J Autism Dev Disord (2017) 47:714–727
DOI 10.1007/s10803-016-3010-3

ORIGINAL PAPER

Understanding Behavioural Rigidity in Autism Spectrum Conditions: The Role of Intentional Control

Edita Poljac[1,2] · **Vincent Hoofs**[1,3] · **Myrthe M. Princen**[1,3] · **Ervin Poljac**[1]

Abstract Although behavioural rigidity belongs to the core symptoms of autism spectrum conditions, little is known about its underlying cognitive mechanisms. The current study investigated the role of intentional control mechanisms in behavioural rigidity in autism. Autistic individuals and their matched controls were instructed to repeatedly choose between two simple cognitive tasks and to respond accordingly to the subsequently presented stimulus. Results showed that autistic participants chose to repeat tasks more often than their controls and when choosing to switch, they demonstrated larger performance costs. These findings illustrate that when required to make their own choices, autistic people demonstrate rigidity at different performance levels, suggesting that intentional control mechanisms might be important for a better understanding of behavioural rigidity in autism.

Keywords Cognitive control · Autism · Intentions · Task switching · Voluntary action

Introduction

People are often exposed to disruptions and unexpected events throughout their day. When this happens, being able to flexibly adapt to the changes introduced by these events is a prerequisite for optimal everyday behaviour. We then rely upon our cognitive control mechanisms, usually without being aware of their existence. These control mechanisms are especially critical in situations requiring optimisation of our goal-directed behaviour. Specifically, cognitive control consists of neurocognitive mechanisms that allow us to keep focus on the current task despite possible distractions in the environment, but it also allows us to change focus if needed (e.g., Koechlin et al. 2003; Miller and Cohen 2001). Various factors seem to influence how well we can control our actions and whether we manage to flexibly adapt to changes. For instance, when we feel tired or ill, we are probably less cognitively flexible. Of course, as with many abilities, people vary among each other in how cognitively flexible they are. In fact, for some individuals adapting to changes in the environment might be demanding to the extent that the way they (re)act in these situations might be considered as a symptom of a condition. For instance, autistic people report to experience distress in situations that require sudden changes in planned activities. When the experienced distress is high, it is often expressed in behaviour as irritation, inability to think of an alternative, but also as panic, outbursts, fear, or anger. Whereas this challenge to behave optimally in changing situations is reported repeatedly in autistic people, the nature of the underlying mechanisms remains unclear. In the current study, we aim to identify the cognitive processes possibly contributing to the observed rigidity.

Autism is a pervasive neurodevelopmental condition characterised by a spectrum of behavioural symptoms,

---

✉ Edita Poljac
edita.poljac@psychologie.uni-freiburg.de

[1] Donders Institute for Brain, Cognition and Behaviour, Centre for Cognition, Radboud University, Nijmegen, Netherlands

[2] Department of Psychology, Cognition, Action, and Sustainability Unit, University of Freiburg, Freiburg, Germany

[3] Department of Experimental Psychology, Ghent University, Ghent, Belgium

reflected in difficulties with social interactions and communication as well as in restricted interests and preference for sameness in behaviour (American Psychiatric Association 1994). Restricted interests and preference for sameness can be seen as examples of behavioural rigidity, which is often reported in autism. Behavioural rigidity can be defined as a tendency to maintain ongoing behaviour in situations when this behaviour is not appropriate anymore. Understanding neurocognitive mechanisms behind behavioural rigidity in autism has recently become a focus of research interest (cf. Poljac and Bekkering 2012). It has, for instance, been suggested that behavioural rigidity might originate from executive dysfunction in autistic people (Hill 2004a, b; Hughes et al. 1994; Russell 1997). This suggestion was mainly based upon reported differences in patterns of behaviour when testing autistic people by means of complex neuropsychological tests on various executive cognitive functions, such as planning (e.g., Hughes 1996; Ozonoff and Jensen 1999), mental flexibility (e.g., Liss et al. 2001; Ozonoff et al. 1994; Rumsey and Hamburger 1990), generativity (e.g., Boucher 1988; Craig and Baron-Cohen 1999; Turner 1999), and inhibition (e.g., Biro and Russell 2001; Ozonoff et al. 1994; Russell et al. 1991). These observations have been useful for broadening our understanding of autism as a whole, by pushing further the research field, which was until then predominantly focused on difficulties in the social domain. The issue with this approach, however, arises when trying to specify the actual neurocognitive mechanisms behind the observed differences in behavioural patterns. First, executive functions cover a wide range of important cognitive functions, such that finding deviations in some of these functions in any clinical group is highly possible. This strongly lowers its discriminant validity, making it quite hard to assign executive dysfunction to any specific clinical group as a useful explanation for their symptoms. Second, executive functions are usually investigated by means of complex neuropsychological tests. While being very helpful for a quick screening of someone's cognitive capacities, these tests rarely allow for any kind of specification of the underlying mechanisms that might be generating the observed differences (cf. Burgess et al. 2006; Manchester et al. 2004; Poljac et al. 2010).

Studies applying well-designed, experimentally controlled investigations of behavioural rigidity in autism are still quite rare (cf. Geurts et al. 2009; Poljac and Bekkering 2012). Interestingly, the few controlled studies that have been conducted so far have demonstrated it to be challenging to find empirical evidence for difficulties with adaptive behaviour and cognitive flexibility in autism (e.g., Poljac et al. 2010; Schmitz et al. 2006; Shafritz et al. 2008; Stahl and Pry 2002; Whitehouse et al. 2006). A typical paradigm used within experimental psychology to test cognitive (in)flexibility, is the so-called task switching paradigm. For instance, Poljac et al. (2010) used geometric figures filled with different colours and required their participants to either attend to the shape or to the colour of the presented figures. Explicit task cues were used to specify the currently relevant task. Importantly, the authors reported that adolescents with autism switched between tasks in a similar way as their typically developing controls and significantly better than their clinical controls. They therefore concluded that the ability to switch between tasks, which has often been taken as an index of cognitive control (for review, see Kiesel et al. 2010; Monsell 2003; Vandierendonck et al. 2010), is not impaired in autism as long as the identity and timing of the required tasks are clearly defined. The important remaining question is, however, how to explain the cognitive mechanisms behind the clearly present need for sameness in autistic individuals and their tendency to perseverate, both observed in daily life behaviour as well as in more complex neuropsychological tests but not in the experimentally controlled settings.

A suggestion has recently been put forward that the challenge for autistic individuals might occur at the intentional level rather than at the level of mere execution of specified tasks, particularly in situations requiring adaptations such is the case in task switching conditions (Poljac et al. 2012). This idea was based on studies indicating difficulties at the intentional level of information processing in autism. Here, we define intentions as behavioural biases generated by neural activation that pushes our cognitive system towards a certain decision most often followed by its corresponding action. The first observation in favour of this suggestion is that autistic individuals often find it challenging to generate novel ideas and behaviours spontaneously (e.g., Boucher 1988; Craig and Baron-Cohen 1999; Turner 1999). Along the same lines, it has been shown that putting demands on their intentional decision making in situations of undefined tasks—which is often the case with the neuropsychological tests used to assess executive functions, such as the Wisconsin Card Sorting Test—generates behavioural patterns in autistics that differ from those of their control peers. On the other hand, reducing referential ambiguity in tasks (Preissler and Carey 2005) and directing of intentions externally (Poljac et al. 2010) facilitates their task performance, successfully eliminating behavioural differences. Altogether, the above mentioned observations seem to be in line with the suggestion that intentional control in autism might be a sensible candidate for explaining behavioural rigidity in autism.

Perhaps the most convincing evidence for the idea that difficulties in the intentional component of behaviour might be relevant for better understanding of behavioural rigidity in autism, comes from the recent study by Poljac et al. (2012), in which a voluntary task switching paradigm (VTS) was used. Poljac and colleagues administered this paradigm in students with no clinical diagnoses but with either high or low autistic traits as estimated by the often used Autism Spectrum Quotient (AQ) Scale (e.g., Baron-Cohen 2001; Hoekstra et al. 2008). Similar to the cued task switching paradigm, in VTS paradigm, participants are required to switch between two simple cognitive tasks, like for instance between indicating the shape (Task 1) or the location (Task 2) of a presented stimulus. The critical difference here is that in the voluntary procedure, participants are free to choose which of the two tasks to perform in each trial (Arrington and Logan 2004, 2005; Yeung 2010). In this way, the VTS paradigm allows for disentangling the intentional (task choice related) component from its implementation into the corresponding action (stimulus related) component. Previous studies have shown that also in the VTS, switch costs are observed in terms of slower and more error prone responding to the stimulus in switch trials (e.g., Arrington and Logan 2004, 2005; Yeung 2010). These performance costs are typically taken as an expression of cognitive control, not necessarily including its voluntary, decision making aspects. The most interesting observation of the VTS studies, however, regards the intentional part: Participants seem to have the tendency to repeat tasks more often than to switch tasks, which is the so-called repetition bias (Mayr and Bell 2006; Millington et al. 2013; Poljac et al. 2012; Yeung 2010). This observation is reminiscent of the observed tendency in autistic people to exhibit repetitive behaviours. Poljac et al. reported that while the repetition bias was demonstrated by all of their participants, this tendency to repeat tasks was significantly stronger in participants with higher autistic traits. In particular, the repetition bias seemed to be stronger in the harder task, suggesting that the repetition bias was not a mere reflection of the participants applying a strategy of least mental effort. Interestingly, this repetition bias *asymmetry* was again larger in participants with more autistic traits. The observed differences in task-choice related repetition bias (asymmetry) across the participants who differ in their amounts of autistic traits suggest that behavioural rigidity in autism, as expressed in terms of repetitive behaviours, might be generated by cognitive mechanisms involved in the formation of general task intentions.

In the current study, we further tested this idea of intentional control mechanisms being relevant to behavioural rigidity in autism in an actual clinical population of individuals diagnosed with autism. To this end, we thoroughly investigated task choice behaviour in autistic individuals and their control peers using a similar version of the VTS paradigm as applied by Poljac et al. (2012). Participants were instructed to make a choice between a shape and a location task in each trial and then press the space bar to indicate that the choice has been made. They were required to respond to the subsequently presented stimulus according to the task they have just chosen for that particular trial. In this way, we were able to look at their intention formation (task choice) separately from their actual responding to the stimulus (task execution). For the intentional part, we investigated different patterns in task choices as well as the time people took to make a task choice. If behavioural rigidity in autism is related to the processes involved in intention formation, then we expected to observe differences in task choice behaviour between the two groups of participants. Specifically, we expected to observe a relatively stronger repetition bias (asymmetry) in autistic participants compared to their control peers (cf. Poljac et al. 2012). Unlike the intentional part, we expected no significant differences between the two groups in the way intentions were translated into actual responding to the presented stimulus. Specifically, we expected no differences in task execution in terms of reaction times and accuracy nor in terms of switch costs between autistic and control participants (cf. Geurts et al. 2009; Poljac et al. 2010).

Methods

Participants

Seventy-seven participants (31 female), ages 16–36 years, took part in the study. One of the participants was excluded from the data analyses, as the error rate was more than three SD above the mean (i.e., more than 30% of trials). The remaining participants consisted of one-half (n = 38) being diagnosed with autism spectrum conditions (ASC) and the other half (n = 38) being their neurotypical (NT) control group. The two groups were matched on their age, full scale intelligence (FSIQ), and gender (see Table 1 for an overview of descriptive measures for the two groups). The intelligence (IQ) was measured by the Dutch version of the Wechsler Intelligence Scale for Children (WISC-III NL; Kort 2005) or by the Dutch version of the Wechsler Adult Intelligence Scale (WAIS- III NL; Uterwijk 2000) for the participants who were 16 years and older. For five of the ASC participants we used the IQ scores that were already available as a part of the standard protocol when entering a clinical institution. For other participants whose IQ was unknown or estimated longer than 4 years ago, we used a short version of the age-appropriate Wechsler Scale. The short version consisted of the following four subtests: Vocabulary and similarities for the verbal IQ (VIQ), Picture completion and block design for the performance IQ (PIQ), based on which their FSIQ was estimated (for further information on the used formulas, see Sattler 2001). As Table 1 shows, the independent-samples *t*-tests confirmed that the matching was successful, as no significant differences between the two groups were observed in

Table 1 Demographic data of the participants

	Autistic (n = 38)		Control (n = 38)			
	Mean	Range	Mean	Range	*t*(74)	*p* values
Age	24.8 (0.8)	16.8–35.0	24.4 (0.7)	16.3–34.6	0.36	0.72
VIQ	111 (1.5)	92–129	114 (1.5)	92–137	−1.25	0.21
PIQ	109 (1.9)	86–134	110 (2.1)	80–137	−0.36	0.72
FSIQ	109 (1.4)	97–131	112 (1.4)	85–131	−0.90	0.37
AQ	28.7 (1.4)	9–43	14.1 (1.0)	3–31	8.68	<0.001
Handedness score	25.5 (1.4)	0–32	27.4 (1.2)	2–32	1.09	0.28

VIQ verbal IQ, *PIQ* performance IQ, *FSIQ* full scale IQ, *AQ* autism spectrum quotient, Standard errors (SE) are given in the parentheses

either their age ($t(74)=0.356$, $p=0.723$) or in their FSIQ ($t(74)=0.356$, $p=0.723$; $t(74) = -0.904$, $p=0.369$). Also the gender matching resulted in about equal groups, with 15 females in the autistic and 16 in the control group.

Participants in the ASC group were recruited through mental health care clinics specialized in autism in the Netherlands, as well as through online posts on the internet pages of the main Dutch autism organisations, and by distributing flyers. All of the participants with ASC were diagnosed with autism (18 with Asperger syndrome, 12 with pervasive developmental disorder-not otherwise specified (PDD-NOS), and 8 with Autism) based upon the DSM-IV criteria (American Psychiatric Association 1994). The diagnosis was made by at least one psychiatrist or clinical psychologist with expertise and considerable experience in autism after extensive diagnostic evaluation including a review of prior records (developmental history, psychiatric and psychological observations and tests, and neurological investigations), a parent interview for children, and a psychiatric observation. Three of the ASC participants had traits of attention deficit hyperactivity disorder (ADHD), one of whom was officially diagnosed. Two additional ASC participants had traits of dyslexia, with one being officially diagnosed. Our NT participants were recruited through the Research Participation System (SONA systems) and the flyers distributed at public (high) schools. None of the controls had any (history of) diagnosed disorders or obvious developmental delay.

All participants completed the short version of Edinburgh Handedness Inventory (Oldfield 1971). In this questionnaire, seven action statements are being judged by the hand used for executing it on a five point Linkert scale. The two groups did not overall differ in handedness ($t(74)=-1.086$, $p=0.281$), with all of the participants being right handed except for the eight left handed (four in each group) and two ambivalent in the autism group. In addition, all participants completed the autism spectrum quotient questionnaire (AQ), consisting of 50 statements about themselves (Baron-Cohen 2001; Hoekstra et al. 2008). The AQ has a total score that ranges between 0 and 50, with the increase in scores corresponding with an increase in autistic traits. It is a validated measure of autism spectrum characteristics found within individuals with an ASC diagnosis (e.g., Berthoz et al. 2013; Pisula et al. 2013), their relatives (e.g., Kose et al. 2013; Wheelwright et al. 2010) and the NT population (e.g., Freeth et al. 2013; Poljac et al. 2013, 2012). As such it is a reliable measurement tool for the comparison of autistic traits between the ASC and NT group. As expected, Table 1 shows a significant difference in autistic traits between the two groups ($t(47)=8.675$, $p<0.001$): compared to an average AQ score of 14 for the NT group, autistic participants had an average AQ score of 29, which is well above the suggested cut-off score of 26 (Woodbury-Smith et al. 2005).

Finally, all participants had normal or corrected-to-normal vision. They received a payment of 20 euro or course credits for their invested time. Prior to any testing, written informed consent was obtained from each participant. For the participants younger than 18 years, both parents provided their written informed consents in addition to their child's consent. All procedures performed in the current study were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Specifically, the protocol was approved by the local medical-ethical committee as well as by the review board of the centre where the study was conducted.

Stimuli and Tasks

In each trial, participants were presented with one of three blue shapes (triangle/square/circle) inside a grid of three adjacent boxes (see Fig. 1). The presented stimulus approximately filled the specific box within the grid, which was 2.6° high and 7.4° wide at a viewing distance of approximately 1 m. Participants responded either to the shape of the stimulus (i.e., shape task) or to its location

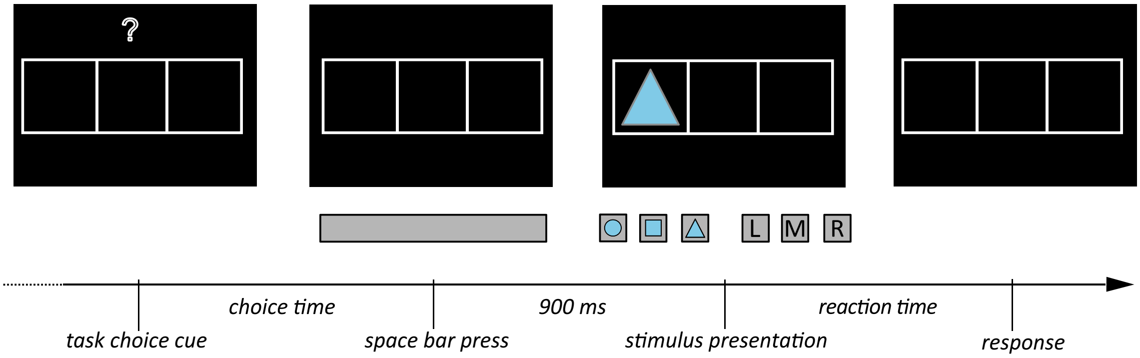

Fig. 1 Schematic overview of trail events. During the entire trial, a grid was presented. The stimuli were geometric figures appearing in one of the three possible locations in the grid. In this way, each stimulus afforded two possible tasks: shape (*circle/square/triangle*) and location (*left/middle/right*). A trial started with the presentation of a question mark right above the grid, indicating that the participants needed to make a deliberate choice of tasks for the upcoming stimulus. They were instructed to press the space bar to indicate that they have made a task choice. The time needed for making this task choice (i.e., choice time) was measured as the interval between the presentation of the question mark and the space bar press. The stimulus was presented on the screen 900 ms after the space bar was pressed. The tasks were mapped separately to the two hands and the participants responded by pressing a key. In the example illustrated here, the left hand is used to respond to the shape (*circle, square, triangle*) and the right hand to the location of the stimulus (*L* left, *M* middle, *R* right). The correct response for the depicted example would be pressing the right most key with the left index finger for the shape task or pressing the left most key with the right hand for the location task. After the response was given, the grid was emptied for 300 ms, followed by the question mark indicating the start of the next trial

within the grid (i.e., location task). They were instructed to first choose voluntarily whether to perform the shape or the location task in each trial. They were further asked to choose the two visuomotor tasks around equally often and in a random order (cf. Arrington and Logan 2004). If these instructions were not clear to the participants, we introduced the 'coin flipping' metaphor, typically used for explaining how to make task choices in the VTS paradigms. Specifically, the participants were told to choose the tasks as if flipping the coin would decide which task to perform next. By pressing the spacebar, they indicated to have made their task choice for that specific trial. In this way, participants indicated *that* they have made the task choice, without explicitly indicating *what* that particular task choice was. This procedure allowed us to avoid introducing any bottom-up biases of task execution that might have been generated by an explicit indication of task choice prior to the stimulus presentation.

The two visuomotor tasks were uniquely mapped to the two hands, with half of the participants responding to the shape by pressing keys with their left hand and to the location by pressing keys with their right hand. The mapping was reversed for the other half of the participants. This procedure resulted in around half of the participants using their non-dominant hand for the harder shape task, with the exact numbers being 18 in the autistic and 23 in the control group. The task-to-hand mapping also allowed for determining the participants' task choices based on the hand they used to respond with. The actual response was given by pressing a key with the index, middle, or ring finger of the two hands. To indicate the shape of the stimulus, participants used their leftmost, middle, and rightmost finger of the appropriate hand for circle, square, and triangle, respectively. The location of the stimulus was mapped compatibly to corresponding responses: leftmost, middle, and rightmost finger were used to indicate the left, centre, and right box, respectively.

Across the whole experiment, stimuli were presented quasi-randomly. Specifically, the two stimulus dimensions (shape and location) were systematically varied, such that between two successive trials, stimulus either repeated fully, partially (either its location or its shape), or not at all. Each of the four possibilities occurred equally often.

Procedure

The participants first practiced 20 trials of each task separately, followed by practicing switching between the two tasks for two blocks of 20 trials each. After the practice, a series of eight experimental blocks started, with 60 trials in each block. Within the blocks, each trial began with an empty grid and a question mark above it (see Fig. 1 for a schematic overview of trail events). Participants were instructed to consider the question mark as a cue for making a choice between the two tasks on that specific trial. They were requested to hit the spacebar with both their thumbs, once that they have made their task choice. The spacebar hit was followed by an interval of 900 ms during which the empty grid was still visible but the question mark was removed. After this interval, a stimulus appeared at one of the three locations within the grid. The stimulus remained on the screen until a response was given. This response initiated a cleared grid presented for 500 ms, followed by the question mark appearing above the grid, cueing the participants that the new trial has started and that they need to make their next task choice. Participants were encouraged to use their time before hitting the space bar to decide which task to perform.

At the end of each block, participants were reminded to try to respond as quickly and accurately as possible and to follow the instructions about equal task distribution and 'random' switching as described above. Also, feedback was provided indicating the average response and choice times, counts of errors, counts of the number of times each of the two tasks was performed, and counts of the number of switch and repeat trials. Participants were encouraged to use the time between blocks to rest if needed.

Data Analyses

In the current study, we looked at the behaviour related to task choices—as a measure of intentions—and at the behaviour related to actual responding to the stimulus—as a measure of the implementation of intentions into the corresponding actions. For the intentional part, we first looked at our main measure of interest, their task choices. Specifically, we looked at Task choice in three different ways. First, we looked at the average number of times that people kept on repeating the same task in a row, the so-called Run length. These were analysed with a 2×2 repeated measures analysis of variance (ANOVA), with Task (location/ shape) as a within-subjects variable and Group (autism/ control) as a between-subjects variable. Second, we calculated the frequencies with which our participants made different run lengths, investigating the distribution of run lengths of 1, 2, 3, 4, 5, and 5+ trial runs. We grouped the runs of more than five trials as these were relatively infrequent when taken separately. The frequencies across the different run lengths were analysed for the two groups by means of the Pearson Chi square test.

Third, we investigated how specific stimulus features influenced the choices of tasks the participants made. This analysis was conducted, because the VTS paradigm used here allowed the bottom-up stimulus information to affect participants' choices. That is, the participants were instructed to make choices in each trial and then to hit the space bar, but they were not asked to specify their actual task choice. In this way, participants might have in some cases ignored their initial intention. To test whether the participants were following their intentions, we looked at a commonly used measure of intention following, the so-called stimulus repetition effect on task choices. Previous research has shown that ignoring the initial intention can happen when the stimulus repeats across trials (Mayr and Bell 2006). The idea behind this measure is that, if one makes a deliberate choice of tasks before the stimulus is presented, then any stimulus-related manipulation introduced in the design should not affect the already made choice. If, however, the task choice is not stable enough, then it is possible for stimulus presentation to modulate the eventual task choice, such as often observed for stimulus repetitions. In the current study, we introduced a within-subjects manipulation of stimulus repetition, with the stimulus repeating either fully across two trials, partially (either its location or its shape), or not at all. Each of the four possible stimulus repetition types (full/ location/ shape/ none) occurred equally often. We submitted percentages of task repetitions to a 4×2×2 (Stimulus repetition×Task×Group) repeated measures ANOVA to investigate intention following measured as the influence of stimulus repetition on participants' choices, and in particular to test if these influences differed between the groups. Note that we did not include task switches, as the two levels of task transition, switched and repeats, were fully dependent on each other here. Therefore, we focused on task repetitions only.

In addition to the task choices, we also looked at the time that the participants took to press the spacebar after the presentation of the question mark as our second measure for the intentional part. We assumed that this Choice time reflected the time that participants needed to make their task choice in each trial. We analysed the median choice time with a 2×2×2 (Task×Transition×Group) repeated measures ANOVA, with Transition (switch/repeat) as a within-subjects variable.

Finally, we analysed the speed and accuracy with which the participants responded to the stimulus as two measures of the actual task performance. Similar to choice time analyses, both median reaction times (RTs) and error rates were submitted to a 2×2×2 (Task×Transition×Group) repeated measures ANOVA. Error rates were calculated for each of the Task×Transition conditions as a relative measure between the number of errors and the total number of times a specific condition was chosen by the participant.

Before running the above described analyses, we applied the following exclusion criteria to our data. For the task choice analyses on run length and run length frequencies, all trials were included. Next, all first trials were excluded from the task choice analyses on percentage task repetitions for testing the intention following, as well as from the analysis on median choice time. In addition to first trials, error trials and the trials following an error were excluded for the analyses of median RTs. As previously explained, the identity of the chosen task was determined by the hand the participant used to respond to the target stimulus. Accordingly, we considered a trial as an error trial when the participant responded with the incorrect finger of the specific hand. Furthermore, whether a given trial was considered a switch or a repeat trial was defined according to the currently performed task relative to the previously performed task.

Results

In what follows, we first present the data related to task choices, which we assumed to represent the intentional part of the paradigm used in the current study. In addition, we present the data related to the time that the participants took to choose the tasks. Finally, to show how the formed intentions were translated into the corresponding action, we present the analyses of stimulus processing, measured in terms of its speed and accuracy.

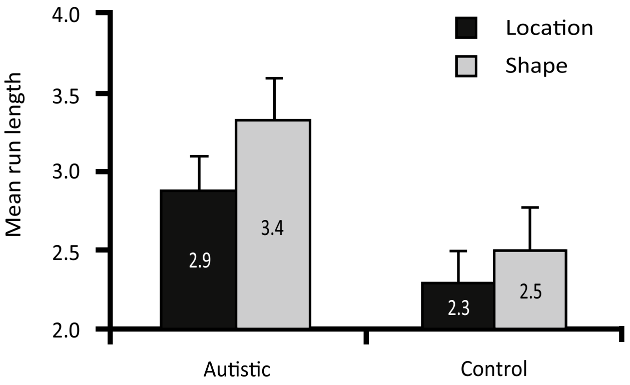

Fig. 2 Mean run length for the autistic and the control group as a function of task (*location* or *shape*). *Error bars* indicate SE of the mean

Task Choice

To investigate the task choices the participants made, we first looked at the average amount of times they have repeated each of the tasks, focusing on the measure called run length. A 2×2 (Task×Group) repeated measures ANOVA revealed a significant main effect of Task, $F(1,74) = 39.43$; $p < 0.001$, demonstrating a stronger tendency in participants to repeat the harder shape task more often (average run length of 2.9) than the easier location task (average run length of 2.6). Although this effect was significant in both the autistic, $F(1,74) = 23.80$; $p < 0.001$, and the control group, $F(1,74) = 17.13$; $p < 0.001$, the tendency to repeat the harder task more often in a row was more strongly pronounced in autistics (repetition bias asymmetry = 0.5) than in their NT peers (repetition bias asymmetry = 0.2). This small but consistent effect was confirmed with a significant interaction between Task and Group, $F(1,74) = 4.99$; $p = 0.029$, see Fig. 2. Finally, a significant main effect of Group was observed, $F(1,74) = 4.43$; $p = 0.039$, with autistic participants being generally more inclined to keep on repeating the same task more often (average run length of 3.1) than their NT controls (average run length of 2.4).

To further investigate task choices, we investigated the frequencies at which different run lengths occurred. We first calculated the frequencies for run lengths of 1–5, and more than five trials in a row for each of the two groups (see Table 2). The frequencies were submitted to the Pearson Chi square test, which allowed us to test associations between Run length and Group. We observed a significant association between type of run length and the group, $\chi2(5) = 87.53$, $p < 0.001$. This seems to represent the fact that, based on the odds ratio, the odds of autistic making runs of 1, 2, 3, 4, 5, and 5+ trials were respectively, 0.80,

Table 2 Frequencies and percentages of run lengths of 1, 2, 3, 4, 5, and 5+ trials for the two groups

	Run length						
	1	2	3	4	5	5+	Total
Autistic							
Average frequencies	63	57	36	16	8	11	191
Percentages within group	32.9	30.1	18.9	8.5	4.1	5.6	100
Standard residuals	−2.8*	0.5	−0.2	−0.9	1.9	6.7*	
Control							
Average frequencies	78	63	41	19	7	6	214
Percentages within group	36.5	29.5	19.1	9.0	3.3	2.7	100
Standard residuals	2.6*	− 0.5	0.1	0.8	−1.8	−6.3*	
Total							
Average frequencies	71	60	38	18	7	8	203
Percentages within group	34.7	29.8	19.0	8.8	3.7	4.1	100

*Standard residuals are considered to indicate statistical significance when reaching values outside of +/− 1.94

0.91, 0.88, 0.83, 1.11, and 1.89 times of those of the controls. Specifically, Table 2 shows that while task runs of one had lower odds of occurring more, the task runs longer than five trials had higher odds of occurring more in the autistic group than in the control group. Together these findings demonstrate a clear difference in the distribution of run lengths between the two groups: autistic participants made significantly less runs of one trials (i.e., immediate task switching) and repeated tasks in runs longer than five trials more often that their NT peers.

Finally, we tested whether participants consistently followed the choices they initially formed during the period before hitting the space bar. Percentages of task repetitions were submitted to a 4 × 2 × 2 (Stimulus repetition × Task × Group), which revealed a main effect of Stimulus repetition only, $F(3,72) = 6.38$; $p = 0.001$. Simple contrast analyses showed that participants were inclined to repeat the task the most when the stimulus fully repeated (63.5%). This effect was significantly stronger than the repetition effect observed when either its location (61.2%) or its shape (59.8%) repeated, $F(1,74) = 7.38$; $p = 0.008$ and $F(1,74) = 13.69$; $p < 0.001$, respectively. The inclination to repeat was still present but the least prominent when none of the stimulus features repeated (58.8%), differing significantly from stimulus' location repetition ($F(1,74) = 10.94$; $p = .001$), shape repetition ($F(1,74) = 3.75$; $p = 0.057$), or full repetition, ($F(1,74) = 18.20$; $p < 0.001$). The effect was not significantly different only between repeating the location and repeating the shape of the stimulus, $F(1,74) = 2.68$; $p = 0.106$. Importantly, however, as can be seen in Fig. 3, the pattern of this stimulus repetition effect on task choices –our measure of intention following—was not different between the two groups, $F < 1$. This suggests that the inclination to repeat tasks more often when the stimulus repeated was similar in the two groups.

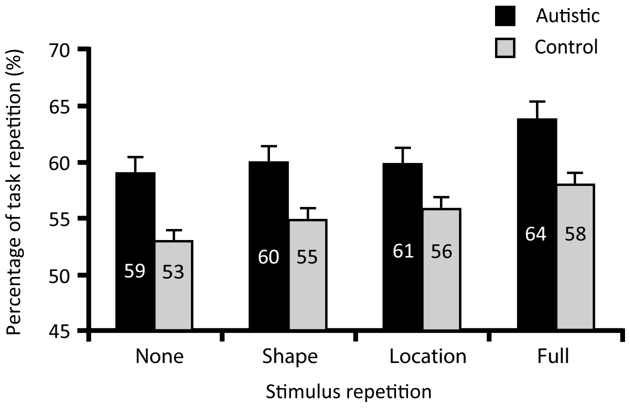

Fig. 3 Percentages of task repetitions in the two groups (*autistic* and *control*) as a function of stimulus repetition (*none, shape, location, full repetition*). *Error bars* indicate SE of the mean

To try to post hoc understand this stimulus effect better, we furthermore tested if the participants who took less time to make deliberate task choices were those who showed this effect the most (cf. Millington et al. 2013). For this analysis, the choice time was used to categorise the participants as 'fast' or 'slow' within both the autism group (range from 84 to 1109 ms, with a median split at 184 ms) and the control group (range from 82 to 961 ms, with a median split at 203 ms) based on a median split on their average median choice time. This 4 × 2 × 2 × 2 (Stimulus repetition × Task × Group × Choice speed) revealed no significant interactions of Choice speed with Stimulus repetition, Fs $(3,70) < 1.70$, ps > 0.18. This revealed that the observed tendency to repeat the tasks more often when the stimulus repeats was similar for those participants who made their choices quickly and for those who took more time to make a deliberate task choice.

Choice Time

Analysing the median time participants took to make their choice of tasks with a 2 × 2 × 2 (Task × Transition × Group) repeated measures ANOVA revealed only a significant interaction between Task and Transition, $F(1,74) = 9.421$; $p = 0.003$. A closer look at this interaction showed that, while for the location task, participants took a similar amount of time to choose for a switch ($M = 256$ ms, $SE = 23.7$) or a repetition ($M = 260$ ms, $SE = 23.7$), $F < 1$; they took significantly more time to choose a switch ($M = 268$ ms, $SE = 25.0$) towards the shape task than to choose a repetition ($M = 248$ ms, $SE = 22.2$) of this task, $F(1,74) = 4.56$; $p = 0.036$. No other main effects or interactions were significant.

Reaction Times

Data were cleaned of the first trials (in total 608 trials for all participants, that is, 1.7%), the error trials, and the trials that followed errors (for the latter two together these were 2096 trials across all participants, that is, 5.8%). This resulted in total of 7.4% of trials that were excluded. Median RTs were then submitted to a 2 × 2 × 2 (Task × Transition × Group) repeated measures ANOVA, which revealed a main effect of Task ($F(1,74) = 208.23$; $p < 0.001$) and Transition ($F(1,74) = 62.26$; $p < 0.001$). As expected, the shape task was a harder task for the participants to perform, as they were on average slower in the shape ($M = 681$ ms, $SE = 16.5$) than in the location task ($M = 517$ ms, $SE = 16.0$), Also, participants demonstrated a significant switch cost of 76 ms on average, with slower RTs after a task switch ($M = 637$ ms, $SE = 18.8$) than after a task repetition ($M = 561$ ms, $SE = 12.5$). We furthermore observed a significant interaction between task and transition (F(1,74) = 9.69; p = 0.003). Further analyses revealed that although significant in both shape (F(1,74) = 67.39; p < .001) and location (F(1,74) = 33.14; p < 0.001), switch costs were stronger in the shape task (switch costs = 91 ms, with M = 726 ms, SE = 20.8 and M = 635 ms, SE = 13.2, for switch and repeat trials, respectively) than in the location task (switch costs = 60 ms, with M = 547 ms, SE = 19.8 and M = 487 ms, SE = 13.2, for switch and repeat trials, respectively). This asymmetry in switch costs between tasks that differ in difficulty has been observed before (for a similar pattern, see Barutchu et al. 2013; Liefooghe et al. 2010; Monsell et al. 2000, but see; Schneider and Anderson 2010 for the reversed pattern).

Importantly, a significant interaction between Transition and Group, F(1,74) = 9.63; p = 0.003, indicated that switch costs differed between the two groups. As can be seen in Fig. 4, panel A, although significant switch costs were demonstrated by both the autistic (F(1,37) = 37.57; p < 0.003) and the control group (F(1,37) = 27.24; p < 0.001), switch costs were larger in the autistic group (switch costs = 105 ms) than in the control group (switch costs = 46 ms). Finally, we observed a significant main effect of group (F(1,74) = 10.46; p = 0.002), with the autistic participants (M = 648 ms, SE = 21.6) being generally slower than their peers (M = 550 ms, SE = 21.6). It is important to take this observation into account, as it is possible that the larger switch costs observed in autistics were merely due to their generally slower responding in this study. According to this idea, one might expect that in slower participants, larger switch costs were simply due to scaling. To address this possibility, we corrected the switch costs for differences in general task execution in each participant in two different ways. The first way of correcting for the group differences in general reaction times was to apply the logarithmic transformation of the RT data, often applied in studies on cognitive (control) processed and aging (e.g., Kray and Lindenberger 2000; Mayr 2001; van der Lubbe and Verleger 2002). After the logarithmic transformation, both of the effects of interest remained significant: Transition x Group interaction was significant, with F(1,74) = 9.197; p =0 .003; as was the main effect of Group, with F(1,74) = 9.549; p = 0.003. The second way of correcting was to calculate per participant their switch costs as a percentage of slowing down in switch trials compared to repeat trials (cf. Poljac et al. 2010). In this way, repeat trials were considered as a baseline performance. When analysing the switch-specific slowing down for the two groups, we confirmed that this slowing down was significantly larger in the autism group than in the control group, F(1,74) = 8.71; p = 0.004; see Fig. 4, Panel B. Both these

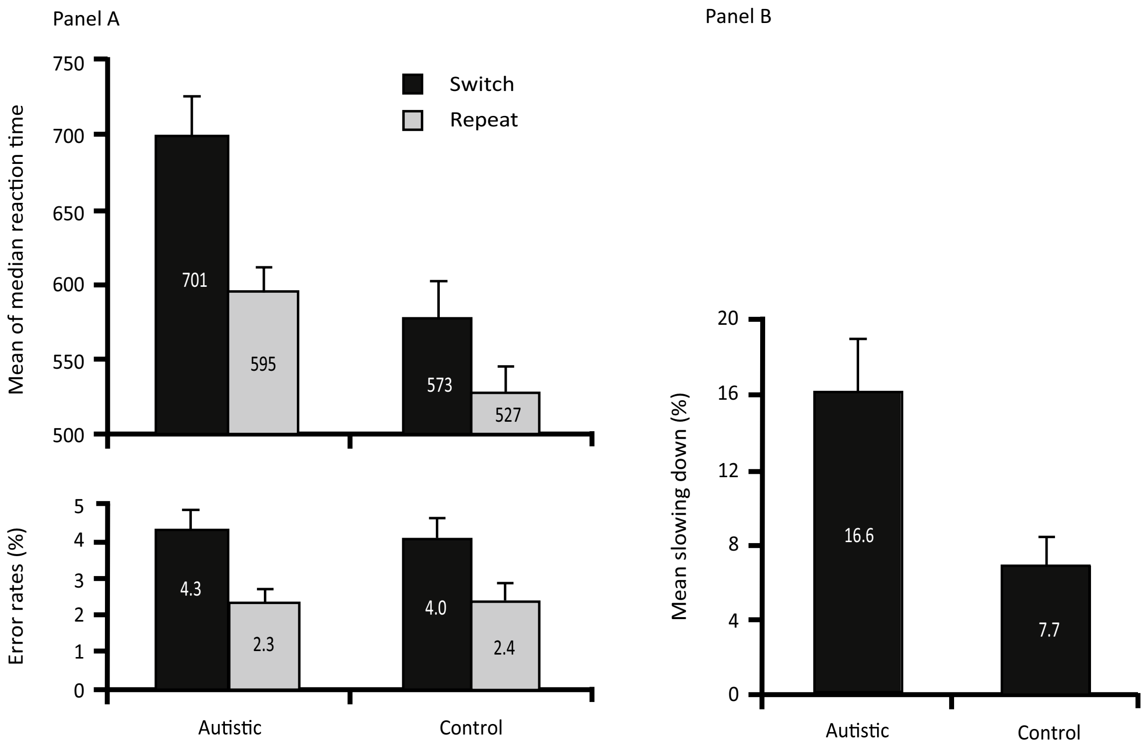

Fig. 4 Task execution data. *Panel A* depicts the mean of median response times (*above*) and error rates (*below*) for the autistic and the control group as a function of transition type (switch or repeat). *Panel B* depicts the mean switch-specific slowing down for the two groups. *Error bars* indicate SE of the mean

corrections together suggested that larger switch costs in autistic participants were not a mere reflection of their generally increased RTs.

Error Rates

Similar to the RTs, mean error rates were submitted to a 2×2×2 (Task×Transition×Group) repeated measures ANOVA, which again revealed main effects for Task (F(1,74) = 91.55; $p < 0.001$) and Transition (F(1,74) = 30.72; $p < 0.001$). The participants were on average less accurate in the shape (M = 4.6%, SE = 0.4) than in the location task (M = 1.9%, SE = 0.2) and after a task switch (M = 4.1%, SE = 0.4) than after a task repetition (M = 2.4%, SE = 0.2). As Fig. 4, Panel A demonstrates, a significant interaction between Task and Transition (F(1,74) = 4.58; $p = 0.036$) was observed also in the error rates. Further analyses revealed a similar pattern as in RTs, showing that switch costs were significant in both shape (F(1,74) = 21.93; $p < 0.001$) and location (F(1,74) = 18.34; $p < 0.001$), but also demonstrating a similar asymmetry, with switch costs being stronger in the shape task (switch costs = 2.3%, with M = 5.7%, SE = 0.5 and M = 3.4%, SE = 0.3, for switch and repeat trials, respectively) than in the location task (switch costs = 1.2%, with M = 2.5%, SE = 0.3 and M = 1.3%, SE = 0.2, for switch and repeat trials, respectively). Importantly, no significant difference between the two groups were observed, nor did Group interact significantly with any other factors.

Discussion

The present findings demonstrate differences in behavioural patterns of task switching between autistics and their NT controls. When participants make their own, binary task choices, these differences emerge both at the level of intentions as well as at the level of their implementation into the corresponding actions. For intentions, we observed a stronger tendency to repeat tasks in autistic participants, which they expressed in larger repetition bias (asymmetry) and in particular in less immediate task switches and more frequent runs that were longer than five trials in a row. For actions, autistic participants demonstrated larger switch costs, which is to our knowledge observed for the first time in a controlled study. These results together suggest that intentional control might be relevant to behavioural rigidity in autism. In what follows, we discuss the implications of these findings for a better understanding of behavioural rigidity in autism, first regarding the contribution of intentional control in VTS to the expression of behavioural rigidity, with a particular focus on the interplay of top-down intentional control and bottom-up factors, and second regarding the relationship between voluntary task choice (intentions) and the subsequent expression of rigidity in task execution (actions) in terms of task switching behaviour.

Shaping Intentions

Our findings demonstrate that the stronger repetition bias in broader autism phenotype, previously reported in individuals with higher autistic traits (Poljac et al. 2012), is also observed when tested in the actual clinical population of individuals diagnosed with autism. This observation is important as it provides—to our knowledge for the first time—empirical evidence for the idea that intentional control mechanisms are possibly highly relevant to behavioural rigidity in autism. Specifically, we observed that the tendency to repeat tasks more often than it would be expected based on the given instructions was significantly stronger in autistic participants than in their NT peers, in particular regarding the task repetitions of more than five trials in a row. A similar pattern of repetition bias has previously been reported in studies looking at voluntary behaviour in non-clinical populations (Arrington and Logan 2004; Mayr and Bell 2006; Yeung 2010), implying that people generally have the bias towards repetitions when given an option of task choice.

It has been suggested that this tendency to perseverate in tasks is associated with both top-down and bottom-up processes (Arrington 2008; Arrington and Logan 2005; Mayr and Bell 2006). For the top-down mechanisms, at least two explanations have been put forward: one in which a representative random sequence is used as a comparison to the recent history of task choices based on which the next task choice is made (Arrington and Logan 2005), and another where each trial is treated as a discrete event, in which active inhibition of the most recent task activation protects the system from perseverating (Mayr and Bell 2006). These top-down views suggest that the repetition bias happens when the top-down control mechanism fails. As for the bottom-up effects contributing to the repetition bias, it has been suggested that task choices are made based on the availability of the external input, such as a stimulus presentation, which then cues the task that it has recently been associated with. Accordingly, repetition bias happens when external stimulation is stronger than the internal aim. So, rather than following the initial intention, one conducts behaviour afforded by the stimulus.

Perhaps the most evident empirical evidence for the bottom-up influences on task choices comes from studies investigating the so-called stimulus-repetition effects in VTS (Arrington et al. 2010; Mayr and Bell 2006). These studies showed that participants are more likely to repeat the previous task if the stimulus repeats from the previous trial. Also in the current study, task repetitions increased with repeating stimulus features between trials. Importantly, however, this stimulus-repetition effect was of a similar size in both participant groups. This implies that the significant difference in repetition bias observed between the autistic and the NT participants was not driven by the stimulus-related biasing of task choices in our study.

A more feasible explanation for our finding of the significantly stronger repetition bias in autistic participants comes from the studies investigating between-task competition in VTS (Millington et al. 2013; Poljac et al. 2012; Yeung 2010). These studies have reported a small but consistent repetition bias asymmetry when asking people to choose between tasks that differ in their relative strength. For instance, Yeung (2010) used similar tasks as in our study: a relatively strong and easy to execute location classification, and a relatively weak and harder to execute shape classification task. Interestingly, although the shape task was harder to perform, participants had a greater tendency to repeat this task than the easier location task. This somehow contra-intuitive observation of the repetition bias asymmetry towards the harder task has been explained in terms of the amount of task interference between the two tasks. Specifically, it has been suggested that weaker tasks are generally more prone to between-task interference even when performed repeatedly, whereas stronger tasks are in principle only modulated by interference on switch trials (see Yeung and Monsell 2003). Therefore for the weaker task to be performed correctly, one needs to exert more cognitive control, generating persisting biases toward the weaker task and hence increasing the difficulty of switching away from this task.

Also in the current study, a repetition bias asymmetry was observed. We found a significantly stronger tendency to repeat the harder shape task than the easier location task. Importantly, however, this repetition bias asymmetry was stronger in autistic participants than in their NT controls. A similar observation was also reported with a broader autism phenotype: Poljac et al. (2012) reported repetition bias asymmetry that was stronger in the participants with relatively higher autistic traits. The observed stronger repetition bias asymmetry in autistic participants in our study suggests that for them this behavioural perseveration was generated by a stronger control bias towards the weaker task, which was needed in order to execute this weaker task correctly. This implies that more cognitive control was needed to be exerted by autistic participants than by their NT peers for the tasks to be executed correctly. Furthermore, considering that differences in task repetition behaviour between autistic and NT participants was modulated by task strength and not by stimulus repetition in our study, we can say that these differences in repetition bias were related to bottom-up effects at the level of tasks, rather than at the level of stimuli. This implies that the stronger perseveration observed in autistic participants in our study originates from an interplay between top-down intentional control and bottom-up task processes, with the interference being generated at the level of tasks.

There are two important methodological points that deserve to be mentioned here. First point concerns the nature of tasks used in our study. Specifically, the type of stimulus–response (S–R) mappings differed between the two tasks: Whereas for the location task, the mappings were direct and needed no further explanation, the shape task involved arbitrary S–R mappings, requiring some practice to be remembered and hence correctly applied. It is therefore plausible that the slower RTs observed for the shape task, labelled by us as a harder and weaker task of the two, were driven by the arbitrary S–R mappings in this task. Interestingly, Stoet & López (2011) have demonstrated that task switching in terms of accuracy becomes challenging for autistic children when using arbitrary S–R mappings that needed to be memorised. Along these lines, it is possible that the autistic participants in our study demonstrated stronger perseveration for the shape task compared to the location task because they were more challenged by arbitrary mappings in the shape task than their NT peers.

Second point regards the type of the VTS paradigm applied in our study. Having used a paradigm in which the choice of tasks was not explicitly indicated by the participants, we needed to derive task intentions from the hand used to reply. In such a design, it is possible that the derived intentions were not matching participants' true task intentions in all trials. It is sensible to expect that these trials were not frequent as otherwise we should have observed much more errors if the participants intentions did not match the hand used. Furthermore, Millington et al. (2013) demonstrated that in NT participants, this paradigm produces behavioural effects similar to those observed when using a paradigm in which task choice is explicitly indicated. However, we cannot exclude this possibility and moreover, we cannot specify the trials in which this might have happened. Further research is needed to investigate if and how these two methodological points might have affected the observations reported in the current study.

Altogether, our findings on task choice indicate that the stronger perseveration tendency in autism can be detected with the VTS paradigm. More importantly, our findings suggest that intentional control mechanisms significantly contribute to behavioural rigidity in autism. Specifically, the interplay between top-down intentional control and bottom-up between-task competition provides a promising account for explaining behavioural rigidity in autism.

Translating Intentions into Actions

Contrary to our expectations, we observed differences in task switching behaviour between the two groups in our study. Specifically, we observed higher switch costs in autistic participants than in their NT peers. This finding is important for at least two reasons. First, to our knowledge, this is the first controlled study to demonstrate empirical evidence for challenges in adapting to task switches in autistic persons. Previous studies that used different paradigms failed to provide such evidence (for an overview see Geurts et al. 2009; but see; Stoet and López 2011, for the effects of arbitrary rules on switch accuracy in autistics). For instance, previous work on task switching with either cued tasks in autistic participants (Poljac et al. 2010) or with VTS in individuals with high autistic traits (Poljac et al. 2012) did not provide evidence for impaired task switching behaviour. Yet in the current study, we observed clearly larger switch costs when comparing autistic participants with their NT peers. One explanation for this discrepancy is that in the study of Poljac et al. (2010), explicit task cues were used, which made intentional control unnecessary for correct task execution. If we assume—as we are suggesting here—that intentional control might play an important role in behavioural rigidity in autism, then it is not surprising that no behavioural rigidity in terms of task switching abilities was observed in the study using explicit task cues. What is surprising, however, is that in the study using a similar VTS paradigm as in the current study, while differences at the level of task choices were observed, no indication of task switching difficulties was demonstrated by individuals with high autistic traits (Poljac et al. 2012). The most parsimonious explanation for this discrepancy is the difference in the participants' profiles: While the previous study assessed the VTS paradigm in a non-clinical population, the current study included clinically diagnosed individuals. It is possible that for the student population included in the study of Poljac and colleagues, the task was not challenging or sensitive enough to discover task switching problems.

Second reason why our finding of task-switching challenges in autistic participants is important is that this observation is in line with behavioural rigidity often reported in daily lives of autistic persons. We must mention here that the level of task complexity used in the current study might be an important factor for the observed task switching difficulty in the autism group (cf. Williams et al. 2006a). Unlike the study of Poljac et al. (2010), in which the main focus was on task switching, the current study also included the intentional component: Our participants were required to make decisions in each trial. This construction makes the whole study more complex, and hence more challenging for the participants. We know from other research fields that complexity plays a role in the way autistic persons perform the tasks. For instance, increasing complexity in tasks developed for testing working memory seems also to expose difficulties in working memory in autism that otherwise stay undetected (e.g., Landa and Goldberg 2005; Williams et al. 2006b). In a similar way, increasing complexity in tasks testing attentional or visuomotor control reveal difficulties performing these tasks in autistic people (cf. Goldstein et al. 2001; Miller and McGonigle-Chalmers 2014). Accordingly, it is possible that also in the current study, the higher complexity generated switch-specific differences between the groups. Future studies are needed to explore the role of task complexity within the context of behavioural rigidity and intentional control in autism.

Conclusion

Collectively, our findings demonstrate behavioural rigidity in autism at the level of task intentions as well as the level of their corresponding actions in a controlled, experimental design. In this way, we provide empirical evidence for the idea that intentional control mechanisms contribute to the behavioural rigidity observed in the daily lives of autistic people. These observations call for further experimental investigation of behavioural rigidity aiming at specifying the neurocognitive mechanisms that are responsible for this core symptom of autism, and the VTS paradigm seems to offer a promising way to proceed.

Acknowledgments Foremost, we owe a special debt of gratitude to all the participants and would like to thank them for their time and efforts. Also, we thank Renske van der Cruijsen, Rianne Haartsen, and Vera van 't Hoff for tremendous help with data collection and scoring of questionnaires. Further, we thank Lea Ueberholz for her help with tables and figures. Edita Poljac was supported by a grant within the Priority Program, SPP 1772 from the German Research Foundation (Deutsche Forschungsgemeinschaft, DFG), Grant No. Ki1388-/7-1. Ervin Poljac was supported by the Marie Skłodowska-Curie mobility programme of the EU FP7 (REA Grant Agreement No. 624080).

Author Contributions EP developed the idea behind the study, analysed the data, and wrote the manuscript. VH collected the data, helped analysing them, and contributed to the fine-tuning of the manuscript. MMP programmed the experiment and helped analysing and interpreting the data. EP helped developing the initial idea, contributed to the data interpretation and the development of the take home message.

Funding The funding was provided by Deutsche Forschungsgemeinschaft (Ki1388-/7-1) and Seventh Framework Programme (624080).

References

American Psychiatric Association (1994). *Diagnostic and statistical manual of mental disorders (DSM-IV)*. Washington, DC: American Psychiatric Association.

Arrington, C. M. (2008). The effect of stimulus availability on task choice in voluntary task switching. *Memory & Cognition, 36*(5), 991–997. doi:10.3758/mc.36.5.991.

Arrington, C. M., & Logan, G. D. (2004). The cost of a voluntary task switch. *Psychological Science, 15*(9), 610–615. doi:10.1111/j.0956-7976.2004.00728.x.

Arrington, C. M., & Logan, G. D. (2005). Voluntary task switching: Chasing the elusive homunculus. *Journal of Experimental Psychology, 31*(4), 683–702. doi:10.1037/0278-7393.31.4.683.

Arrington, C. M., Weaver, S. M., & Pauker, R. L. (2010). Stimulus-based priming of task choice during voluntary task switching. *Journal of Experimental Psychology, 36*(4), 1060–1067. doi:10.1037/a0019646.

Baron-Cohen, S., Wheelwright, S., Skinner, R., Martin, J., & Clubley, E. (2001). The autism-spectrum quotient (AQ): Evidence from Asperger syndrome/high-functioning autism, males and females, scientists and mathematicians. *Journal of Autism and Developmental Disorders, 31*(1), 5–17. doi:10.1023/A:1005653411471.

Barutchu, A., Becker, S. I., Carter, O., Hester, R., & Levy, N. L. (2013). The role of task-related learned representations in explaining asymmetries in task switching. *PLoS ONE, 8*(4), e61729. doi:10.1371/journal.pone.0061729.

Berthoz, S., Lalanne, C., Crane, L., & Hill, E. L. (2013). Investigating emotional impairments in adults with autism spectrum disorders and the broader autism phenotype. *Psychiatry Research, 208*(3), 257–264. doi:10.1016/j.psychres.2013.05.014.

Biro, S., & Russell, J. (2001). The execution of arbitrary procedures by children with autism. *Development and Psychopathology, 13*(01), 97–110. doi:10.1017/S0954579401001079.

Boucher, J. (1988). Word fluency in high-functioning autistic children. *Journal of Autism and Developmental Disorders, 18*(4), 637–645. doi:10.1007/bf02211881.

Burgess, P. W., Alderman, N., Forbes, C., Costello, A., LAURE, M. C., Dawson, D. R., ... & Channon, S. (2006). The case for the development and use of “ecologically valid” measures of executive function in experimental and clinical neuropsychology. *Journal of the International Neuropsychological Society, 12*(2), 194–209. doi:10.1017/S1355617706060310.

Craig, J., & Baron-Cohen, S. (1999). Creativity and imagination in autism and Asperger syndrome. *Journal of Autism and Developmental Disorders, 29*(4), 319–326. doi:10.1023/a:1022163403479.

Field, A. (2009). *Discovering statistics using SPSS*. Thousand Oaks, CA: SAGE.

Freeth, M., Bullock, T., & Milne, E. (2013). The distribution of and relationship between autistic traits and social anxiety in a UK student population. *Autism, 17*(5), 571–581. doi:10.1177/1362361312445511.

Geurts, H. M., Corbett, B., & Solomon, M. (2009). The paradox of cognitive flexibility in autism. *Trends in Cognitive Sciences, 13*(2), 74–82. doi:10.1016/j.tics.2008.11.006.

Goldstein, G., Johnson, C. R., & Minshew, N. J. (2001). Attentional processes in autism. *Journal of Autism and Developmental Disorders, 31*(4), 433–440. doi:10.1023/A:1010620820786.

Hill, E. L. (2004a). Evaluating the theory of executive dysfunction in autism. *Developmental Review, 24*(2), 189–233. doi:10.1016/j.dr.2004.01.001.

Hill, E. L. (2004b). Executive dysfunction in autism. *Trends in Cognitive Sciences, 8*(1), 26–32. doi:10.1016/j.tics.2003.11.003.

Hoekstra, R. A., Bartels, M., Cath, D. C., & Boomsma, D. I. (2008). Factor structure, reliability and criterion validity of the autism-spectrum quotient (AQ): A study in dutch population and patient groups. *Journal of Autism and Developmental Disorders, 38*(8), 1555–1566. doi:10.1007/s10803-008-0538-x.

Hughes, C. (1996). Brief report: Planning problems in autism at the level of motor control. *Journal of Autism and Developmental Disorders, 26*(1), 99–107. doi:10.1007/bf02276237.

Hughes, C., Russell, J., & Robbins, T. W. (1994). Evidence for executive dysfunction in autism. *Neuropsychologia, 32*(4), 477–492. doi:10.1016/0028-3932(94)90092-2.

Kiesel, A., Steinhauser, M., Wendt, M., Falkenstein, M., Jost, K., Philipp, A. M., & Koch, I. (2010). Control and interference in task switching-A review. *Psychological Bulletin, 136*(5), 849–874. doi:10.1037/A0019842.

Koechlin, E., Ody, C., & Kouneiher, F. (2003). The architecture of cognitive control in the human prefrontal cortex. *Science, 302*(5648), 1181–1185. doi:10.1126/science.1088545.

Kort, W., Schittekatte, M., Dekker, P. H., Verhaeghe, P., Compaan, E. L., Bosmans, M., & Vermeir, G. (2005). *WISC-III NL Wechsler intelligence scale for children. Derde Editie NL. Handleiding en Verantwoording. [Dutch version of the WISC-III]*. Amsterdam: Harcourt Test Publishers/Nederlands Instituut voor Psychologen.

Kose, S., Bora, E., Erermiş, S., Özbaran, B., Bildik, T., & Aydın, C. (2013). Broader autistic phenotype in parents of children with autism: Autism Spectrum Quotient–Turkish version. *Psychiatry and Clinical Neurosciences, 67*(1), 20–27. doi:10.1111/pcn.12005.

Kray, J., & Lindenberger, U. (2000). Adult age differences in task switching. *Psychology and Aging, 15*, 126–147. doi:10.1037/0882-7974.15.1.126.

Landa, R. J., & Goldberg, M. C. (2005). Language, social, and executive functions in high functioning autism: A continuum of performance. *Journal of Autism and Developmental Disorders, 35*(5), 557–573. doi:10.1007/s10803-005-0001-1.

Liefooghe, B., Demanet, J., & Vandierendonck, A. (2010). Persisting activation in voluntary task switching: It all depends on the instructions. *Psychonomic Bulletin & Review, 17*(3), 381–386. doi:10.3758/Pbr.17.3.381.

Liss, M., Fein, D., Allen, D., Dunn, M., Feinstein, C., Morris, R., ... Rapin, I (2001). Executive functioning in high-functioning children with autism. *Journal of Child Psychology and Psychiatry, 42*(2), 261–270. doi:10.1111/1469-7610.00717.

Manchester, D., Priestley, N., & Jackson, H. (2004). The assessment of executive functions: Coming out of the office. *Brain Injury, 18*(11), 1067–1081. doi:10.1080/02699050410001672387.

Mayr, U. (2001). Age differences in the selection of mental sets: The role of inhibition, stimulus ambiguity, and response-set overlap. *Psychology and Aging, 16*, 96–109. doi:10.1037/0882-7974.16.1.96.

Mayr, U., & Bell, T. (2006). On how to be unpredictable: Evidence from the voluntary task-switching paradigm. *Psychological Science, 17*(9), 774–780. doi:10.1111/j.1467-9280.2006.01781.x.

Miller, E. K., & Cohen, J. D. (2001). An integrative theory of prefrontal cortex function. *Annual Review of Neuroscience, 24*(1), 167–202. doi:10.1146/annurev.neuro.24.1.167.

Miller, L., & McGonigle-Chalmers, M. (2014). Exploring perceptual skills in children with autism spectrum disorders: From target detection to dynamic perceptual discrimination. *Journal of Autism and Developmental Disorders, 44*(5), 1144–1157. doi:10.1007/s10803-013-1977-6.

Millington, R. S., Poljac, E., & Yeung, N. (2013). Between-task competition for intentions and actions. *The Quarterly Journal of Experimental Psychology, 66*(8), 1504–1516. doi:10.1080/17470218.2012.746381.

Monsell, S. (2003). Task switching. *Trends in Cognitive Sciences, 7*(3), 134–140. doi:10.1016/s1364-6613(03)00028-7.

Monsell, S., Yeung, N., & Azuma, R. (2000). Reconfiguration of task-set: Is it easier to switch to the weaker task? *Psychological Research Psychologische Forschung, 63*(3), 250–264. doi:10.1007/s004269900005.

Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh Inventory. *Neuropsychologia, 9*(1), 97–113. doi:10.1016/0028-3932(71)90067-4.

Ozonoff, S., & Jensen, J. (1999). Brief report: Specific executive function profiles in three neurodevelopmental disorders. *Journal of Autism and Developmental Disorders, 29*(2), 171–177. doi:10.1023/a:1023052913110.

Ozonoff, S., Strayer, D. L., McMahon, W. M., & Filloux, F. (1994). Executive function abilities in autism and Tourette Syndrome: An information processing approach. *Journal of Child Psychology and Psychiatry, 35*(6), 1015–1032. doi:10.1111/j.1469-7610.1994.tb01807.x.

Pisula, E., Kawa, R., Szostakiewicz, Ł., Łucka, I., Kawa, M., & Rynkiewicz, A. (2013). Autistic traits in male and female students and individuals with high functioning autism spectrum disorders measured by the polish version of the autism-spectrum quotient. *PLoS ONE, 8*(9), e75236. doi:10.1371/journal.pone.0075236.

Poljac, E., & Bekkering, H. (2012). A review of intentional and cognitive control in autism. *Frontiers in Psychology, 3*, 436. doi:10.3389/fpsyg.2012.00436.

Poljac, E., Poljac, E., & Wagemans, J. (2013). Reduced accuracy and sensitivity in the perception of emotional facial expressions in individuals with high autism spectrum traits. *Autism, 17*(6), 668–680. doi:10.1177/1362361312455703.

Poljac, E., Poljac, E., & Yeung, N. (2012). Cognitive control of intentions for voluntary actions in ondividuals with a high level of autistic traits. *Journal of Autism and Developmental Disorders, 42*(12), 2523–2533. doi:10.1007/s10803-012-1509-9.

Poljac, E., Simon, S., Ringlever, L., Kalcik, D., Groen, W. B., Buitelaar, J. K., & Bekkering, H. (2010). Impaired task switching performance in children with dyslexia but not in children with autism. *The Quarterly Journal of Experimental Psychology, 63*(2), 401–416. doi:10.1080/17470210902990803.

Preissler, M. A., & Carey, S. (2005). The role of inferences about referential intent in word learning: Evidence from autism. *Cognition, 97*(1), B13–B23. doi:10.1016/j.cognition.2005.01.008.

Rumsey, J. M., & Hamburger, S. D. (1990). Neuropsychological divergence of high-level autism and severe dyslexia. *Journal of Autism and Developmental Disorders, 20*(2), 155–168. doi:10.1007/bf02284715.

Russell, J. (1997). *Autism as an executive disorder*. Oxford: Oxford University Press.

Russell, J., Mauthner, N., Sharpe, S., & Tidswell, T. (1991). The 'windows task' as a measure of strategic deception in preschoolers and autistic subjects. *British Journal of Developmental Psychology, 9*(2), 331–349. doi:10.1111/j.2044-835X.1991.tb00881.x.

Sattler, J. (2001). *Assessment of children: Cognitive applications*. San Diego, CA: Jerome M. Sattler.

Schmitz, N., Rubia, K., Daly, E., Smith, A., Williams, S., & Murphy, D. G. M. (2006). Neural correlates of executive function in autistic spectrum disorders. *Biological Psychiatry, 59*(1), 7–16. doi:10.1016/j.biopsych.2005.06.007.

Schneider, D. W., & Anderson, J. R. (2010). Asymmetric switch costs as sequential difficulty effects. *The Quarterly Journal of Experimental Psychology, 63*(10), 1873–1894. doi:10.1080/17470211003624010.

Shafritz, K. M., Dichter, G. S., Baranek, G. T., & Belger, A. (2008). The neural circuitry mediating shifts in behavioral response and cognitive set in autism. *Biological Psychiatry, 63*(10), 974–980. doi:10.1016/j.biopsych.2007.06.028.

Stahl, L., & Pry, R. (2002). Joint attention and set-shifting in young children with autism. *Autism, 6*(4), 383–396. doi:10.1177/1362361302006004005.

Stoet, G., & López, B. (2011). Task-switching abilities in children with autism spectrum disorder. *European Journal of Developmental Psychology, 8*(2), 244–260. doi:10.1080/17405629.2010.492000.

Turner, M. A. (1999). Generating novel ideas: Fluency performance in high-functioning and learning disabled individuals with autism. *Journal of Child Psychology and Psychiatry, 40*(2), 189–201. doi:10.1111/1469-7610.00432.

Uterwijk, J. (2000). *WAIS-III Nederlandstalige bewerking. Technische handleiding*. Lisse: Swets & Zeitlinger.

van der Lubbe, R., & Verleger, R. (2002). Aging and the Simon task. *Psychophysiology, 39*, 100–110. doi:10.1111/1469-8986.3910100.

Vandierendonck, A., Liefooghe, B., & Verbruggen, F. (2010). Task switching: Interplay of reconfiguration and interference control. *Psychological Bulletin, 136*(4), 601–626. doi:10.1037/A0019791.

Wheelwright, S., Auyeung, B., Allison, C., & Baron-Cohen, S. (2010). Defining the broader, medium and narrow autism phenotype among parents using the Autism Spectrum Quotient (AQ). *Molecular Autism, 1*(1), 1–9. doi:10.1186/2040-2392-1-10.

Whitehouse, A. J. O., Maybery, M. T., & Durkin, K. (2006). Inner speech impairments in autism. *Journal of Child Psychology and Psychiatry, 47*(8), 857–865. doi:10.1111/j.1469-7610.2006.01624.x.

Williams, D. L., Goldstein, G., & Minshew, N. J. (2006). Neuropsychologic functioning in children with autism: Further evidence for disordered complex information-processing. *Child Neuropsychology, 12*(4–5), 21–29. doi:10.1080/09297040600681190.

Williams, D. L., Goldstein, G., & Minshew, N. J. (2006b). The profile of memory function in children with autism. *Neuropsychology, 20*(1), 21–29. doi:10.1037/0894-4105.20.1.21.

Woodbury-Smith, R. M., Robinson, J., Wheelwright, S., & Baron-Cohen, S. (2005). Screening adults for asperger syndrome using the AQ: A preliminary study of its diagnostic validity in clinical practice. *Journal of Autism and Developmental Disorders, 35*(3), 331–335. doi:10.1007/s10803-005-3300-7.

Yeung, N. (2010). Bottom-up influences on voluntary task switching: The elusive homunculus escapes. *Journal of Experimental Psychology, 36*(2), 348–362. doi:10.1037/a0017894.

Yeung, N., & Monsell, S. (2003). Switching between tasks of unequal familiarity: The role of stimulus-attribute and response-set selection. *Journal of Experimental Psychology-Human Perception and Performance, 29*(2), 455–469. doi:10.1037/0096-1523.29.2.455.