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Impaired task switching performance in children with dyslexia but not in children with autism

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Problems with cognitive control in both autism and dyslexia have already been reported in different studies. The present study specifically examined task-switching performance in children with autism and dyslexia. For this purpose, a multiple-trial paradigm was used with cues for colour- and shape-matching tasks presented before a run of trials. The cue could imply a task switch (when the cue changed the task) or a task repetition (when the cue did not change the task). Both reaction times and error rates were measured for switching, restarting, and general task performance. Participants were children with autism (24) and with dyslexia (25) and healthy controls (27) with normal IQ and ages from 12 to 18 years. The main finding was that while similar switching performance was observed between children with autism and the healthy controls, children with dyslexia showed a significant switch-specific delay relative to both healthy controls and children with autism. Furthermore, no deficit in restarting performance was observed for any of the two patient groups. Finally, additional evidence is provided for a more general deficit in information processing in dyslexia. Our data suggest that children with autism are able to switch between tasks in a similar way as do normally developing children as long as the tasks are unambiguously specified. Furthermore, the data imply switch-specific

deficits in dyslexia additionally to the deficits in general information processing already reported in the literature. The implications of our data are further discussed in relation to the interpretation of the Wisconsin Card Sorting Test.

Keywords: Cognitive control; Executive functions; Switch cost; Restart cost; Autism; Dyslexia.

A challenging topic to understand in terms of underlying neurocognitive mechanisms is the ability to execute control over ongoing cognitive processes. It is only when it fails that we become aware of its major role in our daily lives. Cognitive control, such as the ability to react in a flexible way to information in our environment, has been explored with a variety of experimental paradigms. A most common paradigm recently used for this aim is the so-called *task-switching* paradigm, in which participants are asked to repeatedly alternate between tasks (e.g., see Monsell, 2003, for an overview). In the present study, we investigated task-switching performance in two patient groups, namely in autism and dyslexia.

So far, evidence has been found for deficits on the level of cognitive control in individuals with autism as well as in individuals with dyslexia. Various studies on autism reported impairments in planning (e.g., Geurts, Verté, Oosterlaan, Roeyers, & Sergeant, 2004; Hill & Bird, 2006; Hughes, 1996; Hughes, Russell, & Robbins, 1994; Ozonoff et al., 2004; Ozonoff & Jensen, 1999; Ozonoff & McEvoy, 1994) and the inability to generate novel ideas and behaviours spontaneously (e.g., Boucher, 1988; Craig & Baron-Cohen, 1999; Turner, 1999; Wong et al., 2003). Dyslexia, on the other hand, has mostly been related to deficits in working memory (e.g., Smith-Spark & Fisk, 2007; Swanson, Ashbaker, & Lee, 1996) and sometimes with problems in shifting attention (e.g., Hari & Renvall, 2001; Lum, Conti-Ramsden, & Lindell, 2007; but see Badcock, Hogben, & Fletcher, 2008). Moreover, in the literature on autism, executive dysfunction has recently been proposed as a possible central component of this neuropsychological disorder (e.g., Hill 2004a, 2004b). However, although many behavioural studies (as outlined above) as

well as some functional neuroimaging studies (e.g., Just, Cherkassky, Keller, Kana, & Minshew, 2007; Schmitz et al., 2006; Shafritz, Dichter, Baranek, & Belger, 2008) have provided evidence of deviant brain activation supporting the executive-dysfunction idea in autism, this idea needs further specification in order to be functional for diagnosis, intervention, and theoretical understanding. Specifically, as the term "executive functions" covers different cognitive mechanisms (e.g., planning, working memory, cognitive flexibility, etc.), the executive dysfunction theory might apply to almost any neuropsychological disorder as there always might be a part of this concept that is impaired in a certain neuropsychological disorder. For instance, for dyslexia with its well-documented impairments in working memory, it would not be incorrect to say that this neurocognitive disorder can also be explained in terms of executive dysfunction. The danger behind such a broad theoretical concept is that different neuropsychological disorders could falsely appear to stem from similar neurocognitive deficits by placing these deficits under the executive-functions umbrella.

The present study focused on one specific aspect of cognitive control, namely on cognitive flexibility. Cognitive flexibility relates to the ability of the cognitive system to dynamically activate and modify cognitive processes in response to changing task demands and context factors (e.g., Deák, 2003). The cognitive adaptation occurs through a set of processes (e.g., set shifting) that result in representations and actions appropriate to the changed task demands and the current context. In patient studies, a variety of neuropsychological tests have been used to investigate cognitive flexibility, like the Intradimensional/Extradimensional (ID/ED) shift task of the

Cambridge Neuropsychological Test Automated Battery (CANTAB; e.g., Ozonoff et al., 2004), the Dimensional Change Card Sort (see Zelazo, 2006), and so on. A neuropsychological test that has often been used for this aim is the Wisconsin Card Sorting Test (WCST). This neuropsychological test involves cards that need to be sorted on one of three possible dimensions (colour, number, or shape). The currently correct dimension is not explicitly announced and changes according to a fixed number of trials. The experimenter tells the participants whether the card is placed correctly. Based on this feedback, the participants need either to continue or to change their sorting rule. The performance on WCST is measured in terms of errors. Neuropsychological studies on cognitive flexibility have tended to focus on the number of *perseverative* errors, which are seen as a failure to shift to the new sorting rule and, therefore, as an index of cognitive flexibility. Many different studies have shown that individuals with autism are highly perseverative in their response to WCST (see Hill, 2004a, 2004b, for a review) compared to healthy controls. Different from individuals with autism, individuals with dyslexia seem in general not to experience more difficulty on WCST than do normally developing comparison groups (e.g., Bental & Tirosh, 2007; Rumsey & Hamburger, 1990). Helland and Asbjørnsen (2000), however, reported that children with dyslexia made significantly more nonperseverative errors than the healthy controls. Importantly, also in their study, performance on perseverative errors was similar for the two groups.

Altogether, neuropsychological studies indicate that the WCST is (at least) more challenging for individuals with autism than for individuals with dyslexia. Additional evidence confirming this idea comes from the studies that specifically compared the performance on WCST between autistic and dyslexic populations (e.g., Liss et al., 2001; Ozonoff & McEvoy, 1994; Rumsey & Hamburger, 1990; but see Nyden, Gillberg, Hjelmquist, & Heiman, 1999). It is not surprising then that individuals with autism are mostly seen as being cognitively inflexible, or, more precisely,

as having problems with shifting between different thoughts or actions when required (e.g., Hill, 2004b). In accordance with the scores on WCST reported for dyslexic individuals, problems with set shifting have not been assumed in dyslexia. The experiences reported in daily lives from individuals with autism (e.g., extreme resistance to change of any kind) and dyslexia (i.e., no observable problems with the dynamics of daily life) only reinforce these conclusions. Despite the fact that these conclusions may sound reasonable at an intuitive level, we put forward a couple of reasons why it could be interesting to investigate set shifting in these two patient populations in more detail.

To start with, the measures of cognitive control used in experimental and clinical neuropsychology might not always be optimal for their purpose (e.g., Burgess et al., 2006; Manchester, Priestley, & Jackson, 2004). Although potentially useful, the WCST might not be an optimal tool to investigate set-shifting performance (e.g., Cepeda, Cepeda, & Kramer, 2000). The WCST is a complex neuropsychological test requiring different cognitive capacities for successful performance, such as problem solving based on feedback, working memory, and inhibition of prepotent or inappropriate responses. Even on a more fundamental level, WCST requires the ability of recognizing the ("obvious") rules defined by others and the ability of generating and applying a certain rule. Accordingly, poor performance on this multifactorial (e.g., Miyake et al., 2000) test might arise for many different reasons and not only due to poor set shifting. Finally, since the performance on WCST is only measured in terms of errors, the scores are susceptible to speed–accuracy trade-off. In other words, one cannot exclude the possibility that a participant who shows no deviant error performance on the WCST could show a deviant performance on the same test when also measuring reaction times (RTs).

Hence, the present study examined shifting abilities in children with autism and dyslexia with a task-switching paradigm, which allows for a more controlled examining of set-shifting performance by focusing specifically on task-switching abilities. In this way, set-shifting

performance corresponded to task-switching performance in the present study. Specifically, we investigated the ability of performing an actual (local) task switch by means of a *multiple-trials* paradigm (e.g., Altmann & Gray, 2002). The rationale behind this paradigm is similar to that behind the WCST—namely, that the ability to switch repeatedly between tasks can be seen as an obvious expression of cognitive control. As in a typical task-switching paradigm, the stimuli used here contained two features that each could be mapped to an arbitrary response. Specifically, the stimuli were geometrical figures filled with different colours, and the two tasks assigned to these bivalent stimuli were colour- and shape-matching tasks. Since bivalent stimuli as such can call for both tasks, cues were used to specify the required task. The cues occurred intermittently between runs of trials belonging to one of the two tasks. Accordingly, the cue indicated either a task switch (when the cue changed the task) or a task repetition (when the cue did not change the task). Given that the cues unambiguously specify the required task in this paradigm, the performance does not depend on someone's ability to discover a currently correct rule, as in the WCST task. Furthermore, the paradigm includes the measurement of both speed and accuracy and, therefore, allows for controlling the possible presence of speed–accuracy trade-off.

Most importantly, this paradigm makes it possible to examine the ability to switch tasks in isolation from other cognitive processes involved in a more general task execution. Usually, this local task switching is accompanied by a performance cost, the so-called *switch cost*, which is the basic phenomenon of task-switching research and is reported in many studies using different tasks and paradigms. The switch cost is mostly reported in terms of longer RTs or higher error rates on trials immediately after a task switch than in repetition trials, in which the task performed is the same as that in the preceding trial (for details on definitions of switch cost see Altmann, 2007). It has been suggested that the switch cost measures local (i.e., transient) cognitive control during task switching, reflecting a different mechanism from

the one behind a more global (i.e., sustained) type of control also detected in situations of task switching (see, e.g., Braver, Reynolds, & Donaldson, 2003). The present study mainly focused on transient cognitive control mechanisms. Next to switching performance, a multiple-trials paradigm allows for investigating task-restarting performance. Different studies showed that restarting performance is accompanied by a performance cost called *restart cost* (e.g., Allport & Wylie, 2000; Altmann & Gray, 2002; Gopher, Armony, & Greenshpan, 2000; Poljac, De Haan, & Van Galen, 2006). The restart cost is observed in terms of slower performance on the first trial in a run of RT trials, after a brief task interruption but no switch of tasks. Poljac, Koch, and Bekkering (2009) showed that restart cost develops whenever task switching is involved and originates from processes involved in cue-based task activation that is needed to resolve task interference. Accordingly, we used restart cost as an indicator for the general processing of cues in situations involving interference between competing tasks. Specifically, as cue-based task activation takes place on all cued trials in the multiple-trials paradigm, measuring the restart cost allowed us to control for the possible contribution of cue-based task activation to switch cost. Finally, we assumed that the performance on the trials that were not cued in this paradigm reflected the general task performance. Especially in patient studies, it seems crucial to have an estimation of a general performance that can be used as a reference ("baseline") performance to account for possible large individual differences present in patients.

The aim of the present study was to investigate task-switching performance in children with autism and dyslexia and to validate the existing assumptions based on the WCST data about their cognitive (in)flexibility. If the difficulties with WSCT reported for children with autism arise due to impaired switching performance, then we expect to find a greater switch cost in this group than in healthy controls. Following the same logic for children with dyslexia, however, we expect no significant differences in switch cost as compared to healthy controls.

Importantly, if performance on the WCST is not directly related to switching performance, then the results of this study might shine some new light on the cognitive switching capacity in the tested populations. Finally, this study investigated task-restarting performance in both children with autism and those with dyslexia, which has not been addressed before in the literature.

Method

Participants

The participants whose data we analysed in this study included three groups of children: 24 children with autism/pervasive developmental disorder (PDD), 25 children with dyslexia, and 27 typically developing children. The children with autism/PDD were recruited through two clinical institutions (Dr. Leo Kannerhuis and Karakter Child and Adolescent Psychiatry University

Center Nijmegen) specialized in autism in The Netherlands. Of the 24 participants, 17 were diagnosed with autistic disorder and 7 with Asperger's syndrome. All diagnoses were based upon the *DSM-IV* (*Diagnostic and Statistical Manual of Mental Disorders—Fourth Edition*; American Psychiatric Association, 1994) criteria for autistic disorder and Asperger's syndrome and were made by at least one child psychiatrist with expertise and considerable experience in autism after extensive diagnostic evaluation including a review of prior records (developmental history, child psychiatric and psychological observations and tests, and neurological investigations), a parent interview, and a child psychiatric observation. In addition, the Autism Diagnostic Interview–Revised (ADI–R) was administered to the parents of the half of our population with autism by a trained psychiatrist (see Table 1). The children with dyslexia and the healthy controls were

Table 1. *Descriptive measures of the three groups of participants*

	Autistic children			Dyslexic children			Healthy controls				
	N	M (SE)	Range	N	M (SE)	Range	N	M(SE)	Range	F	p
Participants											
Total	24			25			27				
Women	2			5			5				
Left-handed	5			3			6				
ADHD	2			1			0				
Gilles de la Tourette	3			0			0				
Dysthymia	3			0			0				
Age (in years)		15.4 (0.4)	12.0−18.0		15.4 (0.2)	12.6−17.1		15.2 (0.3)	12.8−17.4	0.24	.79
IQ											
Full Scale		102 (3.7)[a]	75−129		101 (1.6)[b]	86−114		96 (1.6)	80−110	(2, 68) 2.3	.11
Verbal Scale		106 (3.1)	70−139		99 (2.3)[b]	81−111		93 (2.4)	75−114	(2, 72) 6.3	.003
Performance Scale		101 (3.1)	72−132		97 (2.3)	72−122		103 (2.4)	83−124	(2, 73) 1.4	.25
ADI−R											
Social		16.08 (1.77)									
Nonverbal		12.83 (1.10)									
Verbal		7.92 (0.75)									
Stereotype		4.17 (0.86)									
Onset		1.75 (0.33)									

Note: The Autism Diagnostic Interview−Revised (ADI−R) was administered to the half of the population of children with autism. These were the children who just entered the clinic and as such followed the most recent screening protocol, which also includes the administration of the ADI−R. ADHD = attention-deficit/hyperactivity disorder. Standard errors (*SE*s) are given in parentheses.
[a]4 missing. [b]1 missing.

recruited from four state schools that provide special aid for dyslexic children. Children with dyslexia were diagnosed by different official Dutch institutions specialized in dyslexia. They all met *DSM–IV* criteria for developmental reading disorder. Except for one child with dyslexia who was also diagnosed with attention-deficit/hyperactivity disorder (ADHD), the children in this group had no additional neurological or developmental disorders. None of the healthy controls had any diagnosed disorder or obvious developmental delay. Table 1 gives an overview of the present comorbidities in the three populations.

We included children from 12 to 18 years old (age criterion), with an IQ above 70 on all three IQ scales (IQ criterion). Next, attempts were made to match each child from a group on chronological age and Performance IQ to a child from the other two groups. IQ was measured by the Dutch version of the Wechsler Intelligence Scale for Children (WISC–III^{NL}) or by the Dutch version of the Wechsler Adult Intelligence Scale (WAIS–III^{NL}) for the participants above 17 years old. For most children with autism/PDD, the IQ scores on WISC–III were available as a part of the standard protocol when entering the clinical institution. A short version of WISC–III (or WAIS–III) was used to estimate the IQ for children whose IQ was unknown (including all children with dyslexia and healthy controls) or was estimated longer than five years ago. The short version consisted of the following four subtests: Similarities and Vocabulary for Verbal IQ; Block Design and Picture Completion or Object Assembly for Performance IQ (see, e.g., Sattler, 2001). Table 1 shows no significant differences in age or Performance IQ between the three groups. For the sake of completeness, Table 1 also shows the Full Scale IQ and the Verbal IQ. Only on the Verbal IQ did we find a significant difference between the groups. Specifically, the healthy controls had a significantly lower Verbal IQ than both children with autism, $F(1, 49) = 9.80$, $p = .003$, and children with dyslexia, $F(1, 49) = 5.07$, $p = .03$. Due to our exclusion and matching criteria, an additional 19 children were excluded from the further data analysis: 1

child with autism who was too young, 2 children with dyslexia who both made errors more than 2 standard deviations from the mean for this group, and 15 healthy controls whom we could not match to the two patient groups due to deviant age and/or IQ. Finally, the protocol was approved by the local medical ethical committee (Commissie Mensgebonden Onderzoek Arnhem Nijmegen). Written informed consent as well as oral consent was obtained from the parents of each child prior to any testing.

The matching task

Four different geometric figures (a square, a triangle, a circle, and a hexagon) displayed in one of four different colours (red, blue, yellow, or green) were used as stimuli. On each trial, a set of stimuli consisting of a reference figure and four match figures was simultaneously presented on a computer screen. The reference figure was displayed in the upper half of the screen, while the four match figures were displayed in the lower half of the screen. The two tasks were to match either the colour or the shape of the reference figure to one of the four match figures. The colour–shape combination of a set of stimuli was randomly chosen in each trial with two restrictions. First, no simultaneous occurrence of the same shape or colour was allowed among the four match figures within a trial. Second, the exact match (in both shape and colour) was not allowed between the reference and the match figures.

The cues used to announce the upcoming task contained an illustrative and a verbal element. For the colour task, an illustration of the four colours together with the words "find the colour" was used. For the shape task, an illustration of the four shapes, in black and white, was presented together with the words "find the shape". Finally, the pace of the matching task was tested in a pilot with 10 children opting for an average error rate between 10 and 20%.

Procedure

Each participant carried out the matching task in a single session. Written instructions were displayed on a Pentium III 650 MHz (17-in. effective

screen), which was placed at a distance of approximately 60 cm. A verbal explanation of the experimental procedure and the task was also given. The participant was asked to respond as quickly and accurately as possible by pressing one of the four buttons on a button box with either the index or the middle finger of either the right or the left hand. The four buttons corresponded to the location of the four match figures that were presented on the screen. Both the reference and the match figures remained on the screen until the participant gave a response or until the maximum response time of 3 seconds had elapsed (no-response). In the latter case, the participant received feedback to respond more quickly.

After the instructions, the participant started practising the tasks. The practising included randomly induced task switching. The actual tasks were organized in runs of six trials on average with a minimum of four and a maximum of eight trials. The actual length of task runs was randomly determined and was, therefore, unpredictable for the participants. The difference between the two matching tasks lay in the relevant stimulus information, which means that either the colour or the shape of the reference figure needed to be matched. The nature of the upcoming task was specified by a cue, which appeared at the centre of the computer screen at the beginning of a task run. The cue remained visible for 1,000 ms and was followed by 700 ms of a blank screen. After the blank screen, the first stimuli set appeared on the screen until a response (or feedback if too slow) was given. The response–stimulus interval (RSI) was fixed at 700 ms within the run, after which period a new stimuli set appeared, followed by a response. This was repeated until the response on the last stimuli set was given. The last response in the task run was followed by 700 ms of the response–cue interval (RCI). After the RCI, a new run started, again preceded by a task cue. No switching between the two tasks occurred within runs.

The 14 task runs of the practice part were followed by the experimental part, which was divided in four sections separated by a break.

The participants were encouraged to use the breaks to recover.

Design

The experimental part consisted of 124 task runs (744 trials), which were equally divided over the four sections. The first task run of each section was considered as a warming-up run of that section. One half of all task runs in the experimental part were the so-called *switch* runs, in which the task differed from the task in the previous run. The other half were the task *repetition* runs, in which the task to be performed was identical to the task in the preceding run. The two tasks were equally represented in both types of task run.

In this study, within-subject variables were run type (switch and repetition) and trial (1, 2, 3, and 4) with group (autistic, dyslexic, and healthy) as the between-subject variable. As the variable task (colour and shape) did not produce any interactions that would change any of our theoretical conclusions, we decided to collapse the data across the task variable. We measured switch cost as the difference in performance on Trial 1 between switch and repetition runs. Restart cost was measured as the difference in performance between Trials 1 and 2 in task repetition runs. General task performance was measured as the performance on the noncued trials—that is, on Trials 2, 3, and 4. As dependent variables, RTs were measured for each button press, and incorrect responses as well as no-responses were recorded. An alpha level of .05 was used for all statistical tests in this study.

Results

Apart from the 14 practice runs that were not analysed, error trials and no-response trials were excluded from the RT analysis as well as the trials that immediately followed. Furthermore, if within a certain task run all trials were error trials, the whole task run that immediately followed was also not included in the analysis. Due to these exclusion criteria, 8.6% of all trials were excluded from the analysis. Finally, error rates were first transformed using the arcsine

transformation (Bishop, Fienberg, & Holland, 1975) to achieve approximate variance equality. The task runs included in the analysis contained on average an error rate of 11.22, 15.65, and 12.09%, for children with autism, dyslexia, and healthy controls, respectively.

Switch cost

A 2×3 (Run Type $\times$ Group) repeated measures analysis of variance (ANOVA) applied on median RTs on Trial 1 yielded significant main effects of run type, $F(1, 73) = 119.49$, $p < .001$; and group, $F(2, 73) = 4.62$, $p < .05$. On average, participants responded significantly slower on Trial 1 after a task switch (982 ms) than after a task repetition (863 ms). Furthermore, univariate contrasts indicated a significant difference in RTs between children with dyslexia and both children with autism, $F(1, 47) = 8.38$, $p = .006$, and healthy controls, $F(1, 50) = 5.59$, $p = .022$. Averaged across run types, the performance on Trial 1 was slower in children with dyslexia (996 ms) than both in children with autism (878 ms) and in healthy controls (895 ms). Performance on Trial 1 was similar for children with autism and healthy controls, $F < 1$.

Figure 1 shows a significant switch cost for each group of participants, with $F(1, 23) = 28.03$, $p < .001$; $F(1, 24) = 47.70$, $p < .001$; and $F(1, 26) = 49.39$, $p < .001$, for autistic (94 ms), dyslexic (168 ms), and healthy group (96 ms), respectively. Importantly, as Figure 1 shows, a significant interaction between run type and group was observed on Trial 1, $F(2, 73) = 4.87$, $p < .01$. Children with dyslexia showed a significantly larger switch cost than did both children with autism, $F(1, 47) = 5.89$, $p = .019$, and healthy controls, $F(1, 50) = 6.82$, $p = .012$. In addition, no difference in switch cost was observed between the last two groups, $F < 1$.

Analysing the error rates on Trial 1 yielded significant main effects of run type, $F(1, 73) = 320.37$, $p < .001$; and group, $F(2, 73) = 3.62$, $p < .05$. On average, participants made significantly more errors on Trial 1 after a task switch (22.16%) than after a task repetition (6.07%). Furthermore, children with dyslexia (16.99%) made significantly more errors than both children with autism (12.05%) and healthy controls (13.30%), which was confirmed by univariate contrasts, with $F(1, 47) = 6.05$, $p = .018$; and $F(1, 50) = 4.57$, $p = .037$, respectively. Also
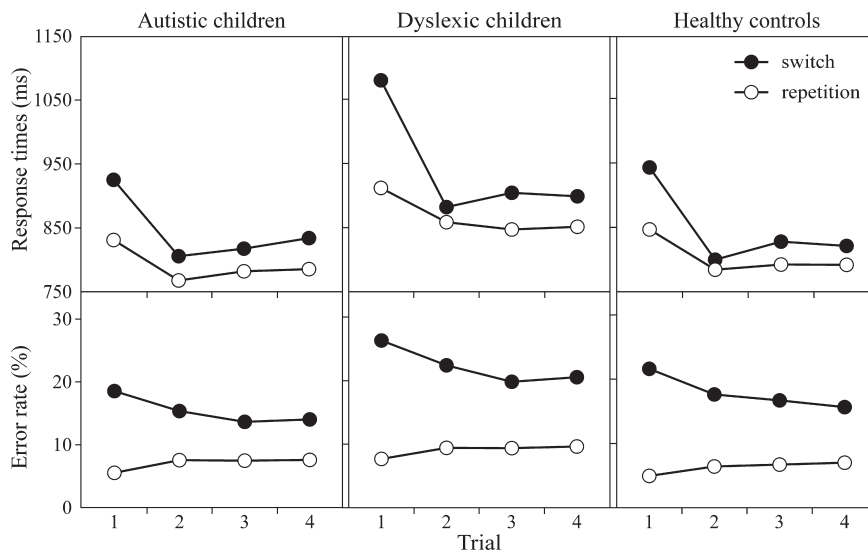

Figure 1. *Means of median response times (in ms) and error rates (in %) as a function of trial position (1, 2, 3, and 4) for two run types (task switch and task repetition), separately for the three groups of children (autistic, dyslexic, and healthy).*

in terms of error rates, performance on Trial 1 did not differ between children with autism and healthy controls, $F < 1$.

Figure 1 shows a significant switch cost also in terms of error rates for each group of participants, with $F(1, 23) = 61.18$, $p < .001$; $F(1, 24) = 53.96$, $p < .001$; and $F(1, 26) = 85.98$, $p < .001$, for autistic, dyslexic, and healthy group, respectively. Importantly, no difference in switch cost was found for errors between the three groups of participants.

Restart cost

A 2×3 (Trial × Group) repeated measures ANOVA applied on median RTs on Trial 1 and Trial 2 after a task repetition yielded significant main effects of trial, $F(1, 73) = 52.13$, $p < .001$; and group, $F(2, 73) = 3.49$, $p < .05$. Participants showed a significant restart cost, observed as slower responses on Trial 1 (863 ms) than on Trial 2 (804 ms) after a task repetition. Furthermore, children with dyslexia were slower (885 ms) than children with autism (800 ms), $F(1, 47) = 6.76$, $p = .012$, and almost significantly slower than healthy controls (816 ms); $F(1, 50) = 3.83$, $p = .056$. No difference was observed between children with autism and healthy controls, $F < 1$.

Figure 1 shows a significant restart cost for each group of participants, with $F(1, 23) = 15.20$, $p < .005$; $F(1, 24) = 10.94$, $p < .005$; and $F(1, 26) = 35.61$, $p < .001$, for autistic, dyslexic, and healthy groups, respectively, as indicated by higher RTs on Trial 1 than on Trial 2 on task repetition trials. Importantly, no difference between groups in restart cost was observed, $F < 1$.

Analysing the error rates on Trial 1 and Trial 2 after a task repetition yielded significant main effects of trial, $F(1, 73) = 12.80$, $p < .005$; and group, $F(2, 73) = 3.83$, $p < .05$. Different from RTs, performance in terms of errors was better on Trial 1 (6.07%) than on Trial 2 (7.08%) after a task repetition. Furthermore, children with dyslexia (8.57%) made again significantly more errors than both children with autism (6.54%) and healthy controls (5.70%), with $F(1, 47) = 4.13$, $p = .048$; and $F(1, 50) = 7.86$, $p = .007$, respectively. No

significant difference in errors was observed between children with autism and healthy controls, $F < 1$.

Figure 1 shows an increased accuracy on Trial 1 compared to Trial 2 for dyslexic and healthy children, with $F(1, 24) = 6.11$, $p = .021$; and $F(1, 26) = 4.40$, $p = .046$, respectively. For children with autism this effect almost reached its significance, $F(1, 23) = 3.64$, $p = .069$. Finally, no other interactions were significant.

General task performance

A $2 \times 3 \times 3$ (Run type × Trial × Group) repeated measures ANOVA applied on median RTs on noncued trials yielded significant main effects of run type, $F(1, 73) = 38.64$, $p < .001$; trial, $F(2, 72) = 5.03$, $p < .01$; and group, $F(2, 73) = 3.77$, $p < .05$. On average, participants responded significantly slower after a task switch (844 ms) than after a task repetition (807 ms). Furthermore, a significant linear trend, $F(1, 73) = 8.27$, $p = .005$, accounted for 85% of the variance due to trial, observed as a gradual increase of RTs for Trial 2 (817 ms), Trial 3 (828 ms), and Trial 4 (831 ms). Also on the noncued trials, children with dyslexia were slower (874 ms) than both children with autism (799 m) and healthy controls (803 ms), with $F(1, 47) = 4.91$, $p = .032$; and $F(1, 50) = 4.18$, $p = .046$, respectively. No difference was observed between children with autism and healthy controls, $F < 1$. Finally, no other interactions were significant.

Analysing the error rates on noncued trials yielded significant main effects of run type, $F(1, 73) = 140.09$, $p < .001$; and group, $F(2, 73) = 3.95$, $p < .05$. On average, participants made significantly more errors on the noncued trials after a task switch (17.31%) than after a task repetition (7.92%). Furthermore, children with dyslexia (15.20%) made significantly more errors than both children with autism (10.20%) and healthy controls (11.69%), with $F(1, 47) = 6.58$, $p = .014$; and $F(1, 50) = 5.64$, $p = .021$, respectively. Performance on noncued trials did not differ between children with autism and healthy controls, $F < 1$. Finally, no other main effects or interactions were significant.

Table 2. *Behavioural symptoms of ADHD as measured by the Dutch ADHD-questionnaire in the dyslexic group*

AVL scale	Mean score (N = 24[a])	Range	N		
			<95th percentile	95th–97th percentile	>97th percentile
Inattention	7 (1.5)	0–22	20	2	2
Hyperactivity	4 (0.8)	0–14	24	0	0
Impulsivity	3 (0.9)	0–17	24	0	0
ADHD Total	14 (3.0)	0–52	22	1	1

Note: ADHD = attention-deficit/hyperactivity disorder. AVL = ADHD-Vragenlijst (Dutch ADHD-questionnaire). Standard errors (*SE*s) in parentheses.
[a]The parents of one child with dyslexia did not fill in the questionnaire.

Additional analyses of switch specific impairment in dyslexia

Two important factors needed to be considered before drawing any conclusions regarding the observed switch-specific impairment in dyslexia. First, as the literature on ADHD has shown task-switching problems in ADHD (e.g., King, Colla, Brass, Heuser, & von Cramon, 2007), we needed to test the possibility that the comorbidity with ADHD present in our population might have accounted for the larger switch cost observed in children with dyslexia. Second, as children with dyslexia were generally poorer in performing the matching task, we needed to test the possibility of general slowing in dyslexia accounting for the differences in switch cost.

ADHD comorbidity. Table 1 shows that two children with autism and one child with dyslexia were also officially diagnosed with ADHD. To test whether dyslexia/ADHD comorbidity might have accounted for the observed increased switch cost in dyslexia, we asked the parents of children with dyslexia to fill in a short Dutch questionnaire assessing the behavioural symptoms of ADHD in children (ADHD-Vragenlijst, AVL; Scholte & van der Ploeg, 2005).[1]

The ADHD-questionnaire confirmed the comorbidity already reported in one child with dyslexia, who scored on the main scale and the Inattention subscale within the clinical range (i.e., above the 98th percentile). Table 2 shows three additional children scoring in the (sub)clinical range: one child scoring within the subclinical range (i.e., between 95th and 97th percentile) on the main scale and within the clinical range on the Inattention subscale. The other two children scored in the subclinical range on the Inattention subscale. Importantly, after excluding these four children with the possible dyslexia/ADHD comorbidity, as well as the two children with autism/ADHD comorbidity, the switch cost was still significantly higher in children with dyslexia (162 ms) then both in children with autism (93 ms) and in the healthy controls (96 ms), with $F(1, 41) = 4.61$, $p = .038$, and $F(1, 46) = 5.49$, $p = .023$, respectively.

Proportion of performance cost. To test the possibility that the significantly larger switch cost reported in terms of RTs in children with dyslexia was observed simply due to their generally impaired performance relative to the other two populations, we calculated the performance on Trial 1 for both switch and

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[1] The Dutch ADHD questionnaire (ADHD-Vragenlijst, AVL) consists of 18 items each describing a certain behaviour. The items are equally divided over three subscales (inattention, hyperactivity, and impulsivity) comprising together the main scale (ADHD Total). A 5-point Likert scale is used to indicate how frequently the behaviour occurs. An item can be scored from 0 to 5 (i.e., never/sometimes/regularly/often/very often). This means that on each subscale the scores were from 0 to 30 and on the main scale from 0 to 90 points. The completion takes approximately 10 minutes. The Dutch Test Committee (COTAN) judged both the reliability and the validity of the AVL as "good".
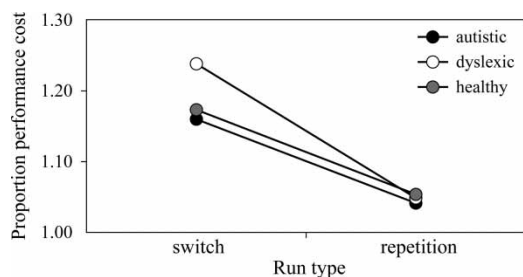
Figure 2. *Means of proportion of performance cost of median response time on Trial 1 as a function of run type (task switch and task repetition) for the three groups of children (autistic, dyslexic, and healthy).*

repetition runs proportionalized with respect to the general task performance (i.e., baseline; for a similar correction in task-switching literature see Mayr & Kliegl, 2000). This baseline was calculated for each participant as an average performance on Trials 2 to 4 including both run types. In this way, we were able to calculate a proportion of performance cost on Trial 1 for switch (i.e., switch Trial 1/baseline) and repetition (i.e., repetition Trial 1/baseline) runs. Importantly, submitting the proportion of performance cost on Trial 1 to a repeated measures ANOVA (Run Type × Group) yielded a significant interaction between run type and group, $F(2, 73) = 3.26$, $p = .044$.

Figure 2 shows a significantly larger proportion of switch cost for children with dyslexia than for both children with autism, $F(1, 47) = 4.00$, $p = .050$, and healthy children, $F(1, 50) = 4.96$, $p = .031$. The task switch translated into a 24% slowing for children with dyslexia compared to a significantly smaller slowing for both children with autism (16%) and the healthy controls (17%).

Discussion

The present study investigated task switching in children with autism and in children with dyslexia. The data on the multiple-trials paradigm used in this study showed a significant switch cost for all participants. Importantly, however, while similar switch cost was observed between children with

autism and the healthy controls, children with dyslexia showed a significantly larger switch cost in terms of RTs than did both healthy controls and children with autism. This finding has at least two important theoretical implications.

First, the finding that children with autism seem to be able to switch between tasks without showing any deviant performance pattern compared to normally developing children implies no switch-specific deficits in children with autism. This finding is in line with at least two previous neuroimaging studies that used a task-switching paradigm to examine cognitive flexibility in autism (e.g., Schmitz et al., 2006; Shafritz et al., 2008). Although reporting some differences in brain activation during task switching, these studies reported no deviant behavioural performance for individuals with autism compared to typically developing adults (for a recent review on cognitive flexibility in autism see Geurts, Corbett, & Solomon, 2009). Accordingly, as our data do not provide evidence for cognitive inflexibility on the level of task switching in autism, it seems necessary to reconsider the plausibility of the conclusions drown from the data reported on the WCST. It is obvious that this neuropsychological test indeed captures a deficit present in individuals with autism, but the present study suggests that it is not a deficit in task switching that is reflected in the WCST data. A closer look at the differences between the WCST and the multiple-trials paradigm offers an alternative explanation for the difficulties with WCST often reported for individuals with autism. Both methods use stimuli that consist of two or more features (e.g., colour, shape, number, size, etc.). In general, these multivalent stimuli as such can be mapped to an infinite number of different tasks (e.g., matching or sorting based on one of the features) and, therefore, can generate task ambiguity as long as the currently relevant task is not explicitly specified in some way. While the WCST does not specify the tasks any further than providing feedback afterwards on the accuracy of someone's guess of the currently required task, the multiple-trials paradigm specifies the tasks in advance by using cues that unambiguously

indicate the required task. In addition to this, while WCST includes no practising of the task, task-switching paradigms typically involve a practice part prior to the experimental part. The advantage of the latter paradigm is that practising both the tasks and switching between them might reduce (e.g., Meiran, Chorev, & Sapir, 2000) but does not abolish (e.g., Stoet & Snyder, 2007) the effect of interest (i.e., the switch cost), while at the same time this practising increases the general task comprehensibility. Accordingly, one could say that task ambiguity is minimized in the multiple-trials paradigm but is clearly present in the WCST. Therefore, rather than task switching per se, task ambiguity might have been a more plausible explanation for cognitive inflexibility as often reported in the literature but also as can be observed in daily lives of individuals with autism.

It has already been reported that individuals with autism find it difficult to generate novel ideas and behaviours spontaneously (e.g., Boucher, 1988; Craig & Baron-Cohen, 1999; Turner, 1999; Wong et al., 2003). It is not surprising then that determining the task rules through own creativity, as required in the WCST, is a difficult task for individuals with autism. Leaving space for personal interpretations in case of autism disorder might lead to behaviour different from commonly expected solutions of a certain situation. For instance, children with autism experience difficulties in mapping novel words onto unnamed entities if they need to rely on speakers' referential intentions (e.g., Baron-Cohen, Baldwin, & Crowson, 1997). Preissler and Carey (2005) showed, however, that restricting the amount of objects without a name when mapping new words to novel objects in the world helps young children with autism to learn meanings of new words equally successfully as healthy controls. Also, studies examining memory functioning in autism showed that, while cued-recall paradigms tend to yield no deviant performance (e.g., Bowler, Matthews, & Gardiner, 1997), free-recall paradigms generally lead to diminished performance in this population (e.g., Gaigg, Gardiner, & Bowler, 2008; Smith, Gardiner, & Bowler, 2007). Interestingly, it

seems that clearly defined situations are the most optimal for children with autism if we want them to meet our expectations.

Certainly, comparing the performance of individuals with autism observed with other neuropsychological tests used for exploring mental flexibility (e.g., ID/ED shift task) is very interesting but complicated. For instance, impairments on the ID/ED shift task have been reported in some (e.g., Hughes et al., 1994; Ozonoff et al., 2004) but not in all studies (e.g., Happé, Booth, Charlton, & Hughes, 2006) using this task. Happé et al. have also shown that cognitive impairments in autism captured by different neuropsychological tests developed to measure mental flexibility, like the ID/ED shift task, the Dimensional Change Card Sort (DCCS; see Zelazo, 2006), and the Battersea Multitask Paradigm (BMP; Mackinlay, Charman, & Karmiloff-Smith, 2006) or questionnaires like the Behaviour Rating Inventory of Executive Function (BRIEF; e.g., Mackinlay et al.) need further specifications in neurocognitive terms. These specifications can only be generated by further research focusing on the neurocognitive mechanisms assumed to be responsible for the reported impairments in the literature. In their recent review, Geurts et al. (2009) discuss this and other issues possibly contributing to inconsistency in findings regarding cognitive flexibility in autism spectrum disorders present in the current literature.

A second important theoretical implication considers children with dyslexia. The data of the present study showed a significantly larger switch cost, implying that, next to deficits in working memory (e.g., Smith-Spark & Fisk, 2007; Swanson et al., 1996), children with dyslexia have difficulties specifically related to switching between different tasks. This finding differs from the expectations based on the WCST data that suggest no cognitive inflexibility in dyslexia. A possible way to reconcile this potential inconsistency is to claim that the WCST cannot detect the task-switching deficits in dyslexia observed in terms of RTs, because it only measures errors. Considering the fact that, also for children with autism, a different task-switching performance was observed than was initially expected based on

the WCST data, a more plausible explanation for the observed inconsistency is that the two paradigms might tackle different cognitive mechanisms. Our observations regarding switching performance both for children with autism and for children with dyslexia imply that the WCST might not be appropriate as a tool for measuring task switching.

The switch-specific deficits in children with dyslexia observed in our study could be based on impairments involved in at least two different but not mutually exclusive levels of cognitive processing. The literature on task switching has provided extensive evidence of the involvement of task-rule-related processes, like active task preparation and passive task-activation decay (e.g., Meiran, 1996) as well as stimulus–related processes, like interference arising from stimulus-specific task cueing (e.g., Koch & Allport, 2006), both determining the task-switching performance. The design of the present study does not allow for a precise specification of the cognitive mechanism(s) causing the switch-specific deficits in dyslexia. However, we assume that the deficit is not arising due to interference on the level of stimulus-specific task cueing, as our stimulus presentation did not include specific stimulus–task associations. Furthermore, we also assume that interference on the level of task rules is not supported by our data, because we would expect also to observe a relatively larger restart cost in dyslexia then. This assumption is based on the idea recently suggested by Poljac et al. (2009) that the restart cost arises from processes involved in resolving task interference through cue-based task activation. We speculate that the observed switch-specific impairments in dyslexia most probably reflect some deficits on the level of activating the currently required task rule or inhibiting the now irrelevant task rule. Reiter, Tucha, and Lange (2005) have already shown that children with dyslexia experience problems with inhibiting inappropriate reactions in more complex cognitive tasks. The precise origin of the deficits in task switching observed for children with dyslexia in the present study will need to be specified in future research.

In line with the present study, previous literature on dyslexia has provided some evidence suggesting impairments in mental flexibility in this population (e.g., Brosnan et al., 2002; Helland & Asbjørnsen, 2000). In a recent study, however, Stoet, Markey, and López (2007) found no evidence for specific impairments in task switching in a group of undergraduate students with dyslexia. The average switch cost of 175 ms was not significantly different from the average switch cost of 145 ms observed in the healthy controls. A possible explanation for this different finding regarding task switching in dyslexia could be given in terms of an important difference between the present study and the study conducted by Stoet et al. While we used incongruent stimuli only, half of the stimuli used by Stoet et al. were congruent. Stimulus congruency in task switching means that a certain bivalent stimulus is associated with the same response independently of in which task context it has been placed. It has been shown that congruency effects can modulate the size of the switch cost in such a way that incongruent situations produce a relatively larger switch cost (e.g., Meiran, 1996, 2000; Meiran et al., 2000; Yehene & Meiran, 2007). We would like to raise the possibility that the difference in the findings between our study and the study by Stoet et al. might be generated by the congruent stimuli possibly attenuating the switch cost in the latter study.

Next to the switch-specific deficits in dyslexia, our data also provide additional evidence for a more general deficit in information processing for this patient population. We observed that children with dyslexia were generally slower and less accurate on the matching task than both healthy controls and children with autism. This difficulty with general task execution could be due to deficits in visual processing (e.g., for review see Stein & Talcott, 1999) also including possible difficulties in inhibition of the surrounding context (Brosnan et al., 2002), or due to deficits in working memory already reported in the literature on dyslexia. The multiple-trials paradigm and the matching task used in this study put indeed high demands on both mechanisms. Children with

dyslexia, however, showed no deviant restart cost. This finding is important as it rules out the possibility that the larger switch cost in dyslexia might be simply due to reading the verbal part of cues in order to know what to do next. If children with dyslexia had any kind of problems with cue processing, then this should be also reflected in the restart cost. On the contrary, it seems that although they were having problems with general task execution, children with dyslexia were experiencing no additional difficulties when required to encode new information about which task would be relevant next. It is only when the task changes that children with dyslexia experience problems with mapping the task cue to the currently correct action. This conclusion was also supported by our analysis applied on the data for proportion of performance cost, showing a significantly larger switch cost even after the correction for the general slowing observed in children with dyslexia. Furthermore, an additional analysis excluded the comorbidity with ADHD as an alternative for the observed switch-specific impairments in dyslexia.

Altogether, the data of the present study suggest that while children with autism are able to switch between tasks in a similar way as do normally developing children as long as the tasks are unambiguously specified, children with dyslexia display performance impairments due to switch-specific deficits. Whereas the former finding brings positive news for the individuals with autism, the latter finding of specific deficits in cognitive control mechanisms in dyslexia deserves more scientific investigation.

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