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The processes underlying flexibility in childhood

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It is now well established in the adult literature that the ability to engage in flexible thought and action is a complex skill that relies on a number of underlying processes. The development of this skill has received growing interest in recent years. However, theories explaining children's ability to switch between different tasks typically focus on a single underlying process and are rarely extended to explain development beyond the preschool years. This article reviews the current literature on set shifting in children in comparison with task switching in adults, in order to highlight the range of factors that impact on children's ability to flexibly shift between tasks. In doing this we hope to set the scene for future research that can begin to establish the relationships between these processes and how they change with age.

Keywords: Flexibility; Task switching; Shifting; Executive function; Cognitive control; Development; Children.

One of our most important skills as humans is the ability to quickly and flexibly adapt to an ever-changing environment, overcoming habitual, prepotent responses in order to engage in purposeful, goal-directed behaviours. This ability is known as cognitive control, or executive function. One of the hallmarks of this kind of behaviour is the ability to flexibly switch between different tasks, commonly termed set shifting or cognitive flexibility. Shifting is considered as one of the main components of cognitive control, along with working memory updating (the ability to manipulate and act on information held in mind) and inhibition (suppressing distracting information or inappropriate responses; Huizinga, Dolan, &

van der Molen, 2006; Miyake et al., 2000). Set shifting is particularly difficult when the same stimuli require different responses depending on the context, such as closing a document in the top left or right hand corner of a computer screen, depending on the operating system. Although we are capable of matching the required response to the changing situation, a deficit in performance is often evident when a shift is made, known as a switch cost.

Set shifting has been extensively, yet separately, investigated in both adults and children. This research has revealed that set shifting has a protracted development from the early preschool years to adulthood, and even in adulthood

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switching task sets comes with a cost in terms of slower performance. However, the independence of these lines of research has resulted in the use of completely different paradigms with children, especially preschoolers, and adults. It has also led to different theoretical accounts of flexibility development and set shifting in adults.

In this article we review the current developmental literature on shifting with reference to the adult task-switching literature, comparing the processes that contribute to flexibility in different age groups. By examining the range of processes that have been identified in adults, we can see the implications these have for developmental theories and identify factors that may be subject to developmental change. Areas where further developmental research is required can also be identified. In this way, we hope that this review can be used to move forward and extend existing research to target how shifting processes change with age, furthering our understanding of the development of flexible thought and action. We begin with a comparison of the different paradigms used in adult and developmental research before addressing the obstacles and control processes that contribute to set shifting.

Paradigm comparison

A number of paradigms have been developed to measure set shifting in both children and adults. Probably the most well known measure of flexibility is the Wisconsin Card Sorting Test (WCST; Grant & Berg, 1948). In this test, participants are given a deck of cards displaying 2–4 coloured shapes. They have to sort the cards first according to one dimension (colour, shape, or number) and, following a certain number of trials, switch to sort by a different dimension. In many versions, the participant is not told when the rule changes, but has to infer this using feedback given by the experimenter. In recent years, the WCST has become less popular, and researchers have extensively used the task-switching paradigm in both adults and, more recently, school-age children (see Meiran, in

press; Monsell, 2003, for a review of the adult task-switching literature).

In the task-switching paradigm, the participant is presented with a bidimensional stimulus that contains properties of both tasks. They are required to switch back and forth between tasks, based on either cues or sequence position information. Traditionally, participants alternate between simple blocks of trials with minimal flexibility demands, where the same task is to be performed across all trials, and mixed blocks in which they must alternate between two or more tasks from trial to trial. These blocks are heavily demanding in terms of set shifting. There are two main versions of the task-switching paradigm. In the alternating-runs version, participants have to switch between tasks in the mixed blocks on the basis of a predictable sequence of tasks (e.g., Task A, Task A, Task B, Task B). In the cueing procedure, tasks alternate unpredictably, and participants must rely on external cues (e.g., words) to decide on which task is relevant on each trial. Switch costs have been repeatedly observed on this paradigm. Adults generally perform better on simple blocks than mixed blocks and in turn on no-switch trials than switch trials.

In contrast, flexibility has mainly been investigated in preschoolers using paradigms reminiscent of the WCST, in which the children must sort cards (Frye, Zelazo, & Palfai, 1995; Zelazo, Frye, & Rapus, 1996; Zelazo, Müller, Frye, & Marcovitch, 2003), or choose items (Chevalier & Blaye, 2008; Deák, 2000; Espy, 1997; Espy & Cwik, 2004; Jacques & Zelazo, 2001; Smidts, Jacobs, & Anderson, 2004), on the basis of various perceptual features, typically colour and shape. The Dimensional Change Card Sort (DCCS; Frye et al., 1995; Zelazo, 2006) is undoubtedly the most widespread of such paradigms. In the first phase of the DCCS, children are explicitly instructed to sort cards according to a specific dimension (e.g., colour). In the second phase, children are required to switch and use the alternative dimension (shape) to sort the cards. It is now well documented that most 3-year-old children succeed in maintaining an

initial sorting dimension over the first phase but fail at switching dimension in the second phase, instead perseverating on the initial criterion. In contrast, most 4- and 5-year-old children successfully switch dimension, hence behaving flexibly (e.g., Kirkham, Cruess, & Diamond, 2003; Kloo & Perner, 2005; Zelazo et al., 2003). Such a progress in set shifting occurring between 3 and 5 years of age has been confirmed by similar age trends observed on other tasks including the Preschool Attentional Switching Task (PAST; Chevalier & Blaye, 2008) and Flexible Induction of Meaning task (FIM; Deák, 2000).

Fewer studies have been performed with school-aged children; however, these tend to use either versions of the task-switching paradigm (Cepeda, Kramer, & Gonzalez de Sather, 2001; Cragg & Nation, 2009; Huizinga et al., 2006; Kray, Eber, & Lindenberger, 2004; Reimers & Maylor, 2005) or the WCST (e.g., Chelune & Baer, 1986; Huizinga & van der Molen, 2007; Welsh, Pennington, & Groisser, 1991). Some studies have adapted the DCCS for use with older children, combining the stimuli used in the preschool task with multiple switches, more similar to the task-switching paradigm. This is known as the Advanced DCCS (Carlson, 2005; Chevalier & Blaye, 2009; Chevalier, Blaye, Dufau, & Lucenet, 2009a; Hongwanishkul, Happaney, Lee, & Zelazo, 2005).

Although there are basic similarities between shifting paradigms used with children and adults, there are many factors that differ. Comparison across age groups is hindered by such differences in paradigms. In the following section we compare different versions of set-shifting paradigms to highlight the similarities and differences and the implications this has for drawing comparisons about underlying processes.

Stimuli

One of the most consistent features of shifting paradigms across adult and developmental research is the presence of multivalent stimuli, which vary on at least two dimensions (i.e., red and blue rabbits and boats). The stimuli remain the same across the tasks, and the tasks are formed by

making decisions about different dimensions of the stimuli. The overlap between tasks at a stimulus level creates conflict between the tasks, which needs to be overcome in order to switch between them. The presence of bivalent stimuli has been found to be a crucial feature of the switching tasks. When tasks use different stimuli or univalent stimuli are used, switching becomes trivially easy, shown by a drastic reduction of switch costs in adults (Allport, Styles, & Hsieh, 1994; Jersild, 1927; Meiran, 2000; Rogers & Monsell, 1995) and a substantial increase in the number of 3-year-olds who can successfully pass the DCCS (Perner & Lang, 2002; Zelazo et al., 2003).

The dimensions typically used with preschoolers and older children are colour and shape, similar to the WCST. In the task-switching paradigm used with adults a variety of tasks have been used, including identifying the word or colour of Stroop stimuli (e.g., Allport et al., 1994; Allport & Wylie, 2000; Wylie & Allport, 2000), making decisions about the horizontal or vertical location of a circle in a grid (e.g., Meiran, 1996, 2000) and deciding whether letters are vowels or consonants and numbers odd or even in letter–number combinations (e.g., Rogers & Monsell, 1995; Sohn & Carlson, 2000). Moreover, developmental studies tend to use two exemplars of each dimension, whereas studies with adults use a larger set of stimuli. These differences have a number of implications. First, it may be easier to selectively attend to perceptual rather than semantic properties (Bialystok, 1999; Bialystok & Martin, 2004). Indeed, it is easier for school-age children to maintain or switch to thematic rules that can be easily conceptualized than it is to maintain or switch to hard-to-conceptualize taxonomic rules (Blaye, Bernard-Peyron, Paour, & Bonthoux, 2006; Blaye, Chevalier, & Paour, 2007; Blaye & Jacques, 2009; Maintenant & Blaye, 2008). Secondly, with a small set size, specific stimulus–response associations rather than task-level associations may be employed (Kray & Eppinger, 2006; Rogers & Monsell, 1995). The extent to which task type and set size influence shifting performance across the lifespan has not yet been systematically investigated.

Responses

In addition to overlapping stimuli, the same responses are typically used for both tasks in shifting paradigms, creating an extra level of competition. This is the case in the task-switching paradigm, where the same two button press responses are used for both tasks. It is also the case in the DCCS, where cards are sorted into the same two boxes. Some paradigms for preschoolers, in which the relevant dimension is labelled (Shape School; Espy, 1997) or the object in the correct colour chosen (PAST; Chevalier & Blaye, 2008) tend to have univalent responses, suggesting that the competition between tasks may be partially reduced in these paradigms, although they remain challenging for preschoolers.

Number of switches

Whereas the use of bivalent stimuli and responses tends to be a consistent feature across shifting paradigms, there are a number of other aspects that differ depending on the age of the participant. One such aspect is the number of switches that participants are required to make. In the DCCS and PAST, children perform one task for a number of trials and are then asked to switch only once to perform the alternative task. Ceiling performance on these paradigms is observed by 4 or 5 years, yet the Advanced DCCS, which requires more than one switch, demonstrates that once children master a single switch they still have difficulty switching back and forward between the same two tasks (Carlson, 2005; Hongwanishkul et al., 2005). Other paradigms that involve several successive switches have shown that set-shifting performance continues to improve. For instance, in the Object Classification Task for Children (OCTC; Smidts et al., 2004), participants must switch twice among object-sorting criteria based on shape, size, and colour. Similarly, on the Flexible Item Selection Task (FIST; Jacques & Zelazo, 2001), children are presented with several triads of pictures. One pivot picture matches each of the two other pictures on different dimensions (shape, colour, or size) while the two nonpivot pictures match on none. For each triad, children must make two successive selections of pictures that “go

well together”, hence leading to several switches among the three dimensions throughout the task. These tasks have been used with children up to the age of 7 years, at which stage ceiling performance has not been reached.

It has been argued that it is easier to consistently inhibit a task rather than repeatedly inhibit/activate the same task (Diamond, 2009). However, the difference between requirements to switch only once or several times has been overlooked in the preschool literature. The distinction may be an important one, as switching back and forth requires the additional process of reactivating a task that was previously abandoned and supposedly inhibited. Therefore, taking the number of switches into account has the potential to more accurately capture the complex dynamics of task switching.

Goal setting

Measures used with preschoolers and those used with older participants also strongly differ in the way a switch is instructed. As a result, their goal-setting demands, deciding which task is relevant on a given trial, differ. As the necessity of switching and the relevant task are explicitly announced and repeated before each trial on the DCCS and PAST, these measures are not demanding in terms of goal setting. In contrast, the measures yielding performance improvement after 4 years are more difficult in this respect since children must decide on their own which task is relevant and when a switch must be implemented. This is similar to the task-switching paradigms used with adults.

The instruction to switch is also indicated differently depending on the specific features of the measures. For example, on the Advanced DCCS (Carlson, 2005; Hongwanishkul et al., 2005), children must switch back and forth between sorting test cards by shape and colour on the basis of a visual cue (e.g., a thick border cues colour whereas a thin one signals shape). Similarly, in the Shape School (Espy, 1997), children must name hatless pictures according to their colour and hatted pictures according to their shape. In such cases, goal setting relies on cue-goal translation (e.g., Miyake, Emerson, Padilla, & Ahn,

2004). The cues used in different paradigms often vary in how informative they are of the upcoming task. In other situations, task goals must be set on the basis of an alternating sequence, as in the TRAILS-P, an adaptation of the Trail Making Test in which children must alternate between stamping dogs and bones from the smallest to the biggest (Espy & Cwik, 2004). These two types of goal setting are also involved in two versions of the task-switching paradigms used in adults: cued task-switching and alternating-runs paradigms, respectively. Comparison of switch costs computed using these two paradigms shows that their magnitude differs and suggests that they may, at least partially, relate to nonoverlapping processes (Altmann, 2007), possibly related to differences in goal setting. Finally, other measures require inferring relevant task goals on the basis of feedback (e.g., WCST), predicate cues (FIM), or even no specific information (children are only told to switch to a new task; e.g., FIST, OCTC), which may also involve different processes.

Dependent variables

The main dependent variable measured in different paradigms typically varies depending on the age of the participant. Switch costs in adults and older children are demonstrated in reaction times (RTs), although accuracy is also measured. In contrast, the main dependent variable in preschoolers is accuracy. Furthermore, whereas accuracy is assessed in terms of percentage correct or number of errors in older preschoolers and school-age children, it is often indexed as a pass/fail criterion in younger preschoolers. An important question when comparing paradigms is whether these different dependent variables are capturing the same processes, just expressed in different ways, or whether they may reflect different aspects of the task. To facilitate comparison, both accuracy and RT information should be

collected in all age groups where possible. Differences largely seem to occur because adults tend to slow down their performance to avoid making errors, whereas children do not. Therefore one possibility to directly compare children and adults on the same dependent variable would be to restrict the amount of time adults are given to respond, forcing them to make errors.

A number of different indices can be measured in shifting paradigms, taking advantage of both accuracy and RT data. For example, the task-switching paradigms offer the possibility of computing different switch-cost indices that specifically target different processes. *Mixing costs* contrast performance on single-block trials (the same task is relevant across all trials) to performance on no-switch trials from mixed blocks (trials for which the relevant task repeats). These are termed global costs when they are computed including all trials from mixed blocks. *Mixing costs* are assumed to reflect the difficulty of maintaining two task sets in working memory and setting the relevant task goal (e.g., Reimers & Maylor, 2005; Rubin & Meiran, 2005). *Local costs* compare performance on switch and no-switch trials within mixed blocks and are thought to reflect the difficulty of implementing a switch in task set per se (e.g., Rubin & Meiran, 2005).¹ Consistent with the claim that mixing and local costs reflect different processes, they have been found to be sensitive to different variables. For instance, mixing costs, but not local costs, are affected by stimulus ambiguity (Rubin & Meiran, 2005) and articulatory suppression (Bryck & Mayr, 2005). Developmental studies have also shown that the two costs reflect different processes, with evidence of different developmental trajectories. Reimers and Maylor (2005) observed a developmental evolution for mixing switch cost with a decrease between 10–11 years of age and 16–17 years and an even increase from late adolescence to late adulthood, whereas

¹ The concept of task set is widespread in the literature but very imprecise. However, it is commonly assumed to encompass a number of parameters related to perceptual, mnemonic, attentional, and motor processes that are essential for a given task goal (e.g., Mayr & Keele, 2000; Schneider & Logan, 2007). A task set allegedly includes stimulus encoding, action rules, and response selection (e.g., Gade & Koch, 2007; Rogers & Monsell, 1995).

local cost remained relatively stable across all age groups.

The computation of local costs and mixing costs allows a much finer grained examination of the processes underlying flexibility than the pass/fail criteria (e.g., standard and Advanced DCCS, PAST) or global efficiency scores (e.g., Shape School, Trails-P) traditionally used in paradigms for preschoolers. Yet, the features of some of these paradigms (Advanced DCCS, Shape School) would allow the computation of such indices. The systematic investigation of local and mixing costs in such paradigms would not only further characterize the processes involved in paradigms for preschoolers but would also facilitate comparison across ages, hence leading to a more unified picture of flexibility development from early childhood to adulthood.

Different processes can also be identified from patterns of errors when more than two tasks are switched between. In paradigms that involve switching between only two tasks (e.g., task-switching paradigm, DCCS, Shape School) participants can either respond correctly, interpreted as a mark of flexibility, or perseverate on the previously relevant (but now irrelevant) response. When more than two tasks are used (e.g., WCST, PAST-3, OCTC, FIM), it provides the opportunity to observe other types of behaviour. For instance the WCST (Grant & Berg, 1948) requires switching among three different sorting dimensions (colour, shape, and number). In this paradigm, perseverative errors can be distinguished from nonperseverative errors such as failure-to-maintain-set errors (occurring after a series of correct responses) or distraction errors, where a different dimension is selected from the one that has just been negatively reinforced (Barceló & Knight, 2002).

Perseverative and nonperseverative errors have been shown to be differently distributed in prefrontal patients and healthy adults (Barceló & Knight, 2002) and to follow different developmental courses (Chevalier & Blaye, 2008; Crone, Ridderinkhof, Worm, Somsen, & van der Molen, 2004; Huizinga & van der Molen, 2007; Somsen, 2007), suggesting that they result from failure of

divergent processes. These findings are particularly valuable in the preschool literature because the use of paradigms with only two response options had lured developmentalists into believing that all manifestations of preschoolers' lack of flexibility were perseverative in nature. This led to theories that accounted only for perseverative tendencies. Yet as these results and others suggest, preschoolers' lack of flexibility cannot be reduced to perseveration but instead is multidetermined.

Summary

Large differences in the paradigms used with children and adults necessarily occur due to the capabilities of the two age groups. These differences are summarized in Table 1. For preschoolers just beginning to demonstrate flexibility, an accuracy measure of a single switch is sufficient to assess their abilities, whereas in adults, for whom this is trivially easy, only the speed at which they can perform multiple successive switches reveals their limitations.

Direct comparison between research in preschoolers and adults is hampered by these differences; however, there are enough similarities between paradigms to undertake some comparison. This could be facilitated in future research by always including both accuracy and RT as dependent variables and measuring variables such as mixing costs and local switch costs, as well as categorizing different kinds of errors. However, in order to gain a better understanding of how flexibility develops, it is essential that more studies directly comparing different age groups are performed. Using paradigms similar to both the DCCS and adult task-switching paradigm, such as the Advanced DCCS, has a great deal to contribute to this area of research. It is also important to parametrically manipulate factors that differ across current paradigms in both children and adults, such as the tasks used and goal-setting demands, in order to determine the influence they have on shifting performance at different ages. This will enable comparison across situations that are as similar as possible and also lead to the development of new measures that can be used across the lifespan.

Table 1. A summary of some widespread shifting paradigms used with adults and children

	<i>Task-switching paradigm</i>	<i>Wisconsin Card Sorting Test (WCST)</i>	<i>Dimensional Change Card Sort (DCCS)</i>	<i>Advanced Dimensional Change Card Sort</i>	<i>Shape School</i>	<i>Flexible Item Selection Task (FIST)</i>	<i>Preschool Attentional Shifting Task (PAST)</i>	<i>Object Classification Task for Children (OCTC)</i>	<i>Flexible Induction of Meaning (FIM)</i>	<i>TRAILS-P</i>
Age group	adults and children over 5 years	adults and children over 5 years	3- to 6-year-olds	adults and children over 5 years	3- to 6-year-olds	3- to 6-year-olds	3- to 6-year-olds	3- to 7-year-olds	3- to 6-year-olds	3- to 5-year-olds
Number of tasks	two	three	two	two	two	three	two (three on PAST-3)	three	three	three
Stimulus valence	bivalent	trivalent	bivalent	bivalent	bivalent	trivalent	bivalent	trivalent	trivalent	univalent
Presentation	computer	cards	cards	computer	booklet	cards	computer	objects	objects	booklet
Response	manual button press	place card with target card	place card with target card	manual button press	label relevant dimension	select two cards that match on relevant dimension	manual button press	group objects according to relevant dimension	manual object selection	manual stamping
Response valence	bivalent	bivalent	bivalent	bivalent	univalent	bivalent	univalent	univalent	univalent	univalent
Dependent variable	RT and accuracy	accuracy, error types	accuracy	RT and accuracy	accuracy and completion time	accuracy	accuracy	accuracy	accuracy	RT and accuracy
Stimulus congruency	congruent and incongruent	congruent and incongruent	incongruent	incongruent	incongruent	incongruent	congruent and incongruent	incongruent	incongruent	incongruent
Number of switches	many	many	one	many	many	one switch for each triad; many triads	one	two	many	many
Indication of switch	cue presented in advance of the stimulus or alternating rule, e.g., AABB	switches must be inferred from feedback or told of switch but must infer new task (Nelson, 1976)	the switch and newly relevant task are explicitly announced	arbitrary cue presented with stimulus	arbitrary cue presented with stimulus	switches are explicitly announced but children must infer the newly relevant task	the switch and newly relevant task are explicitly announced	switches are explicitly announced but children must infer the newly relevant task	switches must be inferred from predicate cues	switches depend on an alternating rule

Note: RT = reaction time.

The wide array of paradigms used to assess set shifting in children may give a fragmented picture of its development; however, they also point out the diversity of the processes underlying flexibility. Specifying and taking advantage of the differences between paradigms can help to tease apart the different processes that contribute to developmental improvements in flexibility. We now move on to a discussion of these processes.

Processes contributing to flexibility

A number of theories have been proposed to account for the emergence of the ability to shift task in the preschool years (e.g., cognitive complexity and control theory, Zelazo et al., 2003; attentional-inertia theory, Kirkham et al., 2003; active/latent-representation theory, Morton & Munakata, 2002; object-redescription theory, Kloo & Perner, 2003). Although these theories sometimes acknowledge that multiple processes underlie switching, they typically argue that changes in a single process drive developmental improvement in switching. Moreover, they have rarely been extended to explain developmental trajectories beyond preschool years. Despite knowing that set shifting continues to develop into the teenage years (Chelune & Baer, 1986; Crone, Donohue, Honomichl, Wendelken, & Bunge, 2006; Crone et al., 2004; Huizinga & van der Molen, 2007; Welsh et al., 1991), comparatively little research has been undertaken to investigate factors affecting shifting performance in school-aged children and adolescents. As a result, these theories only explain the beginnings of the switching ability, rather than the extended developmental trajectory.

Many theories have been proposed to account for switch costs in adulthood, pointing out the role of processes and phenomenon such as active task set configuration (Rogers & Monsell, 1995), proactive interference remaining from having recently performed the alternative task (Allport et al., 1994), activation of the relevant, and suppression of the irrelevant, task set (Allport et al., 1994; Dreisbach & Goschke, 2004; Meiran, 1996; Rogers & Monsell, 1995), and filtering

task-irrelevant information (Mayr & Bryck, 2007; Meiran, 2000; Rubin & Meiran, 2005), as well as goal maintenance and performance monitoring (Baddeley, Chincotta, & Adlam, 2001; Gruber & Goschke, 2004; Miyake et al., 2004). Although these processes have the potential to shed new explanatory light on set-shifting development, they have not systematically been investigated in a developmental context. In the present section we discuss the main processes that have been identified in the developmental and adult literature and integrate findings from both of these lines of research.

Task decision and goal setting

When switching task, one of the first processes involved is selecting the appropriate task set. Although task sets are poorly defined, they are often thought to include elements related to task goals, task rules, stimulus encoding, and response selection, as well as parameters linked with perceptual, attentional, mnemonic, and motor processes (e.g., Mayr & Keele, 2000; Rogers & Monsell, 1995). Among the elements included in task sets, task goals have been given a specific status. Many authors have proposed theories of set shifting that include both a component dedicated to goal setting and a component for switching task set per se (Baddeley et al., 2001; Fagot, 1994, as cited in Allport & Wylie, 2000; Gruber & Goschke, 2004; Emerson & Miyake, 2003; Rubinstein, Meyer, & Evans, 2001). Although these theories diverge regarding details and terminology, they all agree with the claim that successful set shifting requires (a) determining which task goal is relevant and, if it is different from the previous one, (b) implementing a switch in task set (i.e., reorienting attention to the newly relevant information, selecting the correct response, and so on).

One such theory (Gruber & Goschke, 2004) distinguishes two distinct systems allegedly involved in set shifting. One of these systems is thought to depend on prefrontal-parietal and prefrontal-temporal cortex and would be used to temporarily maintain task-relevant information and “to exert top-down control by regulating and

modulating activity in different domain-specific sensory association areas” (p. 111). This would be achieved through activation of brain areas that process task-relevant information and inhibition of brain areas that process task-irrelevant information. The other system is assumed to rely on parietal and left premotor cortex and would be strongly associated with verbal rehearsal and inner speech. This system is allegedly involved in setting and maintaining verbal representations of task goals, especially when the relevant task goal is new. Goal setting is thought to be intrinsically dependent on inner speech and verbal memory.

Goal setting has also been shown to contribute substantially to performance on the task-switching paradigm. In the cued paradigm, goal setting has been hypothesized to be achieved using inner speech to translate task cues into verbal representations of task goals. Consistent with this hypothesis, Miyake et al. (2004) observed a detrimental effect of verbal dual tasks, such as articulatory suppression (e.g., repeating “the”), on switch costs whereas nonverbal dual tasks did not affect adults’ performance. In addition, the effect of articulatory suppression on switch costs was reduced when arbitrary or poorly transparent task cues (e.g., “S” for a shape-matching task and “C” for a colour-matching task) were replaced with more transparent ones (e.g., “SHAPE” and “COLOUR”), suggesting that, when inner speech is prevented, the difficulty of cue–goal translation depends on cue transparency (Miyake et al., 2004).

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 signalling the next task goal and thus must be translated through inner speech. Similarly, Logan and Schneider (2006) 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 processes underlying goal setting probably vary according to the specific features of

paradigms. Whereas goal setting depends on cue translation in the cued task-switching paradigm, it relies on goal retrieval, updating, and maintenance on the basis of a task sequence (e.g., alternate on every second trial: Task A, Task A, Task B, Task B) in the alternating-runs task-switching paradigm. Studies conducted with adults have shown that goal setting in such situations also depends on inner-speech recruitment and cue transparency (e.g., Baddeley et al., 2001; Bryck & Mayr, 2005; Emerson & Miyake, 2003; Kray et al., 2004; Saeki & Saito, 2004). Moreover, the close relation between goal setting and language in this paradigm is further attested by the facilitative effect of goal-related verbalizations on switching performance in both adults (Goschke, 2000) and school-age children (Kray, Eber, & Karbach, 2008).

Some paradigms for preschool and school-age children require translating task cues into task goals in the exact same way as the cued task-switching paradigm (Advanced-DCCS, Shape School). As children have been shown not to recruit inner speech spontaneously and efficiently on some memory tasks such as serial recall tasks (e.g., Flavell, Beach, & Chinsky, 1966; Gathercole, 1998; Halliday, Hitch, Lennon, & Pettipher, 1990), they may encounter similar goal-setting difficulties to those experienced by adults under articulatory suppression. Goal-setting difficulties on paradigms such as the Advanced DCCS and the Shape School seem all the more probable as these paradigms use arbitrary cues that are difficult to translate into verbal representations of task goals. Consistent with this, 5-to-6-year-old children’s performance has been shown to increase as a function of cue transparency on the Advanced DCCS even with no articulatory-suppression task (Chevalier & Blaye, 2009).

The structure of the Advanced DCCS (two simple blocks, in which the same dimension is relevant across all trials, followed by a mixed block in which dimensions alternate) allows computing both local and mixing switch-costs. Cue transparency has been found to affect only mixing costs—that is, the type of switch cost that specifically targets goal setting (Rubin & Meiran,

2005). These results evidence that preschoolers' set-shifting difficulties result at least partially from goal-setting failures. In addition, a decreasing effect of cue transparency on accuracy-based mixing costs in 7- and 9-year-olds and adults (although they remained significant on RTs), suggests that set-shifting progress occurring at school age relates partially to increasingly efficient goal-setting skills (Chevalier & Blaye, 2009). Such goal-setting improvement is likely to be related to the increase in inner-speech efficiency that occurs during school age (e.g., Flavell et al., 1966), although direct evidence of this still needs to be reported.

The Cognitive Complexity and Control (CCC) theory (Zelazo et al., 2003) suggests that children's flexibility is a function of the increasing ability to organize rules related to multiple tasks into a single hierarchical rule structure that allows children to determine which task is relevant and therefore which rules must be selected. Inhibition processes, supposedly in charge of switching task set per se, would be entirely dependent on task selection (Happaney & Zelazo, 2003), which is consistent with some hypotheses that only focus on goal setting to account for adults' performance in the task-switching paradigm (e.g., Schneider & Logan, 2006; Sohn & Anderson, 2001).

It can be argued that CCC theory emphasizes the role of goal setting, also termed task decision, in preschoolers' developing set-shifting skills. However, the CCC theory fails to satisfactorily explain at least two main phenomena regarding goal setting. First, it cannot explain why task decision is more difficult in the Advanced DCCS than the standard DCCS since both paradigms are characterized by the same rule structure. Second, if set shifting exclusively relates to task decision (goal setting), why do children and adults show significant local costs whereas their computation mode excludes goal-setting demands? Consequently, it appears that the relation between goal setting and task set switching is much more complex than is hypothesized by the CCC theory.

In summary, goal setting, deciding which task is relevant, is an important prerequisite of

switching task. It does not feature in the specific switching process, rather it occurs on every trial in situations where more than one task may be relevant. Research with adults has shown that goal setting is supported by inner speech and is affected by the transparency of the cues used to signal the upcoming task. A lack of spontaneous inner speech may explain why young children struggle with goal setting; however, further research is needed to probe the relationship between goal setting and inner speech in children more directly.

Overcoming the previously relevant task

One of the early theories to explain switch costs on the task-switching paradigm in adults, termed *task set inertia* (TSI; Allport et al., 1994) proposed that persisting involuntary activation of a previous task set remained after that task had been performed and interfered with performance of the current task. Allport et al. ran an experiment in which a group of participants were asked to switch between naming the colour of Stroop stimuli and stating the numerosity (how many there were) of a group of identical digits (i.e., ignoring the value of the digit). No switch cost was evident in this condition; however, when the participants were then asked to switch between reading the word of the Stroop stimuli and naming the value of the digits, large switch costs became apparent. These were attributed to interference effects from persisting activation of the irrelevant task that had previously been performed. This persisting activation decays with time, shown by the fact that increasing the time between trials reduces the switch cost (Allport et al., 1994; Meiran, Chorev, & Sapir, 2000).

In addition to persisting proactive interference from the previous trial, research in adults has shown that stimuli can also re-elicite irrelevant task sets due to stimulus-set binding. If a certain stimulus is associated with Task A in some trials, that stimulus will activate the task set for Task A even when Task B is being performed, creating interference and slowing performance. As a result, switch costs are increased for stimuli that have previously been associated with the alternative task set (Allport & Wylie, 2000; Gilbert &

Shallice, 2002; Waszak, Hommel, & Allport, 2003).

Waszak et al. (2003) found that stimulus-based priming occurred for congruent as well as incongruent stimuli, suggesting that priming occurs at the task level and is not confined to specific stimulus–response associations. However, it has been proposed that with a small stimulus set, as used with children, there is less need to engage task set level processes as the experiment progresses, due to associative learning strengthening the more basic stimulus–response mappings (Kray & Eppinger, 2006; Rogers & Monsell, 1995). Indeed, Kray and Eppinger (2006) found a greater reduction in switch costs with practice for a set size of 4 stimuli (animal and nonanimal words of one or two syllables) compared to a set size of 96. The influence of set size on switch costs has not been addressed in children; however, it would be an interesting issue to pursue as it may provide some insight on the extent to which children employ task-level representations when switching, compared to lower level item-specific stimulus–response mappings.

The effect of TSI on school-aged children's ability to switch tasks was explored by Cepeda et al. (2001) using the task-switching paradigm. They found that increasing the time between trials (while controlling for preparation time) reduced switch costs in adults, but not in children (aged 10 years and above). This suggests that children and adolescents experience greater interference from the persisting activation of previous, irrelevant, task set activations than do adults.

A similar concept to the task set inertia theory has been introduced to account for 3-year-olds' perseveration on the DCCS. Based on evidence that labelling the relevant dimension in the post-switch phase improves switching performance and leaving the sorted cards face up impairs switching performance, Diamond and Kirkham (2005; Kirkham et al., 2003) argue that children err because of *attentional inertia*—that is, because their attention is captured by the dimension relevant in the previous task, hence activating formerly relevant representations of the stimuli. However, contrary to Allport's theory that activation of the

previous task is due to involuntary priming effects (e.g., Allport et al., 1994; Allport & Wylie, 2000), Kirkham et al. (2003) postulate that attentional inertia is due to a difficulty actively inhibiting the previously relevant dimension. Diamond (e.g., 2006) argues that inhibition is one of the two main contributors to flexibility. She equates flexibility with a complex executive function that is involved in situation with working-memory demand to maintain two tasks in an active state and inhibition to switch from one task to the other.

The role of inhibition has also been highlighted by Bialystok (1999) who additionally suggested that inhibition demands are modulated by task complexity and related analysis demands. More precisely, flexible behaviour would be easier to engage in when the task to switch to only necessitates processing perceptual features of stimuli rather than when it requires identifying and interpreting semantic features. Consistent with this, preschoolers scored better on the traditional version of the DCCS (that involves switching between perceptual tasks) than on a version that required switching between semantic tasks (things that go outside/inside and toys/clothes; Bialystok & Martin, 2004; for convergent evidence, see Blaye et al., 2007; Blaye & Jacques, 2009; Blaye et al., 2006).

In summary, research in adults has shown that persisting involuntary activation from a previous task set, and priming of that task set from irrelevant stimulus dimensions, can interfere with performance on the currently relevant task. While in the adult literature overcoming interference from the previous task is thought to be one of many processes involved in shifting, it plays a central role in some theories of preschoolers' ability to shift tasks, such as the attentional inertia theory. Children may experience a greater amount of interference than adults (Cepeda et al., 2001), however this does not mean that it is the sole obstacle in children's ability to shift between tasks. An important point to consider when comparing interference in children and adults is that the difference in the stimuli used with children and adults may mean that interference from the previous task is experienced in different ways in the two age groups.

The small set sizes often used with children may mean that interference occurs between stimulus–response associations, rather than at a task level. Indeed, Bialystok and Martin (2004) showed that preschoolers did better with a traditional colour–shape version of the DCCS than a semantic version that used 10 items. However, this confounded set size with the type of categorization the task required (perceptual vs. conceptual), which may also independently influence shifting performance in children. Future research should use targeted experimental manipulations of set size and perceptual versus categorical tasks in both children and adults to directly address this question.

Overcoming the previously irrelevant task

Research in adults has shown that persisting interference can also arise from the inhibition as well as the activation of previous task sets (Allport & Wylie, 2000; Arbuthnott & Frank, 2000; Mayr, 2001; Mayr & Keele, 2000; Schuch & Koch, 2003). Mayr and Keele (2000) demonstrated this by comparing the switch from Task B to Task A in the sequence ABA, where Task A had just been abandoned, to the sequence CBA, where Task A was abandoned less recently. They found that it was more difficult to switch in the ABA than the CBA sequence. This is attributed to greater persisting inhibition of Task A, which takes time to overcome before Task A can be performed again. Mayr and Keele showed that this inhibition is not restricted to inhibition of specific exemplars, but occurs at an abstract task level. Moreover, using a variant in which Task A in the sequence ABA was not the irrelevant dimension for Task B, Mayr and Keele (Experiment 2) demonstrated that backward inhibition is not simply a variant of negative priming, whereby a distractor is inhibited, slowing responses when it becomes the target on the subsequent trial (although greater inhibition did occur when Task A was the distractor). Put a different way, backward inhibition reflects inhibition of the previous task set, not simply the current distractor.

Backward inhibition has not yet been investigated in children; however, negative priming has

been found to play a role in the DCCS. Zelazo and colleagues (Müller, Dick, Gela, Overton, & Zelazo, 2006; Zelazo et al., 2003, Experiments 8 and 9) showed that even when the values of the relevant sorting dimension in the preswitch phase (e.g., red and blue boats and rabbits, sorting by colour) were replaced in the postswitch phase (e.g., yellow and green boats and rabbits, now sorting by shape) children still performed as badly as on the standard version. As interference from the previously relevant dimension cannot be occurring in this case, children must be experiencing difficulty in reactivating the previously irrelevant dimension. Furthermore, Müller et al. (2006) showed that more 3-year-olds failed the task when the same values of the irrelevant dimension were present on the test and target cards during the preswitch phase (i.e., there was the possibility of responding according to the irrelevant dimension) than when the irrelevant values on the test card did not match the irrelevant values on the target card. This suggests that negative priming in the DCCS “largely depends on the presence of two possible ways of matching test and target during the preswitch phase and on the selection of specific rules or values in the context of competing distractors” (Müller et al., 2006, p. 401). The revised version of the CCC theory (CCC-r) takes these findings into account to include the inhibition as well as the activation of rules and also highlighting the relevance of conflict between tasks. However, the theory still maintains that age-related changes are due to increases in the maximum complexity of the rules that children can formulate, controlling the balance of activation and inhibition between tasks in a top-down manner.

Positive priming of the previously relevant set and negative priming of the previously irrelevant set have been proposed to explain the phenomena of asymmetrical switch costs in task switching in adults. Where two tasks are unequal in difficulty, such as word reading (easy) and colour naming (difficult) in the Stroop paradigm, larger costs are often found for switching to the easier task than for switching to the more difficult task (Allport et al., 1994; Allport & Wylie, 2000;

Wylie & Allport, 2000), although only under certain conditions (Monsell, Yeung, & Azuma, 2000; Yeung & Monsell, 2003). While this may seem counterintuitive, it is explained by the fact that in order to perform the more difficult task, greater activation of this task and greater inhibition of the easier task are required in order to overcome interference from the stronger easier task. These need to be overcome when the stronger task is switched back to, resulting in a larger switch cost.

Asymmetric switch costs have been demonstrated in school-aged children in task-switching paradigms that require switching between decisions about the colour or shape of coloured objects. Larger switch costs are found for the colour task, which participants find easier to perform (Cragg & Nation, 2009; Ellefson, Shapiro, & Chater, 2006). Interestingly, the DCCS also employs colour and shape tasks; however, no difference has been found in switching between the two tasks (e.g., Frye et al., 1995). This could be due to the fact that colour and shape tasks are equally difficult for preschoolers, or may suggest that asymmetric switch costs only arise in situations where frequent switches occur between the two tasks. A further possibility is that the asymmetry between colour and shape may be so subtle that it is conspicuous with reaction times but not with accuracy indices, especially pass/fail criteria.

In summary, as well as persisting activation of previous task sets, persisting inhibition also occurs. This is demonstrated in two ways. Backward inhibition shows that when a task switches, the previously relevant task is inhibited, and this inhibition then has to be overcome when that task is performed again. Additional inhibition is required when this task forms a distractor for the new task, as evidenced by negative priming. Manipulations of the DCCS have shown that negative priming influences preschoolers' ability to switch tasks. The CCC-r theory suggests that while this process is involved in shifting, it does not contribute to developmental improvements in performance. However, this hypothesis has not been explicitly tested, and it is

not known if and how changes in negative priming may influence development in shifting. Furthermore, no research has yet been undertaken to explore the role that backward inhibition may play in improvements in shifting with age.

Persisting inhibition of previous task sets is thought to contribute to the asymmetric switch costs seen in both adults and children when the tasks used vary in difficulty. This issue highlights the need to consider the relative difficulty of the tasks on shifting performance and to control for task difficulty if this factor is not of interest. Moreover, the fact that the relative difficulty of tasks may change across the lifespan, as appears to be the case with colour and shape, and is certainly true with colour naming and word reading, has important implications for designing studies that can be used with all age groups.

Which contributes more to shifting: Inhibition of the previously relevant task or activation of the previously irrelevant task?

A number of studies have been undertaken in order to ascertain which provides the biggest barrier to switching: inhibiting the previously relevant task or reactivating the previously irrelevant task. Dreisbach and Goschke (2004) addressed this question by presenting adult participants with pairs of letters displayed in different colours (e.g., a red "T" and a blue "A") and instructing them to indicate whether the letter in the relevant colour was a vowel or a consonant. After a series of trials, the relevant colour was changed. The authors manipulated the colours displayed before and after the switch in order to isolate, after the switch, the difficulty of disengaging from the previously relevant colour and the difficulty of activating the newly relevant one. In the "perseveration" version, the previously to-be-ignored colour disappeared after the switch whereas the initially relevant colour became irrelevant after the switch; switch costs could thus only reflect the difficulty of disengaging from the formerly relevant colour. In the "learned irrelevance" version, the initially relevant colour disappeared after the switch whereas the previously irrelevant one became relevant after the switch so that switch costs

could only reflect the difficulty of activation of the previously to-be-ignored colour. The results showed that the magnitude of switch costs was comparable across versions, suggesting that flexible set shifting depends on both successful disengagement from previously relevant task sets and successful activation of previously irrelevant task sets. Other studies suggest that activation of previously irrelevant task sets mainly account for switch costs, hence leaving only a minor role to task set disengagement (Maes, Damen, & Eling, 2004; Maes, Vitch, & Eling, 2006).

Similar mixed results have been obtained in preschoolers. Studies on the DCCS pointed out the equivalent contribution of failures to disengage from the previous dimension and failed activation of the newly relevant dimension to 3-year-olds' switching difficulty (Zelazo et al., 2003; see also Müller et al., 2006). On the PAST, results spoke to a greater difficulty of activating previously ignored task sets than disengagement from initial ones (Chevalier & Blaye, 2008). In sum, the studies led on both adults and preschool children converged to the conclusion that set shifting at least partially relies on activation of previously irrelevant information, while disengagement from previously relevant information is also challenging.

The studies reported in this section provide compelling evidence that a number of processes contribute to successful shifting. In turn, this has a tremendous impact on how preschoolers' lack of flexibility is construed. Preschoolers' lack of flexibility was thought to reflect failure to disengage from processing previously relevant information at a cognitive level (whether this failed disengagement result from immature inhibition or other factors; see Chevalier & Blaye, 2006; Garon, Bryson, & Smith, 2008, for reviews of these factors), triggering perseveration at the behavioural level (i.e., repetition of previous correct but now incorrect responses). Instead, evidence for difficulty activating previously irrelevant tasks shows that at least part of preschoolers' difficulty is not perseverative in nature. This highlights the need to distinguish between perseverative processing and perseverative outcomes, as the latter is not necessarily caused by the former (Chevalier & Blaye, 2008).

The fact that activating the previously irrelevant task and inhibiting the previously relevant task appear to contribute approximately equally in both children and adults suggests that the relative importance of these processes does not change with age. However, for overcoming both previously relevant and previously irrelevant task sets, an unresolved issue concerns the extent to which these involve passive priming effects versus active control processes. Difficulty reactivating previously irrelevant task sets has been thought to result from negative-priming phenomena that, in turn, are often assumed to be related to active inhibition (e.g., Tipper, 2001). Yet, activation failure evidence in 3-year-olds (Chevalier & Blaye, 2008; Müller et al., 2006; Zelazo et al., 2003) and negative-priming evidence even in 18-month-olds (Amso & Johnson, 2005) whose inhibitory control is immature suggest that activation failures may instead relate to automatic phenomena (see also Maes et al., 2004). Indeed, negative priming has been proposed to result from episodic retrieval processes (Neill, 1997) or automatic inhibition (Harnishfeger, 1995). While both passive and active processes are likely to be involved, the relative influence of these has important implications for the extent to which set shifting is considered an "executive" process.

One way to determine the balance between passive and active processes is to study developmental trajectories. Indeed, Cepeda et al. (2001) found that children as young as 7 years were as likely as adults to benefit from increased preparation time to actively prepare for the upcoming task, but that children did not benefit from a longer interval to overcome interference from the previous trial. This perhaps suggests that active processes of preparation mature earlier than overcoming the passive interference from the previous trial.

Information filtering

A well-established finding in the adult task-switching literature is the task congruency effect that arises due to the overlapping stimulus-response mappings of the two tasks (e.g., Goschke, 2000; Meiran, 1996; Rogers &

Monsell, 1995). Specifically, when the two dimensions of the stimuli indicate the same response (e.g., red and boat both require a left response) performance is faster than when the two dimensions indicate differing responses (e.g., red requires a left response, and boat requires a right response). This demonstrates that the irrelevant task remains active and interferes with performance on the current task. Congruence effects cannot be investigated in many preschool tasks as they only include incongruent stimuli. However, a comparison of the congruence effect in school-age children and adults using the task-switching paradigm (Cepeda et al., 2001) demonstrated a larger congruence effect in children, suggesting that they experience greater interference from incongruent stimulus-response mappings. Furthermore, a study comparing 5- to 8-year-olds and 9- to 11-year-olds suggested that this interference decreases with age (Cragg & Nation, 2009).

A further issue regarding information filtering concerns whether the interference largely occurs at the level of the stimulus or at the level of the response, which if bivalent, both contain properties of the two tasks. It is also of interest how this conflict affects switching performance. This question has been investigated in adults by comparing switching for univalent versus bivalent stimuli and responses. By manipulating the valence of both the stimuli and responses, Meiran (2000) showed that stimulus and response level interference have independent effects on switch costs, with a lower switch cost when univalent stimuli and responses are used. Other studies have failed to find an influence of stimulus and response interference on switch costs, but do show a reduction in mixing or global costs when univalent stimuli and responses are used (Mayr, 2001; Mayr & Bryck, 2007; Rubin & Meiran, 2005). This suggests that interference between tasks needs to be resolved on all trials in mixed blocks, not just on switch trials.

The influence of interference at the level of the stimulus and the response has also been investigated in children. Perner and Lang (2002) found that children performed better in a "same-silly" version of the DCCS than in the standard

DCCS when univalent test cards were used. In the same-silly version, children are instructed, in the postswitch phase, to keep sorting according to the same dimension (e.g., shape) but this time to put the test cards with the "wrong" target (e.g., boats with the rabbit target and rabbits with the boat target). Children were also better on the same-silly version with bivalent cards when the second dimension did not form a task (Kloo, Perner, Kerschhuber, Dabernig, & Aichhorn, 2008a). This suggests that the difficulty lies with conflict between tasks rather than simply a problem of selectively attending to one dimension, although this may also play a role (Brooks, Hanauer, Padowska, & Rosman, 2003). Some researchers have taken advantage of the fact that spatially separating the dimensions reduces the conflict between them (Garner & Felfoldy, 1970; Shepp & Barrett, 1991) by presenting children with cards showing either a coloured circle and adjacent outline of the shape (Kloo & Perner, 2005) or a black shape on a coloured card (Diamond, Carlson, & Beck, 2005). Consistent with theories that difficulties on the DCCS are caused by redescribing stimuli (Kloo & Perner, 2005; Perner & Lang, 2002) or disengaging from the previous dimension (e.g., Kirkham et al., 2003), separating the dimensions in this way improved switching performance in preschoolers. It appeared, however, that separating the dimensions on the test cards but not the target cards caused this improvement (Kloo & Perner, 2005). This suggests that children are more influenced by interference at the stimulus level than at the response level. Further evidence for this comes from the fact that separating the target locations so that there are four boxes, two for each task, does not improve preschoolers' performance on the DCCS (Rennie, Bull, & Diamond, 2004; Towse, Redbond, Houston-Price, & Cook, 2000). Interestingly, recent eye-tracking data have shown that from 4 years on, children's fixations on responses on the Advanced DCCS are very scarce as compared to fixations on the stimulus (Chevalier et al., 2009a), perhaps explaining why interference at this level has a greater effect on children's performance.

In a version of the task-switching paradigm used with older children, separating responses was found to help 9- to 11-year-olds but not 5- to 7-year-olds switch task (Cragg & Nation, 2009, Experiment 2), perhaps indicating that the level at which conflict causes most difficulty may change with age. In contrast to the work with preschoolers, separating the stimulus dimensions by placing the shape on a coloured background increased stimulus-level conflict in this study, particularly for the 5- to 7-year-olds. A similar finding has also been demonstrated with the Garner interference paradigm (Ridderinkhof, van der Molen, Band, & Bashore, 1997) and a switching paradigm in adults (Kloo, Perner, Trendl, Schmidhuber, & Aichhorn, 2008b). The reasons for this discrepancy between preschoolers and older children are unclear and warrant further investigation, particularly as this seems to be one area in which the processes underlying flexibility may undergo considerable changes during development.

In addition to interference between dimensions of the stimuli and between the responses, there is an additional level of conflict in the DCCS between the test cards (e.g., red boats and blue rabbits) and the target cards (e.g., blue boats and red rabbits) as they only match on one dimension. Some authors have postulated that children encounter set-shifting difficulty because of the visual conflict that arises between the bidimensional test and target cards (Garon et al., 2008; Perner & Lang, 2002) based on evidence that children's performance was found to improve when the bidimensional target cards were replaced with puppets. There are many pitfalls to this interpretation, however. First, spatially dissociating the dimensions on the target cards (Kloo & Perner, 2005) and using univalent responses (Rennie et al., 2004; Towse et al., 2000) also reduce conflict between test and target cards; however, this does not improve performance on the task. Second, set-shifting difficulties are observed on other paradigms such as the PAST in which responses are unidimensional (Chevalier & Blaye, 2008) and the Shape School in which the responses must be given verbally (Espy, 1997). In such paradigms the response options do not visually conflict with

the stimuli, and their meanings do not change as a function of the relevant task. These results suggest that visual conflict between stimuli and responses is not necessary to observe set-shifting difficulties in preschoolers. Instead, it seems that preschoolers encounter shifting difficulties whenever there is conflict among several possible responses to stimuli (whether or not the materialization of such responses visually conflict with stimuli). The fact that the use of puppets improves children's performance may be due to alternative reasons, such as helping to conceptualize the task or making the rules easier to remember.

Congruence effects demonstrate the importance of overcoming conflict in shifting paradigms, whether this occurs at the level of the stimulus, response, or in the DCCS, between test and target cards. Although congruence effects have not been directly measured in preschoolers, studies in older children and adults indicate that the ability to resolve conflict shows considerable improvement during development. Furthermore, the differential effects of spatially separating stimuli and responses in preschoolers, school-age children, and adults suggest that conflict may be experienced in different ways at different ages. This is one aspect of switching that has been studied across different age groups; however, the exact nature of these changes and how they influence the development of flexibility are still not understood. Theories of shifting development also need to be adapted to incorporate these developmental changes. The redescription and attentional inertia theories both explain the obstacle that stimulus conflict poses to preschoolers. Yet if preschoolers become able to switch task because they become able to redescribe the stimuli, why do older children and adults still struggle with stimulus conflict? Similarly, if improvements in shifting are due to changes in attentional inertia, how can the influence of response conflict be explained?

Goal maintenance and monitoring

In the paradigms used with younger preschoolers (DCCS, PAST), goal-management demands are greatly reduced by task switches being explicitly

announced and the relevant task being repeated before every trial. Although such situations do not require children to decide on their own which task is relevant, they may be demanding in terms of goal maintenance. Marcovitch, Boseovski, and Knapp (2007) showed that 4- to 5-year-olds' performance on the DCCS can be decreased with the introduction of nonconflicting trials (i.e., colour and shape lead to the same responses). The authors interpret this result in terms of goal neglect—that is, disregard of task requirements despite understanding and remembering them (Duncan, Emslie, Williams, Johnson, & Freer, 1996). They showed that when the series of postswitch trials mainly included nonconflicting trials, children progressively tended to neglect the new task goal (i.e., respond on the basis of the newly relevant dimension). Yet, goal neglect is detrimental for conflicting trials in which the two dimensions lead to different responses. By contrast, when the postswitch trials were mainly conflicting, the children had to refer to the new task goal to respond correctly, which helped them to actively maintain it. As goal maintenance depends on working-memory capacity, and working memory develops over the preschool period (e.g., Carlson, 2005), 3-year-old children may encounter goal-maintenance difficulty on the standard DCCS even though all trials are conflicting. Consistent with this, DCCS performance has been shown to be positively correlated with a task that favours goal neglect (Towse, Lewis, & Knowles, 2007).

Further evidence that maintenance is linked to set-shifting performance comes from Cepeda and Munakata (2007), who observed that children who correctly switched on the DCCS answered knowledge questions (e.g., "In the colour game, where do red ones go?") more quickly than perseverators did. According to the authors, these quicker responses reflect the higher strength with which switchers can actively maintain a representation of the newly relevant dimension as compared with perseverators, suggesting that maintenance capacity plays an important role in set shifting. These results are in line with Morton and Munakata's (2002; Munakata, 2001)

active/latent representation theory, which assumes that set shifting is dependent on the relative strength of active representations of the task to be switched to and the latent representation of the task to be abandoned. According to this theory, set-shifting development would be a function of age-related increase in active-memory resources.

Failures of goal maintenance have been indexed using nonperseverative errors and more specifically failures-to-maintain-set errors and distraction errors (e.g., Barceló & Knight, 2002). When tested on a version of the PAST with three response options that allowed distinguishing between perseverative and distraction errors, 3-year-olds were found to commit as many distraction as perseverative errors, suggesting that their difficulties on that paradigm relates at least partially to goal-maintenance failures (Chevalier & Blaye, 2008). On the WCST and WCST-like paradigms in which task goals must be set and maintained on the basis of feedback, distraction errors have been shown to follow a different developmental path from that of perseverative errors (e.g., Crone et al., 2004; Somsen, 2007). In particular, Crone et al. (2004) observed that perseverative errors attained adult levels by 11–12 years of age whereas distraction errors kept decreasing until 13–15 years.

Furthermore, 4- to 6-year-olds' performance on an inductive version of the PAST, in which the relevant colour had to be discovered on the basis of feedback, was found to improve throughout phases (i.e., colour changes), especially for older children (Chevalier, Dauvier, & Blaye, 2009b). This result suggests that preschoolers benefit from previous experience on the PAST to better process feedback, leading to increasingly efficient goal setting and maintenance on subsequent phases (e.g., having experienced on the first phases that a colour remained relevant for a whole series of trials, children may be inclined to strongly maintain the goal of a newly relevant colour on following phases). Consequently, it appears that feedback-based goal setting and maintenance progresses not only with age but also with experience with the switching context at a given age.

Task-goal maintenance in complex situations in which the relevant task must be ascertained on the basis of feedback is intrinsically related to monitoring control requirements and making necessary adjustments in behaviour. There is evidence to suggest that a monitoring difficulty may substantially contribute to children's difficulty with the WCST. Schouten, Oostrom, Peters, Verloop, and Jennekens-Schinkel (2000) found that with a simplified version of the WCST 4- to 10-year-old children did not appear to perseverate but instead adopted a trial-and-error approach to switching, suggesting that they were not monitoring performance cues. In addition, Crone et al. (2004) found that indicating the rule change attenuated perseverative responding in 8- to 9-year-olds on a task that involved switching stimulus-response mappings. From this they suggested that perseverative errors in the WCST may reflect children's failure to monitor performance feedback when switches are not explicitly cued, rather than a failure to switch attention away from the previous task.

Very young children may struggle to monitor performance even in situations where switching is explicitly announced. Bohlmann and Fenson (2005) showed that 3-year-olds' performance can be greatly improved on the DCCS by explicit feedback on the postswitch phase of the DCCS that clearly indicates that their responses are no longer relevant for the goal to be reached. This helps children to understand that they must behave differently (see also Deák, 2003; Kloo & Perner, 2005, for arguments in favour of children's misunderstanding of the mismatch between instructions and their responses on the DCCS).

In contrast to the task-switching paradigm, paradigms such as the WCST and the DCCS have a number of trials between switches, meaning that the currently relevant task must be maintained. Difficulties in maintaining the relevant task, as evidenced by distraction errors and poorer performance on knowledge questions, appear to contribute to preschoolers' difficulties with the task, as suggested by the active/latent representation theory (Morton & Munakata, 2002; Munakata, 2001). In addition to task maintenance, monitoring of performance in situations where the

task must be deduced on the basis of feedback also seems to pose difficulties for children. These findings are particularly important in that they stress that cognitive flexibility is not confined to switching processes in response to relevant environmental cues but it also encompasses maintenance of a given task set in the face of irrelevant environmental cues. Yet, this maintenance aspect of flexibility is often overlooked. The investigation of nonperseverative errors, derived from the literature on the WCST, has clearly shown that children's lack of flexibility partly relates to failure to maintain a task set after successfully switching to it. This difficulty once again suggests that there is much more to flexibility development than an increasing ability to override perseveration.

Conclusions and future directions

In summary, it can be seen that many of the processes involved in shifting in adults are also employed when children switch between tasks. In contrast to a widespread idea (e.g., Miyake et al., 2000) research in adults and children has shown that cognitive flexibility or task switching cannot be reduced to a single shifting process. Instead, flexibility appears to be underpinned by an array of processes: some being related to task decision/goal setting and others to shifting task sets *per se*; some being intentional in nature and others being automatic. Once a decision to switch is made, and the relevant task set is selected, persisting patterns of positive and negative priming from the previous task must be overcome while inhibiting the previously relevant task set and reactivating the previously irrelevant task set. Conflict from the stimulus-response mappings of the irrelevant task must also be filtered out and the currently relevant task then maintained until the next switch.

The present review has emphasized that work conducted on adults' flexibility can enrich the understanding of the mechanisms driving developmental changes. In particular, the fact that costs related to switching tasks do not exclusively reflect the difficulty of disengaging from the previously relevant task casts into doubt the dominant claim that preschoolers' lack of flexibility results

only from perseverative tendencies. Indeed, in addition to the specific process of switching and implementing the new task, research on the task-switching paradigm and the Advanced DCCS has identified the essential role of goal setting and maintenance for flexible behaviour. As evidenced by a larger influence on mixing costs than local switch costs, these processes seem to be involved in most situations requiring executive control, not simply when a switch in task is required. This demonstrates that flexibility is not just about switching.

The developmental studies reviewed have also informed our understanding of the end-state of shifting development in adults. Identifying diverging developmental trajectories for processes, such as preparation for the upcoming task versus dissipation of previous interference (Cepeda et al., 2001), perseverative versus nonperseverative errors (Chevalier & Blaye, 2008), or rule representation versus task set suppression (Crone et al., 2006), shows that these are separable, independent processes and consequently thus helps to formulate hypotheses about how these processes interact. Developmental studies can also generate testable predictions for adult research. According to Bialystok (1999), it is easier to selectively attend to perceptual properties that are generally relatively simple and readily available, rather than semantic properties that are complex and need interpretation to be identified. Therefore, conceptual aspects (here, stimulus complexity) are assumed to directly influence executive processes such as inhibition. Alternatively, it may be argued that conceptual aspects influence flexibility through goal setting because it is especially difficult to build a strong representation of the goal to be reached when this goal is hardly conceptualized. These hypotheses could be tested in adults using the task-switching paradigm, which allows identification of the processes related to either goal setting or switching through the computation of mixing costs and local costs, respectively.

This review has shown that flexibility is a complex executive function that taps into other widely acknowledged cognitive control mechanisms: inhibition and working memory. Many

results speak to the involvement of inhibition in task switching, and goal setting has been shown to be closely related to working memory (Gruber & Goschke, 2004; Miyake et al., 2004). This is consistent with Diamond's (2006) claim that flexibility requires the combination of working memory and inhibition. However, as our review points out, flexibility cannot be reduced to the conjunction of demands on working memory, to actively maintain two task goals, and on inhibition, to override the previous task set. Instead, the relations between flexibility and each of these executive functions are much more complex and involve multiple processes. However, studying the development of shifting and how this relates to changes in working memory and inhibitory skills is undoubtedly a useful way to determine the extent to which shifting does rely on inhibitory and memory processes. Furthermore, given that shifting incorporates working memory and inhibition, research on task switching not only furthers our understanding of the processes underlying flexibility and its development but also provides promising ways to further examine other executive functions.

In conclusion, the current literature demonstrates that similar processes underlie flexibility in both children and adults; however, we still know very little about how these processes change with age and which have the most influence on shifting development. For example, does the passive interference from positive and negative priming of previous tasks get weaker with age, or do the control processes required to overcome these get stronger? A further question that needs to be answered concerns whether qualitative changes take place, or if developmental improvements are simply quantitative. Given the similarity of the processes involved between children and adults, many of the changes may be quantitative. However, research into the role of perceptual, stimulus-level, and response-level conflict suggests that qualitative changes in the locus of interference between tasks may occur. Moreover, young children may face additional conceptual demands that are not a problem for older children and adults, such as the ability to see the same item in

different ways (Kloo & Perner, 2003). This is probably the case of 3-year-old children who are often unable to implement a single explicitly announced switch, as in the DCCS, but benefit from different parameter variations that disambiguate the necessity to forsake previously relevant behaviours.

Future research into the development of flexibility needs to combine experimental methodology with a developmental approach in order to understand how the processes involved in flexible thinking change with age. Additionally, more studies are needed with school-age children and adolescents in order to bridge the gap between the existing preschool and adult literatures. The use of paradigms such as the Advanced DCCS, which contain features of both the DCCS and task-switching paradigms, will aid in this endeavour. But there is also scope for the development of new paradigms that are suitable for use with different age groups. Importantly, there is a need to acknowledge the range of processes that shifting involves and begin to explore the relationships between these, rather than continue to pursue the single explanation theories that have dominated the field so far.

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