goals on the basis of such cues. This was confirmed by the analyses comparing performance across auditory transparent, visual arbitrary, and auditory arbitrary cues including only the subset of children succeeding at recalling all cue meanings. Consistent with the cue translation hypothesis and contrary to the processing channel hypothesis, the auditory arbitrary condition led to lower accuracy than did the auditory transparent and even the visual arbitrary condition. The auditory arbitrary condition also led to higher latencies than did the auditory transparent condition but was not significantly different from the visual arbitrary condition in this respect. Therefore, the gradation of performance across cue types cannot be explained merely by cue encoding time or by whether or not cues and stimuli can be simultaneously processed through different channels. Instead, it seems to relate to the varying difficulty of setting verbal representations of task goals as a function of cue transparency. Our claim is not that cue format has no influence at all on goal setting but that its influence depends on cue transparency. The auditory format is particularly helpful when cues are transparent because it almost suppresses the need for translation. Similarly, the present findings suggest that the auditory format is particularly detrimental for goal setting when cues are arbitrary, probably because they interfere more with cue translation and cue–task association maintenance in the phonological loop than do visual arbitrary cues. Taken together, Experiments 1 and 2 showed that goal setting contributes substantially to older preschoolers’ performance in the Advanced DCCS. Experiment 3 was designed to investigate whether the effect of cue transparency decreases in older children and adults as efficient use of inner speech develops.

Experiment 3

Experiments 1 and 2 showed that older preschoolers’ performance is a function of cue transparency on the Advanced DCCS. The effect of cue transparency, without the concomitant articulatory suppression task, suggests that older preschoolers’ goal-setting difficulty may be linked to inefficient use of inner speech. If, as hypothesized, goal setting and inner speech are closely related (Baddley et al., 2001; Emerson & Miyake, 2003; Miyake et al., 2004), then the effect of cue transparency should decrease from 7 and 9 years of age to adulthood because the ability to efficiently use inner speech increases in late childhood (Halliday et al., 1990; Thorn & Gathercole, 2000). However, as cues and stimuli are simultaneously displayed in the Advanced DCCS, despite efficient inner speech, successful cue translation could require more time for nontransparent cues than for transparent cues even. Therefore, the cue transparency effect was expected to decrease, although not fully disappear, even in adults on RT measures.

Method

Participants

Participants were 29 (18 female, 11 male) 7-year-old children (M = 90.9 months, SD = 3.4 months, range = 86–97 months); 29 (15 female, 14 male) 9-year-old children (M = 113.6 months, SD = 3.9 months, range = 104–120 months); and 26 (16 female, 10 male) adults (M = 26.6 years, SD = 3.11 years, range = 23–36 years). Children were recruited from two schools located in a small town in the south of France. The adult participants were students who received course credit in exchange for their participation. Most participants were Caucasian and came from middle-class backgrounds, although race and socioeconomic status data were not collected. Data from one additional 7-year-old and one additional 9-year-old were eliminated because of errors on the part of the experimenter. Written consent was received from adults and children’s parents. Children were tested individually in a quiet room in their preschools. None had participated in Experiment 1 or 2. Adults were individually tested in a quiet room in our laboratory or at home.

Procedure

Participants were tested in the auditory transparent cues condition, the visual transparent cues condition, and the visual arbitrary cues condition. Testing for children occurred in two sessions 1 or 2 days apart (the two conditions in the first session lasted a total of about 20 min, and the third condition, administered in the second session, lasted about 10 min). For adults, testing took place in one session (about 30 min). Condition order was counterbalanced across participants. Apparatus, materials, and procedure were strictly identical to those of Experiment 2 except that there were 2 × 16 simple-block test trials and 62 mixed-block test trials.

Results

Following the same procedure as in Experiment 1, 4.3% of trials were excluded from RT analyses. All participants perfectly answered cue questions for both visual transparent and visual arbitrary cues. To control for baseline differences in RTs among age groups, we conducted all RT analyses with RTs transformed to natural logarithm (following Meiran, 1996). For the sake of clarity, reported values were back-transformed. Data are shown in Table 1 and Figure 5.

We performed two (age: 7 years, 9 years, adults) × 3 (cue transparency: auditory transparent, visual transparent, auditory arbitrary) × 3 (trial type: single block, no switch, switch) ANOVAs on accuracy and RTs, with age as a between-subjects variable and cue transparency and trial type as within-subject variables. Both analyses revealed significant main effects of age, F(2, 81) = 11.02, MSE = 258, p < .0001, η² = .21, for accuracy; F(2, 162) = 71.49, MSE = .34, p < .0001, η² = .64 for RTs; of cue transparency, F(2, 162) = 9.45, MSE = 70, p < .0001, η² = .10, for accuracy; F(2, 162) = 56.88, MSE = 0.06, p < .0001, η² = .41, for RTs; and of trial type, F(2, 162) = 69.74, MSE = 73.00, p < .0001, η² = .46, for accuracy; F(2, 162) = 29.18, MSE = 0.03, p < .0001, η² = .93 for RTs. These main effects were qualified by significant Age × Trial Type interactions, F(4, 162) = 3.11, MSE = 73.00, p < .05, η² = .07, for accuracy; F(4, 162) = 3.40,
As an Age × Cue Transparency interaction for accuracy that approached significance, \( F(4, 162) = 2.15, \text{MSE} = 70, p = .07, \eta^2_p = .05; F < 1 \) for RTs. Most importantly, we obtained significant Cue Transparency × Trial Type interactions for both accuracy and RTs, \( F(4, 324) = 8.74, \text{MSE} = 34.00, p < .0001, \eta^2_p = .10 \); \( F(4, 324) = 16.94, \text{MSE} = 0.01, p < .0001, \eta^2_p = .17 \), respectively. Finally, the Age × Cue Transparency × Trial Type interaction fell just short of significance for accuracy, \( F(8, 324) = 1.86, \text{MSE} = 34.00, p = .06, \eta^2_p = .05 \), and was nonsignificant for RTs \( (p > .37) \).

### Mixing Costs

Overall, mixing costs were significant for accuracy, \( F(1, 81) = 27.53, \text{MSE} = 82.00, p < .0001, \eta^2_p = .25 \). They were significant for 7- and 9- year-olds, \( F(1, 81) = 20.40, \text{MSE} = 82.00, p < .0001, \eta^2_p = .20 \); \( F(1, 81) = 11.19, \text{MSE} = 82.00, p < .01, \eta^2_p = .12 \), respectively, but not for adults \( (p > .18) \). Mixing costs were significantly higher for visual arbitrary cues (7.9%) than for visual transparent cues (3.6%), \( F(1, 81) = 11.32, \text{MSE} = 34.00, p < .01, \eta^2_p = .12 \), and auditory transparent cues (1.3%), \( F(1, 81) = 17.17, \text{MSE} = 52.00, p < .0001, \eta^2_p = .18 \), which did not significantly differ \( (p = .10) \). Most importantly, the effect of cue transparency on mixing costs was moderated by age. For 7-year-olds, the gradation among auditory transparent, visual transparent, and visual arbitrary cues was significant, \( F(1, 81) = 3.97, \text{MSE} = 40.00, p < .05, \eta^2_p = .05; F(1, 81) = 5.42, \text{MSE} = 34.00, p < .05, \eta^2_p = .06 \), respectively. For 9-year-olds, the difference in mixing costs between auditory and visual transparent cues was not significant \( (p > .16) \), whereas the difference between visual transparent and visual arbitrary cues was significant, \( F(1, 81) = 8.78, \text{MSE} = 34.00, p < .01, \eta^2_p = .10 \). Finally, mixing costs did not differ across cue types in adults \( (\text{all } ps > .54) \).

Mixing costs on RTs were significant, \( F(1, 81) = 1,266.80, \text{MSE} = 0.03, p < .0001, \eta^2_p = .94 \), and remained so within each age group: for 7-year-olds, \( F(1, 81) = 426.58, \text{MSE} = 0.03, p < .0001, \eta^2_p = .84; \) for 9-year-olds, \( F(1, 81) = 498.61, \text{MSE} = 0.03, p < .0001, \eta^2_p = .86 \); and for adults, \( F(1, 81) = 352.84, \text{MSE} = 0.03, p < .0001, \eta^2_p = .81 \). Mixing costs increased both from auditory transparent cues (452 ms) to visual transparent cues (637 ms), \( F(1, 81) = 13.07, \text{MSE} = 0.01, p < .0001, \eta^2_p = .14 \), and from visual transparent cues to visual arbitrary cues (764 ms), \( F(1, 81) = 6.67, \text{MSE} = 0.02, p < .05, \eta^2_p = .08 \).
Local Costs

Local costs computed on accuracy rates were significant, $F(1, 81) = 58.82, MSE = 48.00, p < .0001, \eta^2_p = .25$, and remained so within each age group: for 7-year-olds, $F(1, 81) = 27.19, MSE = 48.00, p < .0001, \eta^2_p = .24$; and for adults, $F(1, 81) = 9.49, MSE = 48.00, p < .01, \eta^2_p = .11$. Local costs tended to increase between auditory transparent and visual transparent cues, $F(1, 81) = 3.09, MSE = 21.00, p = .08, \eta^2_p = .04$, and significantly decreased from visual transparent cues to visual arbitrary cues, $F(1, 81) = 4.82, MSE = 27, p < .05, \eta^2_p = .06$. Within each age group, this pattern was observed in 7-year-olds ($p > .12$ and $p < .05$, respectively) but not in older participants (all $ps > .22$).

Local costs on RTs were significant, $F(1, 81) = 20.70, MSE = 0.02, p < .0001, \eta^2_p = .20$. They were moderated by age, as they were significant for 7-year-olds, $F(1, 81) = 30.69, MSE = 0.02, p < .0001, \eta^2_p = .27$, but not for 9-year-olds ($p > .13$) or adults ($p > .34$). Local costs on RTs tended to increase between auditory transparent cues and visual transparent cues, $F(1, 81) = 3.03, MSE = 0.01, p = .08, \eta^2_p = .04$, but not between the two types of visual cues ($p > .91$).

Discussion

Experiment 3 examined the effects of cue transparency in 7- and 9-year-old children and in adults on the Advanced DCCS. The results replicated the effect of cue transparency on mixing costs. Most importantly, this effect progressively declined over age for accuracy, which is consistent with the claim that goal setting becomes easier as inner speech efficiency increases. Actually, mixing costs even disappeared in adults, suggesting that goal setting is no longer difficult when inner speech is efficiently recruited. The gradation of performance across cue types was fully significant at 7 years of age, partially significant at 9 years of age, and nonsignificant in adults. This partial cue transparency effect for 9-year-olds, even though children of this age are thought to resort to inner speech, suggests that children of middle childhood may still not use inner speech efficiently enough to fully compensate for the additional difficulty of arbitrary cues and/or may not use it spontaneously and, thus, in the experiment might have benefited from explicit instructions to do so. Consistent with this possibility, Kray et al. (2004) showed that switching performance of children of this age was less influenced than was older participants’ performance by task-incompatible verbalizations, suggesting little sensitivity to articulatory suppression.

Although the cue transparency effects on mixing costs decreased with age for accuracy, it remained significant for RTs in all age groups, including adults. Regardless of how efficient inner speech is, arbitrary cues may require more time to be translated. This additional time is necessarily included in latencies when cues and stimuli are simultaneously displayed. With no concomitant articulatory suppression, the additional time may not be captured in studies featuring long delays between cue and target onsets (see Kray & Eber, 2003, for consistent findings).

In addition to significant cue transparency effects on mixing costs, cue transparency also affected local costs (though to a lesser extent than mixing costs). Although not expected if one considers that local costs mostly reflect the switching process, this result could be consistent with the claim that goal reactivation is easier for no-switch than for switch trials because it matches the goal previously activated (Logan & Schneider, 2006).

Finally, regardless of cue transparency, we did not observe a uniform pattern of switch-cost reduction, but changes across age groups depended on the type of cost and the type of measure (disappearance of mixing costs on accuracy in adults and of local costs on RTs in 9-year-olds and adults). To date, the few studies that have examined such switch cost indices in children led to mixed results, sometimes finding age effects on both mixing and local costs (e.g., Cepeda et al., 2001; Davidson, Amso, Anderson, & Diamond, 2006), at other times finding age effects on mixing costs only (e.g., Dibbets & Jolles, 2006; Karbach & Kray, 2007; Reimers & Maylor, 2005), and in yet other instances, finding age effects on neither mixing or local costs (e.g., Ellefson, Shapiro, & Chater, 2006). Studies differed not only in the tasks to be switched but also in many parameters that have been shown to mediate the magnitude of switch costs, such as stimulus sample size (e.g., Kray & Eppinger, 2006), proportion of switches (e.g., Monsell, 2005), and cue–stimulus interval (e.g., Monsell, 2003). Indeed, some of these parameters may account for the surprising disappearance of local costs in 9-year-olds and adults. Local costs are largely reduced when stimuli frequently repeat because specific associations between cues, stimuli, and responses can be easily learned by younger but not older adults (Kray & Eppinger, 2006). In our study, as there were only two different stimuli in each condition, they very frequently repeated. Adults and 9-year-olds may have been more prone than 7-year-olds and preschoolers to infer and use these contingencies to override the cost of having to switch. In addition, switch costs are reduced with a high proportion of switch trials, as in the present study (50%), because participants expect switches to occur (Monsell, 2005; Monsell & Mizon, 2006; see also Schneider & Logan, 2006). Older children and adults may have anticipated switches more than younger children did, which could have reduced their local costs. Further research is clearly needed to disentangle the respective effects of such parameters on switch-cost evolution over age.

General Discussion

Older preschoolers have been shown to encounter difficulty on the Advanced DCCS, whereas they typically obtain ceiling performance on the standard DCCS. The Advanced DCCS differs from the standard version in the requirement to switch back and forth between two tasks and to set the relevant task goal on each trial on the basis of arbitrary cues. The present study addressed whether goal setting could account for preschoolers’ lingering difficulty by varying the degree of cue transparency. Moreover, the study also addressed whether cue transparency continues to affect goal setting in 7- and 9-year-olds and in adults. Experiments 1 and 2 showed that preschoolers’ performance increased as a function of cue transparency. In particular, preschoolers’ performance was higher with auditory transparent cues, which greatly reduced any need for translation, than with visual arbitrary cues. Experiment 2 further showed that the advantage of auditory transparent cues over visual cues was not related to the possibility of processing cues and stimuli through separate channels. Finally, Experiment 3 showed that the effect of cue transparency on accuracy perfor-
mance decreased with age, whereas it remained significant for RTs in older children and adults.

The difference in mixing cost between visual transparent and arbitrary cues was significant for accuracy rates but not for RTs in preschoolers (Experiment 1), whereas the reverse was observed for 7- and 9-year-olds and adults (Experiment 3). One might argue that the lack of significant difference in some cases might relate to a lack of distinctiveness between the two pairs of cues (both used a square). However, this seems unlikely because there is no reason to expect the cues to be distinctive enough to affect one index and not the other (unless RTs are not sufficiently reliable in preschoolers). In addition, although the increase in mixing costs between visual transparent and visual arbitrary cues reached significance in Experiment 1 only for accuracy and did not reach significance at all in Experiment 2, it was significant in Experiment 3, suggesting that the lack of significant effects in the previous experiment might relate to a lack of statistical power because of either poor reliability of RTs for young children (Experiments 1 and 2) and/or limited sample size (accuracy in Experiment 2). Instead, accuracy and RTs might reflect a trade-off between how hard the participants tried to translate visual arbitrary cues and the outcomes of their translation attempts. Because of the special difficulty of visual arbitrary cues, preschoolers might not have tried to translate them much longer than they attempted to translate visual transparent cues (no significant difference in RTs), but the translation was more often successful for transparent than for arbitrary cues (significant difference in accuracy rates). In contrast, in the majority of instances, older children and adults completed the translation of both cue types, hence leading to no differences in accuracy but showing the extra time needed to successfully translate visual arbitrary cues.

The cue transparency observed on the Advanced DCCS is consistent with some previous findings. Towsé et al. (2007) showed that on a task that required selective attention to one of two locations, 3- to 5-year-old children performed better with explicit arrow cues than with less transparent color cues. Similarly, Davidson et al. (2006) showed that 4- to 13-year-old children performed better on a classical Simon task with transparent stimuli than on a version in which they had to determine which rule to use according to arbitrary stimuli.

Similarly, the use of arbitrary cues and their simultaneous onset with stimuli, which are usual features of the Advanced DCCS, contribute to underestimating older preschoolers’ flexibility. Children in this age range encounter difficulty in setting task goals on the basis of such cues, which are difficult to translate and require maintaining cue–task associations in memory. Consequently, variables related to goal setting and/or switching per se should be distinguished in future research, and studies focusing on the switching process should use transparent cues that minimize goal-setting demands.

Thus far, goal setting has not been directly addressed by the main theoretical accounts of flexibility development. Previous work has focused on variables involved in the switching process (e.g., inhibition; Bialystok & Martin, 2004; Kirkham, Cruess, & Diamond, 2003; negative priming; Chevalier & Blaye, 2008; Zelazo, Müller, Frye, & Marcovitch, 2003). In contrast, the cognitive complexity and control theory (Zelazo et al., 2003) posits that flexibility depends on the ability to organize tasks into a hierarchical structure and to use this framework to select the relevant task. Although task selection and goal setting may be thought of as similar concepts, the present study extends this conceptualization further by suggesting (a) that goal setting and switching are two separable components of flexibility and (b) how they may be related. The findings suggest that goal setting is necessary for flexibility and that some inflexible behavior relates to failures at this level (as evidenced by the cue transparency effect on mixing costs). However, goal setting is not sufficient, as flexibility also requires successful switching once the correct goal is set (as evidenced by significant local costs even with the most transparent cues).

As goal setting is assumed to relate to verbal memory (e.g., Miyake et al., 2004), such a goal setting plus switching process account of flexibility adds substance to Munakata’s and his colleague’s proposal about the interaction between flexibility and memory development (Munakata & Miyake, 2007; Munakata, 2001) and is in line with recent evidence for goal maintenance failures in some measures of flexibility (Chevalier & Blaye, 2008; Marcovitch, Bosovski, & Knapp, 2007). Although memory and inhibition are not entirely independent (see Miyake et al., 2000), the goal setting plus switching process account has the potential to clarify Diamond’s (2006) hypothesis that flexibility involves both memory and inhibition by suggesting that memory may mostly mediate goal setting, whereas inhibition may primarily influence the switching process. One way to further explore this would consist in examining how mixing costs and local costs relate to different measures of inhibition and memory. Although, to our knowledge, this has not been tested thus far, Espy and Bull (2005) reported findings consistent with this possibility. These authors observed that high-span children (as measured by the forward digit span) have been shown to outscore low-span children in the flexibility part of the Shape School measure, which requires switching between color and shape naming in accordance with arbitrary cues, but not in the inhibition part of the task (Espy & Bull, 2005). Finally, whereas cognitive flexibility and, more broadly, executive control, has been thought to depend on the control component of working memory (e.g., Baddeley, 2003; Cowan, 1999; Engle, Kane, & Tuholski, 1999), evidence for the role of goal setting in flexibility and its relation with the phonological loop suggests that voluntary control of thought and actions involves not only the central executive but also a storage component, specifically, verbal short-term memory (Emerson & Miyake, 2003).

In the task-switching literature, goal setting is assumed to be achieved by recruiting inner speech. In Experiment 3, the effect of cue transparency was significant in 7- and 9-year-olds but disappeared in adults for accuracy, whereas it remained significant on RTs for all age groups. This suggests that efficient use of inner speech, as in adults, may be a powerful tool for translating arbitrary cues (no cue transparency effect on accuracy), though successful translation still slows responses, at least when cues and stimuli are simultaneously displayed. This suggests that cognitive flexibility development remains limited by poor goal-setting efficiency until at least 9 years of age. The ability to set goals probably develops at some point during late childhood and adolescence, as adult performance was found to be less affected by cue transparency than that of children. Goal setting may therefore play a major role in flexibility development, which occurs in that age range, though of course this needs further examination. The present study brought only indirect evidence regarding the relation between goal
setting and inner speech, as inner speech efficiency was not directly assessed and further research is needed to clarify the relation between inner speech and flexibility in children. Evidence for such a relation would back up the claim that language, in particular private or inner speech, is involved in executive control (e.g., Luria, 1961; Vygotsky, 1962), and it would shed new explanatory light on findings showing that children’s executive control often benefits from overt verbalizations (e.g., Diamond, Kirkham, & Amso, 2002; Fernyhough & Fradley, 2005; Kirkham et al., 2003; Kray et al., 2008; Kray, Eenshuistra, Kerstner, Weidema, & Hommel, 2006; Müller et al., 2004).

Although findings converge to show that verbalizations enhance executive control, there may remain executive processes that cannot (or cannot fully) be verbalized. In the present experiment, consistent with our hypotheses, local costs were not significantly decreased by verbal transparent cues, suggesting that verbalizing task names did not affect switching per se. Switching may depend on automatic phenomena that cannot be verbalized, such as task set inertia, that is, the lingering interference of the previous task set during its progressive decay (Allport et al., 1994), or response-based strengthening of stimulus–response associations (Steinhäuser & Hübner, 2006). This is not to say that switch implementation cannot be improved by verbalizations of any kind. Switching is also thought to involve voluntary processes (e.g., Monsell & Mizon, 2006), which could be mediated by verbal information other than task names. For instance, attention reorientation might benefit from verbal mediators related to the newly relevant dimension, value of the stimuli. Most importantly, even with verbal transparent cues, we observed a significant mixing cost in our series of experiments, suggesting that other processes, over and above those that can be fully verbalized, may contribute to this type of cost. Indeed, mixing costs are thought to reflect both goal setting and maintenance of two task sets in an active state (e.g., Miyake et al., 2004; Monsell, 2003). Of particular interest for future work would be to determine whether children can benefit from extra time between the cue and the stimulus to compensate for the difficulty of translating non-transparent cues. Children whose inner speech efficiency is low might not benefit from long intervals, whereas the cue transparency effect might disappear with long intervals in children whose inner speech efficiency is more advanced. In addition, future work should examine whether preschoolers’ performance improves with explicit instructions to use verbal task names for goal setting, as is the case for older children and adults (e.g., Kray et al., 2008).

In conclusion, the present study showed that children’s performance on the Advanced DCCS is influenced by cue transparency. Findings converge on the conclusion that cue transparency affects the difficulty of translating cues to set relevant task goals. However, as cues often are not available in everyday life, goal setting cannot be reduced to cue translation in all situations. Future research is needed to examine how children set goals in situations where goal setting cannot be achieved through cue translation and children must rely on other information (e.g., response feedback).

References


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