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Task Switching in Autism:  
An EEG Study on Intentions and Actions

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**Abstract**

One of the main symptoms of Autism Spectrum Conditions (ASC) is experiencing cognitive inflexibility when adjustments of behaviour are required. While this so-called behavioural rigidity is broadly recognised in ASC, finding evidence for the underlying neurocognitive mechanisms remains challenging. In this electroencephalographic (EEG) study, participants with ASC and matched controls were instructed to choose between two cognitive tasks in each trial, and to respond to the subsequently presented target stimulus according to their task choice. While doing so, we tracked the frontally distributed contingent negative variation (CNV) during the task preparation interval as a measure of intentional control, and the posteriorly measured P3 during the task execution interval to monitor the translation of intentions into actions. The results support the notion of intentional control difficulties in ASC, where the CNV was attenuated in the ASC group compared to the control group. Furthermore, the CNV was differentiated between the tasks and transition types in the control group only, suggesting that the ASC group was less fine-tuning the required amount of intentional control to contextual circumstances. In contrast, the P3 showed no significant differences between the groups. Together, these findings highlight the importance of intentional control mechanisms as a crucial future route for a better understanding of cognitive flexibility and behavioural rigidity in ASC.

**Keywords:** autism, cognitive flexibility, behavioural rigidity, intention, action, EEG

## Task Switching in Autism: An EEG Study on Intentions and Actions

Autism Spectrum Conditions (ASC) refer to a spectrum of neurodevelopmental conditions that are characterized by two groups of main symptoms: impairments of reciprocal social interactions and communication; and a restricted and repetitive range of behaviours and interests (American Psychiatric Association, 2013). Behavioural rigidity, originating from reduced cognitive flexibility in ASC, is included in the latter group of symptoms and is often expressed as an increased tendency to exhibit stereotyped and repetitive behaviour (Olney, 2000; Rutgers, Van Ijzendoorn, Bakermans-Kranenburg, & Swinkels, 2007). Although previous complex neuropsychological tests have provided some evidence for the notion of behavioural rigidity in ASC being the consequence of attenuated cognitive flexibility (e.g., Bennetto, Pennington, & Rogers, 1996; Rumsey & Hamburger, 1990; Yasuda et al., 2014), finding clear empirical evidence for this idea in experimentally controlled settings, and providing specification of the underlying neurocognitive mechanisms remains challenging (De Vries & Geurts, 2012). To this end, the aim of the present electroencephalography (EEG) study was to further investigate the possible neurocognitive mechanisms that contribute to the cognitive inflexibility underlying behavioural rigidity in ASC.

Early task switching studies in ASC utilised neuropsychological tests, such as the Wisconsin Card Sorting Test (WSCT), and reported highly preservative responses in ASC groups compared to control groups when required to shift to a new rule (Hill, 2004; Pascualvaca, Fantie, Papageorgiou, & Mirsky, 1998; Van Eylen et al., 2011). In contrast, experimental paradigms with unambiguous choice criteria often could not provide such empirical evidence for cognitive inflexibility during task switching performance in ASC participants (Geurts, Corbett, & Solomon, 2009; Poljac et al., 2010; Van Eylen, Boets, Steyaert, Wagemans, & Noens, 2015). Recently, however, assessment of task switching under conditions of random task choice by applying a voluntary task switching (VTS) paradigm showed that an ASC group compared to a matched control group had significantly increased reaction times after task

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switches compared to task repetitions, as well as a more pronounced repetition bias (Poljac, Hoofs, Princen, & Poljac, 2017). Specifically, even though participants generally have a pronounced tendency to repeat an ongoing task more often than switching to another task (Arrington & Logan, 2004; Mayr & Bell, 2006; Yeung, 2010), this tendency seems to be even stronger in participants with ASC (Poljac et al., 2017). Together, it seems that cognitive inflexibility in task switching is stronger in ASC when tasks are chosen voluntarily. This observation under conditions of random task choice implies an important role of higher-order decision making processes such as intentional control for a better understanding of cognitive inflexibility underlying behavioural rigidity in ASC (for review, see Poljac & Bekkering, 2012).

Interestingly, despite similar behavioural observations between ASC and control groups in studies that implemented predefined task switching, results from neuroimaging studies show that such unaffected behavioural flexibility in ASC participants are often accompanied by differences in their neural activations (Schmitz et al., 2006; Yerys et al., 2015), indicating an altered cognitive control in ASC that may not be apparent when only using behavioural measures (Solomon, Hogeveen, Libero, & Nordahl, 2017). For example, in a functional magnetic resonance imaging (fMRI) study, Schmitz et al. (2006) observed that unimpaired behavioural measures of task switching in an ASC group were accompanied by increased activation of the right inferior and left mesial parietal cortex compared to a control group. Another task switching fMRI study examining children with ASC also demonstrated unimpaired task switching behaviour, however, their performance was again accompanied by increased frontal brain activation (Yerys et al., 2015). Finally, the notion of altered neural responses to task switching in ASC was further supported by a study of Shafritz, Dichter, Baranek, and Belger (2008), which revealed that task switching was associated with reduced activation in (among others) the frontal and parietal regions for their ASC group.

Despite such fMRI studies, corresponding studies that utilise EEG measurements to examine the neural correlates of task switching in ASC are to the best of our knowledge, non-

existing. This is interesting considering the fact that EEG is an informative method for studying task switching in non-clinical participants (e.g., Kang, Diraddo, Logan, & Woodman, 2014; Karayanidis, Coltheart, Michie, & Murphy, 2003; Steinhauser, Hübner, & Druey, 2009), with an excellent (millisecond) temporal resolution (Handy, 2005; Niedermeyer & Silva, 2012). As such, the present EEG study should allow us to further specify *when* possible differentiations of underlying neurocognitive mechanisms involved in task switching may occur, and *how these develop* across time when directly comparing an ASC group to a matched control group. To this end, we used the VTS paradigm which has already been shown to be sensitive in tracking behavioural indications for task switching difficulties in both students with high levels of ASC traits (Poljac, Poljac, & Yeung, 2012), as well as in a clinical ASC population (Poljac et al., 2017). The currently applied VTS paradigm provided participants a task-choice cue (i.e., question mark) in each trial, indicating that they had to choose between performing a shape or location classification task. After indicating that this choice has been performed, the target stimulus appeared, requiring the appropriate response according to the task choice made before (Poljac et al., 2017). During task performance, we recorded EEG measures during the intervals of task preparation and task execution in order to investigate intention formation (task preparation), and its translation into a corresponding action (task execution) in order to unveil both processes' contribution to cognitive inflexibility that underlie behavioural rigidity in ASC.

Previous EEG studies on task switching in non-clinical participants demonstrated that while task preparation is associated with a slowly developing negative wave across frontal sites (i.e., contingent negative variation, CNV; e.g., Falkenstein, Hoormann, Hohnsbein, & Kleinsorge, 2003; Poljac & Yeung, 2014), task execution seems to be reflected in the stimulus-evoked positivity (i.e., P3) in the post-stimulus interval (Doucet & Stelmack, 1999). Regarding the preparatory frontally distributed CNV, studies on the neural correlates of participants' effort revealed the CNV to be increased in trials where participants made particular effort in anticipation of a target in order to perform well, suggesting that the CNV tracks the

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reassignment of participants' resources (Falkenstein et al., 2003). Additionally, the CNV seems to act as a useful representation of intentional task preparation in voluntary task switching, being stronger in task switch trials (Kang et al., 2014; Vandamme et al., 2010), and most pronounced in fast responses (Lavric, Mizon, & Monsell, 2008; Poljac & Yeung, 2014). Altogether, it seems that the CNV provides a sensitive measure of participants' task switching preparedness.

The stimulus-evoked P3, on the other hand, has been suggested to show modulations after stimulus presentation in task switching studies (Karayanidis et al., 2003; Poulsen, Luu, Davey, & Tucker, 2005), and to mediate between perceptual analysis and subsequent response initiation (McGinnis & Keil, 2011). Usually, the P3 is attenuated in switch trials compared to repeat trials in both cued (e.g., Kieffaber & Hetrick, 2005; Poulsen et al., 2005), and voluntary task switching paradigms (Poljac & Yeung, 2014; Vandamme et al., 2010), as well as smaller and occurring earlier for easier tasks (Ford, Roth, Mohs, & Hopkins, 1979; Polich, 1987). The characteristic waveform of this component allows for the analysis of its latencies in addition to the usual amplitude analysis. As a result of these features, the P3 seems to be an appropriate measure of cognitive processes within the task execution interval.

In sum, the present study utilised the VTS paradigm to track participants' EEG signal while they voluntarily chose between two simple cognitive tasks in each trial. By directly comparing EEG signals between an ASC and a matched control group, we aimed to obtain a better understanding of which neurocognitive mechanisms may be underlying the cognitive inflexibility and behavioural rigidity in ASC. In the preparation interval, which we assumed to be the period of intention formation, we focused on the CNV as measure for task (switch) preparation processes<sup>1</sup>. We expected that intentional control difficulties in the ASC group would lead to a generally weaker CNV than in the control group. Furthermore, challenges in intentional control were expected to generate a less pronounced differentiation in the CNV between switch and repeat trials in the ASC group than in the control group. Additionally, we assumed the P3 to index task execution processes in the post stimulus interval. We expected the P3 to show the

typical amplitude attenuation and latency delay in switch trials compared to repeat trials (e.g., Kieffaber & Hetrick, 2005; Poulsen et al., 2005; Scisco, Leynes, & Kang, 2008). Furthermore, P3 was expected to be diminished and to occur earlier for the easy location task than for the harder shape task (Ford et al., 1979; Polich, 1987). Last, due to the switch costs in the behavioural data showing that voluntary task switching performance is more challenging for the ASC group, we expected between-group differences in P3 in amplitude and latency, potentially reflecting further increased attenuation and delay in switch trials compared to repeat trials in the ASC group.

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<sup>1</sup> Before inspection of the average EEG signal, we expected to observe preparatory posterior positivity as an additional measure of intentional control (c.f., Karayanidis, Provost, Brown, Paton, & Heathcote, 2011; Kieffaber & Hetrick, 2005; Poljac & Yeung, 2014). However, we observed strong posterior negativity instead, which possibly reflected a neural response evoked by the increased anticipation for the upcoming target stimulus as a consequence of trial-by-trial task-choice cue presentation (i.e., question mark) in the present study (stimulus preceding negativity; Brunia & van Boxtel, 2001, 2004; Brunia, 1988). This made the interpretation of the posterior ERP component difficult and inconclusive within the current task context. We therefore did not include further analysis of this component in the results section, and only briefly turn to this point in the discussion section.

## Method

### Participants

Sixty-four participants took part in this study. The data of one participant with ASC were excluded from the data analyses because of below-average task performance, with error rates exceeding the range of three standard deviations from the group mean. Consequently, data from 31 ASC participants and 32 control participants were analysed. The groups were matched on age ( $t(61) = 0.02$ ,  $p = .982$ ), gender (13 females in each group), IQ (all  $p \geq .341$ ), and



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handedness ( $t(61) = -0.99$ ;  $p = .328$ ). For the IQ measure, we used participants' scores on Wechsler Adult Intelligence Scale (WAIS) or Wechsler Intelligence Scale for Children (WISC) if these were available and measured within the last two years as part of a standard intake interview for entering a clinical institution. To obtain the rest of the IQ scores, we used a short version of the WAIS-III (Wechsler, 1997) prior to the testing day. Considering that the youngest participant was 17.3 years of age, no short version of the WISC was applied. The subtests 'Vocabulary' and 'Similarities' were used to estimate the verbal intelligence IQ, and 'Picture Completion' and 'Block Design' for estimating the performance IQ. By calculating the means of these scores, the Full Scale IQ estimation was made for each participant (for further information on the applied calculations, see Sattler, 2001). Additionally, all participants filled out the short version of the Edinburgh Handedness Inventory (Oldfield, 1971), which required participants to indicate the preferred hand for performing particular actions on five point Likert scales. The majority of both groups' participants had a right-hand preference, with only four participants in each group preferring left hand use. Last, all participants completed the autism spectrum quotient questionnaire (AQ; Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001), which is considered to be a well-validated measure of ASC characteristics in people with ASC (Berthoz, Lalanne, Crane, & Hill, 2013; Pisula et al., 2013), their parents (Kose et al., 2013; Wheelwright, Auyeung, Allison, & Baron-Cohen, 2010), and controls (Freeth, Bullock, & Milne, 2013; Poljac et al., 2012). As such, participants' individual answers to 50 statements measuring the degree to which a participant has traits associated with ASC were translated into one single score between 0 and 50, with higher scores associated with an increase in ASC traits. Analysis revealed that the ASC and control group differed significantly in the amount of estimated ASC traits ( $t(61) = 8.15$ ,  $p < .001$ ), with the ASC group's average AQ score of 28 being above the suggested threshold score of 26 for good discriminative validity and screening (Woodbury-Smith, Robinson, Wheelwright, & Baron-Cohen, 2005), and the control group's average AQ score of 13 being far below this threshold. An overview of the descriptive measures of both

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participant groups can be seen in Table 1.

Recruitment of ASC participants was performed through mental health care clinics in the Netherlands, as well as through online posts from Dutch organizations for autism. The participants with ASC were diagnosed with either autism ( $n = 7$ ), Asperger syndrome ( $n = 12$ ), or with pervasive developmental disorder – not otherwise specified (PDD-NOS,  $n = 12$ ) by licensed clinicians according to the DSM-IV criteria (American Psychiatric Association, 2000). Control participants were recruited through a research participation system, and via flyers that were distributed at (high) schools. All of the control participants had no (history of) diagnosed disorders. Further inclusion criteria were ages between 16 and 30 years, IQ above 80, and normal or corrected-to-normal vision. Participants received 20 euro or course credits for participation. All participants gave oral and signed informed consent prior to participation. For participants younger than 18 years, additional written informed consents were provided by both parents. All procedures performed in the present study were in accordance with the ethical standards of the institutional and national research committees, and with the 1964 Helsinki declaration and its later amendments (or comparable ethical standards). The complete experimental protocol was approved by the ethical commission of CMO (Commissie Mensgebonden Onderzoek) Arnhem - Nijmegen, as well as by the Donders Centre for Cognition Review Board.

-- Please add Table 1 around here --

### **Stimuli and Tasks**

In each trial of the VTS paradigm, participants were first presented an empty grid consisting of three boxes adjacent to one another with a question mark above it, indicating that they were expected to choose between responding to either the shape (task 1) or location (task 2) of the upcoming target stimulus. In order to help them make 'random' task choices, participants were

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instructed to choose the current task as if they were tossing a coin. Accordingly, they would sometimes choose to perform the location task, and other times the shape task. Additionally, participants were asked to choose both tasks at a rate of about 50% each throughout the experiment, and to prepare their task choice prior to target stimulus presentation. By pressing the spacebar with both thumbs, participants indicated that they performed their task choice, and that they were ready to be presented with the target stimulus. In this way, participants indicated *that* they had made a task choice, without indicating explicitly *what* that task choice was. After an interval (900ms) in which the empty grid was still visible, the target stimulus was presented, which was a blue triangle, square, or circle that almost filled out one of the three boxes (2.6° high and 7.4° wide). The response to the target stimulus was made by pressing one of the six response buttons as fast and accurately as possible, and was followed by an interval (500ms) in which only an empty grid (of three boxes) was visible. After this interval, the question mark reappeared, indicating the beginning of a new task choice trial (Fig. 1). Three keyboard buttons were directly linked to the matching positions in the grid, and were used for the location task, while the three other buttons were linked to the shapes to which the participants would respond to if they chose to perform the shape task. Hand-task associations (e.g., which hand was mapped to which task) were counterbalanced across participants, with half of the participants responding to the shape of the target stimulus with left hand button presses, and to the location of the target stimulus with right hand button presses, while this mapping was reversed for the other half of participants. To indicate the shape of the target stimulus, participants used the leftmost, middle, and rightmost finger of the appropriate hand for circle, square, and triangle responses, respectively. The location of the target stimulus was mapped compatibly to corresponding responses: the leftmost, middle and rightmost finger were used to indicate left, centre, and right box, respectively. Throughout the experiment, target stimuli were presented quasi-randomly, meaning that between two successive trials, stimuli could either be repeated completely (i.e., same shape and location), partly (i.e., same shape or same location), or not at

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all (i.e., different shape and location), and that these four combinations (full repetition, shape repetition, location repetition, no repetition) occurred equally often.

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## Procedure and Design

The experiment was administered in a sparsely-lit, electrically-shielded chamber. The VTS paradigm was programmed in Presentation (Neurobehavioral Systems Inc), and stimuli were displayed on a 24 inch monitor placed approximately 1m from the participant. The EEG electrodes were third generation active ActiCAP electrodes used in combination with a BrainAmp DC amplifier (Brain Products GmbH). EEG data analyses were performed with Fieldtrip (Oostenveld, Fries, Maris, & Schoffelen, 2011) implemented in Matlab.

Participants started with four practice blocks, consisting of 20 trials each. In the first practice block, participants performed the location task only, while in the second practice block only the shape task was practiced in order to become acquainted with the response mappings of both tasks. Following this, participants practiced switching voluntarily between the two tasks for two blocks. At this point, both the question mark above the empty grid serving as cue for task choice performance, and the space bar press to indicate that the task choice was prepared, were introduced. Participants were encouraged to take their time before hitting the space bar to deliberately decide which task they wanted to perform next, and to press the space bar with both thumbs when they finished making their task choice. After the practice blocks, participants completed eight experimental blocks consisting of 60 trials each (i.e., 480 trials in total). At the end of each block, feedback showing the mean response and choice times, amount of errors, the number of times that each of the two tasks was performed, and the number of switch and repeat trials was provided in order to encourage participants to respond as fast and accurately as possible to the target stimuli, and to perform the task according to the given instructions

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regarding equal task distribution and ‘random’ switching. After a self-paced interval, participants continued with the next experimental block. After finishing the first four experimental blocks, participants received a fixed break of approximately five minutes, after which the experiment continued with the remaining four blocks. During the experiment, run lengths, choice times (CTs), reaction times (RTs), and errors were recorded, together with continuously measured EEG.

### EEG Data Acquisition

The EEG signal was recorded from 32 electrodes, either placed in the fabric cap or directly on the face. The recorded channels were FP1, FP2, F7, F3, Fz, F4, F8, FC5, FC1, FC2, FC6, T7, C3, Cz, C4, T8, CP5, CP1, CP6, P7, P3, Pz, P4, O1, O2, O3. Additional electrodes were placed on the left and right canthi, above and below the right eye and on both mastoids. All electrode recordings were referenced to the left mastoid and offline re-referenced to the linked mastoids. The electrode impedances were kept below 10kOhm. The data were continuously recorded at a sampling rate of 1000Hz, and after amplification sent to the recording computer that added the EEG markers to the data.

### Data Analysis

**Behavioural Data Analysis.** Data were cleaned of the first trials of each block, error trials, and trials following errors (infrequently occurring events as errors can orient attention away from the task in the next trials; Notebaert et al., 2009). Next, trials with CTs and/or RTs exceeding the range of three standard deviations from the mean (considered per condition of each participant) were excluded from the CT and RT analyses. Errors were defined as trials in which the incorrect finger of a specific hand was used. Finally, depending on the task choices made by the participants, there were switch trials (i.e., previous and current task choice were different) and

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repeat trials (i.e., previous and current task choice were identical).

Task choice behaviour was analysed by submitting run length to a 2 x 2 repeated measures ANOVA (rANOVA) with Task (location/shape) as the within-subject factor, and Group (ASC/control) as the between-subject factor. Next, CTs were submitted to a 2 x 2 x 2 rANOVA with Task (location/shape) and Transition (switch/repeat) as the within-subject factors, and Group (ASC/control) as the between-subject factor. For analysing behaviour related to the actual response to the stimulus, RTs and error rates were submitted to a 2 x 2 x 2 rANOVA with Task (location/shape) and Transition (switch/repeat) as the within-subject factors, and Group (ASC/control) as the between-subject factor.

**EEG Data Analysis.** The first step was to preprocess the EEG signal, and to prepare it for electrode and time-window selection procedures. Epochs were extracted from the continuously recorded EEG, starting from 1800ms before until 1000ms after target stimulus onset (long epoch segmentation has been shown to improve the identification and separation of components in the independent components analysis (ICA), which was performed at a later stage; Debener, Thorne, Schneider, & Viola, 2010). Next, high- and low-pass filters were applied to only include frequencies higher than 0.1Hz and lower than 50Hz and to reduce distortions caused by, for example, skin potentials, electronic noise from environmental devices, and muscle activity (Luck, 2005). Subsequently, an ICA was performed to identify artefacts induced by eye movements (left-right and up-down), heartbeats, neck strain and other noise-related sources, followed by the removal of the components representing these artefacts from the data. Last, in addition to the first trials of each block, trials with variances and/or kurtosis values exceeding the range of three standard deviations from the mean, trials on which an erroneous response was made, and trials following such erroneous trials, were excluded from the data. The remaining data were used for electrode and time-window selection.

In the second step, previous studies focusing on the CNV (e.g., Poljac & Yeung, 2014;

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Vandamme et al., 2010) and P3 (e.g., Karayanidis, Provost, Brown, Paton, & Heathcote, 2011; Polich, 2007; van Hoogmoed, van den Brink, & Janzen, 2012) were used to define initial component specific regions of interest (ROIs) and global time intervals for measuring EEG signals. By collapsing scalp topographies across all conditions and participants within the identified time intervals of interest, and calculating grand averaged ERP waveforms across all conditions and participants for each electrode within the identified ROIs and time intervals of interest, we were able to fine-tune and finalise our electrode and time window selections, which were orthogonal to the conditions of interest (for similar procedure, see Schevernels, Krebs, Santens, Woldorff, & Boehler, 2014). This procedure is assumed to increase the likelihood of the observed effects reflecting true differences between groups and/or conditions (Luck & Gaspelin, 2017). As a result, the frontal CNV was analysed on the frontal F3, Fz, F4 electrodes, and the P3 was analysed using the posterior P3, Pz, P4 electrodes. The time window for CNV analysis was from -600 to 0ms before target stimulus onset, while the window for P3 was from 300 to 500ms after target onset. Epochs from each channel were baseline corrected relative to the -900 to -800ms period before target stimulus onset for the CNV, and relative to -100 to 0ms before target stimulus onset for the P3.

In the third step, the EEG signal was assigned to experimental conditions for each individual participant, and statistically tested on differences. The within-group factors were Task (location/shape) and Transition (repetition/switch), and Group (ASC/control) was applied as the between-group factor. The averages of the CNV were compared to the mean voltage, and the averages of the P3 to the maximum peak amplitude and maximum peak latency. Once we established between-group differences in CNV within our time window of 600ms, we conducted further exploratory analyses by dividing the time interval into 6 smaller intervals of 100ms in order to reveal the more specific time period in which these between-group differences would have occurred.

## Results

Since the EEG data of this study were acquired in a subset of the participants who participated in the study of Poljac et al. (2017), we refer to this study for more detailed behavioural analyses of the run lengths, CTs, RTs, and errors. For the purpose of transparency and completeness, we briefly discuss the behavioural results of the participants in the present study.

### Behavioural Results

Within the current experimental context, run length and CTs were assumed to be related to intentional control processes (run length and CTs), and RTs and error rates were assumed to reflect processes of task execution.

**Run Length.** Analysis of the mean averages for the numbers of times that a task was repeated in a row (i.e., the run length) revealed a significant main effect of Task ( $F(1,61) = 29.40, p < .001; \eta^2_p = .325$ ), with an increased run length in the shape task ( $M = 3.53, SE = .22$ ) compared to the location task ( $M = 3.24, SE = .19$ ). Next, a marginally significant difference in the run length was observed between the groups ( $F(1,61) = 3.84, p = .055; \eta^2_p = .059$ ), indicating that the ASC group ( $M = 3.78, SE = .29$ ) had an increased tendency to repeat tasks compared to the control group ( $M = 2.99, SE = .28$ ). Furthermore, a significant interaction effect between Task and Group was observed ( $F(1,61) = 4.44, p = .039; \eta^2_p = .068$ ), driven by a more pronounced difference in run length between the two tasks in the ASC group ( $M$  shape task – location task = .40,  $SE = .09$ ) than in the control group ( $M$  shape task - location task = .18,  $SE = .06$ ). Simple contrast analysis revealed that the observed repetition bias asymmetry was significant in both the ASC group ( $F(1,30) = 19.28, p < .001; \eta^2_p = .391$ ) and control group ( $F(1,31) = 9.85, p = .004; \eta^2_p = .241$ ).

**CTs.** No significant main effects or interactions (all  $p \geq .190$ ) were observed for CTs.



**RTs.** Participants were overall faster when performing the location task ( $M = 561\text{ms}$ ,  $SE = 19.45$ ) than when performing the shape task ( $M = 710\text{ms}$ ,  $SE = 20.01$ ;  $F(1,61) = 154.31$ ,  $p < .001$ ;  $\eta^2_p = .717$ ), confirming that the shape task could be considered as the harder task. Also, participants were faster in repeat trials ( $M = 597\text{ms}$ ,  $SE = 16.40$ ) than in switch trials ( $M = 675\text{ms}$ ,  $SE = 22.19$ ;  $F(1,61) = 55.90$ ,  $p < .001$ ;  $\eta^2_p = .478$ ). When comparing between the groups, a significant general slowing was observed ( $F(1,61) = 7.76$ ,  $p = .007$ ;  $\eta^2_p = .113$ ) in the ASC group ( $M = 688\text{ms}$ ,  $SE = 26.79$ ) compared to the control group ( $M = 583\text{ms}$ ,  $SE = 26.37$ ). Switch cost analyses, which are generally accepted to reflect the quality of task switching processes (Monsell, 2003), revealed that switch costs (i.e., RTs in switch trials – RTs in repeat trials) were significantly larger in the ASC group ( $M = 106\text{ms}$ ,  $SE = 14.94$ ) compared to the control group ( $M = 50\text{ms}$ ,  $SE = 14.70$ ), which was also confirmed by a significant Transition x Group interaction ( $F(1,61) = 7.10$ ,  $p = .010$ ;  $\eta^2_p = .104$ ). Even when correcting for the general slowing by analysing the participants' increases in percentages of RTs in switch trials compared to repeat trials ( $M_{ASC} = 16.43\%$ ,  $SE = 2.23$ ;  $M_{CON} = 8.64\%$ ,  $SE = 2.19$ ), the difference between the groups was still observed ( $t(61) = 2.49$ ,  $p = .016$ ;  $d = .627$ ).

**Errors.** The error rates showed similar main effects of Task ( $M_{location} = 1.98\%$ ,  $SE = .26$ ;  $M_{shape} = 4.25\%$ ,  $SE = .39$ ;  $F(1,61) = 57.54$ ,  $p < .001$ ;  $\eta^2_p = .485$ ) and Transition ( $M_{switch} = 3.92\%$ ,  $SE = .40$ ;  $M_{repetition} = 2.31\%$ ,  $SE = .24$ ;  $F(1,61) = 32.34$ ,  $p < .001$ ;  $\eta^2_p = .346$ ). No difference in error percentages ( $F(1,61) = 0.09$ ,  $p = .770$ ;  $\eta^2_p = .001$ ) or in error data switch costs ( $F(1,61) = 1.06$ ,  $p = .309$ ;  $\eta^2_p = .017$ ) was observed between the two groups.

## EEG Results

Here, CNV was assumed to be related to intentional control processes, and P3 (latency) was assumed to track processes of task execution.

**CNV.** Fig. 2A and Fig. 2B depict the CNV and scalp topography of the brain surface signal over time, respectively. Fig. 2C and Fig. 2D illustrate the CNV averaged across the analysis time

window of -600 to 0ms before target stimulus onset. As can be seen in Fig. 2A, the CNV showed main effects of both Transition ( $F(1,61) = 11.25, p = .001; \eta^2_p = .156$ ) and Group ( $F(1,61) = 4.06, p = .048; \eta^2_p = .062$ ). Specifically, a stronger negativity during the preparation interval was observed in switch trials ( $M = -.20\mu V, SE = .34$ ) compared to repeat trials ( $M = .20\mu V, SE = .35$ ), and in trials performed by the control group ( $M = -.68\mu V, SE = 0.47$ ) compared to the ASC group ( $M = .68\mu V, SE = .48$ ; Fig. 2C). Furthermore, a marginally significant three-way interaction of Task x Transition x Group ( $F(1,61) = 3.64, p = .061; \eta^2_p = .056$ ) was observed, arising from a significant interaction between Task and Transition in the control group ( $F(1,31) = 5.04, p = .032; \eta^2_p = .140$ ), but not in the ASC group ( $F(1,30) = 0.27, p = .609; \eta^2_p = .009$ ; Fig. 2D). Teasing apart the significant interaction between Task and Transition in the control group further revealed that CNV differentiated between switch and repeat trials in the location task ( $t(31) = -3.61, p = .001; d = -.638$ ), but not in the shape task ( $t(31) = 0.06, p = .951; d = .011$ ). It seems that in the control group, preparation of a switch to the location task was accompanied by the strongest CNV ( $M = -1.07\mu V, SE = .46$ ), whereas preparing to repeat the location task showed the least pronounced CNV ( $M = -.27\mu V, SE = .48$ ).

--- Please add Fig. 2 around here ---

Careful inspection of the scalp topography in Fig. 2B revealed that the slowly developing negativity across frontal sites was clearly changing over the 600ms of the preparation interval. As such, it seemed relevant to further investigate whether such over-time differences in signal unfolding across conditions may have influenced the effects of interest in this study. Therefore, we reanalysed the data by dividing the 600ms of the preparation interval into six intervals of 100ms. The results showed that the main effect of Group (Table 2A) and the interaction between Task, Transition, and Group (Table 2B) were generally strongest in the time bins close to the stimulus presentation. For instance, in the interval shortest before target stimulus onset

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(i.e., -100 to 0ms), both the main effect of Group ( $F(1,61) = 4.32, p = .042; \eta^2_p = .066$ ), and the Task x Transition x Group interaction ( $F(1,61) = 4.43; p = .039 \eta^2_p = .068$ ) displayed one of their strongest differentiations between the ASC and control group.

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**Post-stimulus P3.** The P3 is depicted over time in Fig. 3. In the P3 amplitude data, a main effect of Transition ( $F(1,61) = 10.17, p = .002; \eta^2_p = .143$ ) was observed, indicating increased P3 amplitudes in repeat trials ( $M = 12.03\mu V; SE = .61$ ) compared to switch trials ( $M = 11.37\mu V, SE = .58$ ). No other significant main effects or interactions were observed (all  $p \geq .112$ ).

**P3 Latency.** The characteristic peaked waveform of the P3 allowed for a peak latency analysis. This yielded a marginal main effect of Transition ( $F(1,61) = 2.82, p = .099, \eta^2_p = .044$ ), numerically indicating increased latencies for switch trials ( $M = 361ms, SE = 3.34$ ) compared to repeat trials ( $M = 358ms, SE = 3.33$ ; Fig. 3). No other significant main effects or interactions were observed (all  $p \geq .118$ ).

--- Please add Fig. 3 around here ---

## Discussion

The main goal of the present study was to obtain a better understanding of the neurocognitive mechanisms underlying cognitive inflexibility leading to behavioural rigidity in ASC by directly comparing EEG signals between an ASC and a matched control group measured under voluntary task-switching conditions. The results of this study extend the evidence for the notion of intentional control difficulties in ASC, as the preparatory component CNV, assumed to track

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intentional control processes, was found to be globally attenuated in the ASC group.

Furthermore, while the CNV distinguished between specific task conditions in the control group, no such differentiation was observed in the ASC group, suggesting potential difficulties with fine-tuning of the amount of intentional control to the contextual requirements in ASC. In contrast, the stimulus-evoked P3 did not show such between-group differences, providing no evidence for the presence of altered task execution in ASC. Altogether, the results of the present study emphasize the importance of considering intentional control to explain cognitive inflexibility during task switching in ASC.

### **Intentional control**

The CNV findings support the idea of deviant intentional control processes underlying cognitive inflexibility in ASC, as this EEG measure of intentional control was generally weaker and less distinctive in differentiating between conditions in the ASC group compared to the control group. To the best of our knowledge, such observation of differences between an ASC and a control group using EEG, is novel.

Previous studies in control participants have suggested that the CNV reflects task preparation in voluntary task switching (Kang et al., 2014; Vandamme et al., 2010), and that it is most pronounced for better prepared responses (i.e., fast responses; Lavric et al., 2008; Poljac & Yeung, 2014). The first observation in our study, a generally reduced CNV accompanying task performance of the ASC group, gives an indication for attenuated task preparation and intentional control in the ASC group. This finding is line with previous studies that have already reported atypical prefrontal neural activity in ASC when top-down control processes are needed to be exerted across several domains (Cook, Barbalat, & Blakemore, 2012; Frith, 2003).

In addition to the generally attenuated CNV in the ASC group, it was observed that while the CNV in both the ASC and control group was increased in switch trials compared to repeat trials, more specific CNV modulations by the different tasks (i.e., location and shape task) were

observed in the control group only (see Poljac & Yeung, 2014 for similar task specific modulations of CNV in non-clinical participants). When relating this finding to previous studies, which used response speed as an index of effective task preparation (Karayanidis et al., 2011; Lavric et al., 2008; Poljac & Yeung, 2014) and typically interpreted the conventionally observed CNV elevation in fast trials as proof for the CNV's characteristic to reflect to the quality of task preparation (Lavric et al., 2008; Poljac & Yeung, 2014), the current observation of the CNV failing to reflect specific modulations between tasks in the ASC group suggests that in both tasks, trials are accompanied by the same extent of applied task preparation in the ASC group. Therefore, it seems that there are fine-tuning difficulties in ASC with assigning the needed amount of intentional control for responding to the different combinations of tasks and transitions. Nevertheless, while this interpretation may sound generally valid, further studies (applying other approaches) may be needed for a better understanding of the characteristics of CNV, and the meaning of specific differences in CNV between conditions and groups (for instance, see Steinhäuser, Maier, & Ernst (2017) for an investigation of the EEG signal accompanying specific switch errors revealing new insights about posterior positivity and reconfiguration processes in task switching).

An important paradigm choice to consider in relation to the sensitivity of CNV is the use of bivalent target stimuli, meaning that these have features which are relevant to more than one task (Bunge & Zelazo, 2006). In a task switching study assessing different types of stimuli, CNV increase for switch trials was observed for this type of stimuli only (Mueller, Swainson, & Jackson, 2007), requiring participants to flexibly recode response meanings at the time of each task switch (Meiran, 2000). While such ambiguous stimuli did not evoke task switching difficulties in an ASC group when a cue explicitly indicated what type of response mapping was needed for responding to the upcoming target stimulus (Poljac et al., 2010), it could not be ruled out that the combination of absent cues with ambiguous stimuli supported the emergence of task switching difficulties in ASC. Possibly, though on a speculative note, the switch-insensitive

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CNV in the ASC group may be explained by an increased tendency to maintain more active representations for each finger with either task (as conventionally applied for reacting to univalent stimuli), perhaps with the goal to minimize trial-by-trial recoding of response mappings. Interestingly, there are indications for behaviourally impaired procedural learning in ASC (Mostofsky, Goldberg, Landa, & Denckla, 2000), and difficulties with response shifting that is independent of whether also a shift in cognitive set is required, with the latter being accompanied with ineffective adaptations in neural signals when altering behavioural responses (Shafritz et al., 2008).

Another possible explanation for the absent CNV modulation by the different task conditions in the ASC group may be related to the earlier notion of attenuated top-down intentional control processes in ASC. In this case, specific adjustments to task requirements are likely to be absent or postponed until the task execution interval, making the ASC participants rely more on bottom-up sources of information. Indications for the presence of such delayed adjustments to the task requirements are observed in the behavioural data, in terms of increased switch costs in the ASC group. Interestingly, in the domain of attentional orienting, it has already been observed that children with ASC have an increased reliance on bottom-up strategies (Amso, Haas, Tenenbaum, Markant, & Sheinkopf, 2014; Senju, Kikuchi, Hasegawa, Tojo, & Osanai, 2008), and that a possible explanation for some of these results may be that people with ASC have difficulties with developing top-down strategies for attending to, for example, socially relevant stimuli (Neumann, Spezio, Piven, & Adolphs, 2006). As such, inadequate top-down control in ASC should be taken into account as a potential explanation for the observed impairments in both the domains of social interactions and task switching.

Importantly, there is one methodological aspect of studying EEG measures in the context of voluntary task switching that deserves special attention, which is that there can be potential differences in the numbers of trials used to calculate the EEG epochs. Specifically, conditions in the VTS paradigm are formed by participants' choices rather than by predefined

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and controlled specific (combinations of) presented stimuli, such as, for example, in cued switching paradigms (cf., Poljac et al., 2010; Yerys et al., 2015). Therefore, the generally decreased switch preference in ASC participants (Poljac et al., 2017) may have led to differences in the ERP components' signal-to-noise ratios, potentially influencing the present findings to some extent. Nevertheless, as each of the conditions' number of trials underlying the ERP components used here was well-above the recommended 30-60 trials per condition for investigation of large components such as the CNV or P3 (Handy, 2005), with the least number of trials per condition being an average of 80 trials in the ERP analyses (i.e., the 'shape switch' condition in the ASC group), we believe that the major findings are not strongly driven by the differences in signal-to-noise ratios in our study. However, careful interpretation is recommended for EEG studies applying voluntary task switching procedures, including the present one.

In sum, the CNV differences observed between the ASC and control group are (among) the first EEG findings that suggest an important role of intentional control in understanding cognitive inflexibility during task switching in ASC.

### **Task execution**

To investigate the impact of neurocognitive mechanisms concerned with the translation of intentions into actions, EEG measures of task execution were also tracked in the post stimulus interval. No differences in P3 amplitude or latency were observed between the groups, suggesting similar task-related stimulus evaluation processes across groups. Specifically, the characteristic P3 attenuation in switch trials compared to repeat trials (Kieffaber & Hetrick, 2005; Poljac & Yeung, 2014; Vandamme et al., 2010) was observed in both groups, possibly reflecting consolidation of task-related stimulus evaluation due to task repetition (Mueller et al., 2007). In addition, the expected increase in P3 latencies was observed for switch trials compared to repeat trials as well, which is in line with the notion that more difficult conditions (such as

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switching tasks compared to repeating a task) are accompanied by increased P3 latencies (Ford et al., 1979; Polich, 1987). Following this logic, one would also have expected to observe a difference in P3 if tasks differ in difficulty, however, no such difference in P3 was observed between the easier location task and the harder shape task in the current data.

Although we assumed that testing a clinical population would increase the sensitivity of the present study in the detection of behavioural task switch execution difficulties in ASC (cf. Poljac et al., 2012), and that incorporation of a trial-by-trial task choice element may have led to higher overall task load and difficulty, which would have added strain on the cognitive flexibility abilities of ASC participants in particular (Goldberg et al., 2005; Hill, 2004), the EEG measures showed no support for altered task execution processes in the ASC group. The reason for the behavioural indications of task execution difficulties (i.e., increased repetition bias (asymmetry) not being accompanied by differences in the EEG signal, remains unclear. A possible explanation may be that the stimulus-evoked P3 is not a suitable measure for detecting alterations in task execution between an ASC and control group in a (voluntary) task switching paradigm. Studies that have found the P3 to provide a useful representation of task execution processes in a voluntary switching context (Poljac & Yeung, 2014; Vandamme et al., 2010) observed this component's ability to track task execution processes by comparing conditions within-subjects. For example, Poljac & Yeung (2014) showed that even in the absence of large behavioural switch costs, alterations within the shape task's neural signal could be tracked, resonating from differences between participants' neural signal in switch and repeat trials of the shape task (i.e., a within-subject design). While our data only provided global differences between switch and repeat trials across participants in the first place, inferring task execution alterations from differences between the groups' switch and repeat asymmetries would require even more sensitivity from the P3 than in the aforementioned studies to overcome the increase in substantial noise that is introduced by applying between-group comparisons (Charness, Gneezy, & Kuhn, 2012). As such, the P3 in the present study may either have lacked sensitivity



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in order to reveal group specific differences in neural signal, or alternatively, such group specific differences were absent in the present study.

In sum, there is no EEG evidence in the present study for the idea that difficulties with task execution contributes to cognitive inflexibility in ASC.

## **Conclusion**

The current neurophysiological findings provide empirical evidence for intentional control difficulties in ASC in the context of voluntary task switching. These observations put forward intentional control as an important neurocognitive candidate behind cognitive inflexibility leading to behavioural rigidity in ASC. As such, these findings open a fruitful future route to further investigations into the cognitive inflexibility and behavioural rigidity behaviours observed in ASC.

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### **Conflict of interest**

Vincent Hoofs, Myrthe M. Princen, Ervin Poljac, Arjen Stolk and Edita Poljac declare that they have no conflicts of interest.

### **Ethical approval**

All procedures performed in studies involving human participants 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).

### **Figure captions**

*Fig. 1.* Schematic trial overview. Each trial started with a question mark, indicating to participants that they had to perform a task choice. The time invested, the so-called choice time, lasted until the spacebar was pressed with both thumbs. The spacebar press evoked disappearance of the question mark, while the empty grid of three boxes remained on the screen for another 900ms. After this interval, the target stimulus appeared in one of the three boxes of the grid, and afforded two different sets of responses. For instance, if presented with a triangle in the middle box of the grid, participants were expected to respond with a triangle-button press if they chose the shape task, or with a middle-button press if they chose the location task. After the response was made, the target stimulus disappeared resulting in the presentation of an empty grid for 500ms, which was then followed by the presentation of a new question mark, indicating the beginning of the next trial.

*Fig. 2. (A)* Grand average event-related contingent negative variation (CNV), measured at electrodes F3, Fz, and F4, for both Transition types (switch/repeat) per Task (location/shape) in the Autism Spectrum Conditions (ASC) group (*left*) and the control group (*right*). The signal is time-locked to target stimulus presentation onset, and analysed using an interval of 600ms prior

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to target stimulus onset. (B) The scalp topography of the average signal difference between switch and repeat trials for both tasks (*above*: location task/ *below*: shape task) across 100ms intervals, starting from 600ms before target stimulus onset in the ASC group (*left*) and the control group (*right*). (C) Time-averaged CNV (-600 to 0ms before target stimulus onset), measured at electrodes F3, Fz, and F4, in the ASC group (*left*) and control group (*right*). (D) Difference in time-averaged CNV (-600 to 0ms before target stimulus onset) between switch and repeat trials, measured at electrodes F3, Fz, and F4, for both tasks (location/shape) in the ASC group (*left*) and control group (*right*). Error bars indicate SE of the mean.

*Fig. 3.* Grand average event-related P3, measured at electrodes P3, Pz, and P4, for both Transition types (switch/repeat) per Task (location/shape) in the Autism Spectrum Conditions group (*left*) and the control group (*right*). The signal is time-locked to stimulus presentation, and analysed using an interval of 300-500ms after target stimulus onset.

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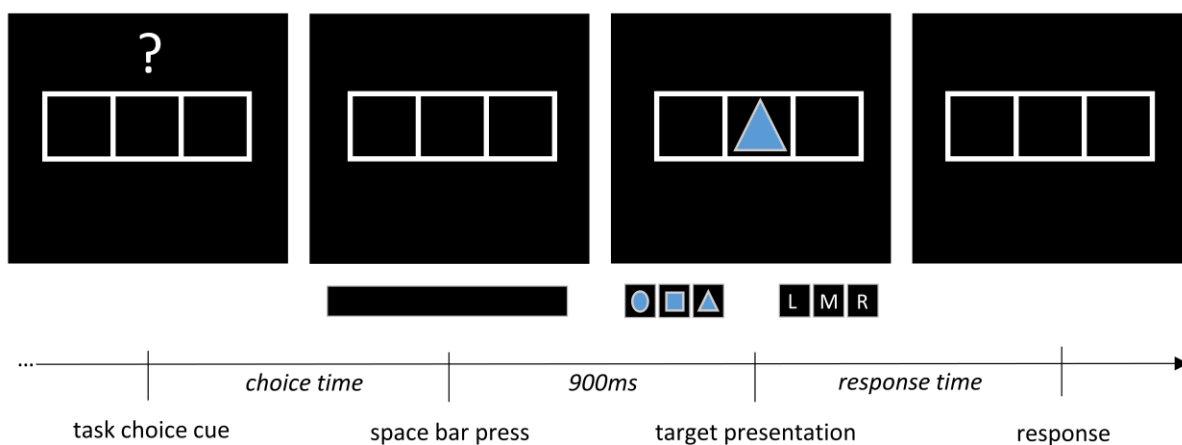
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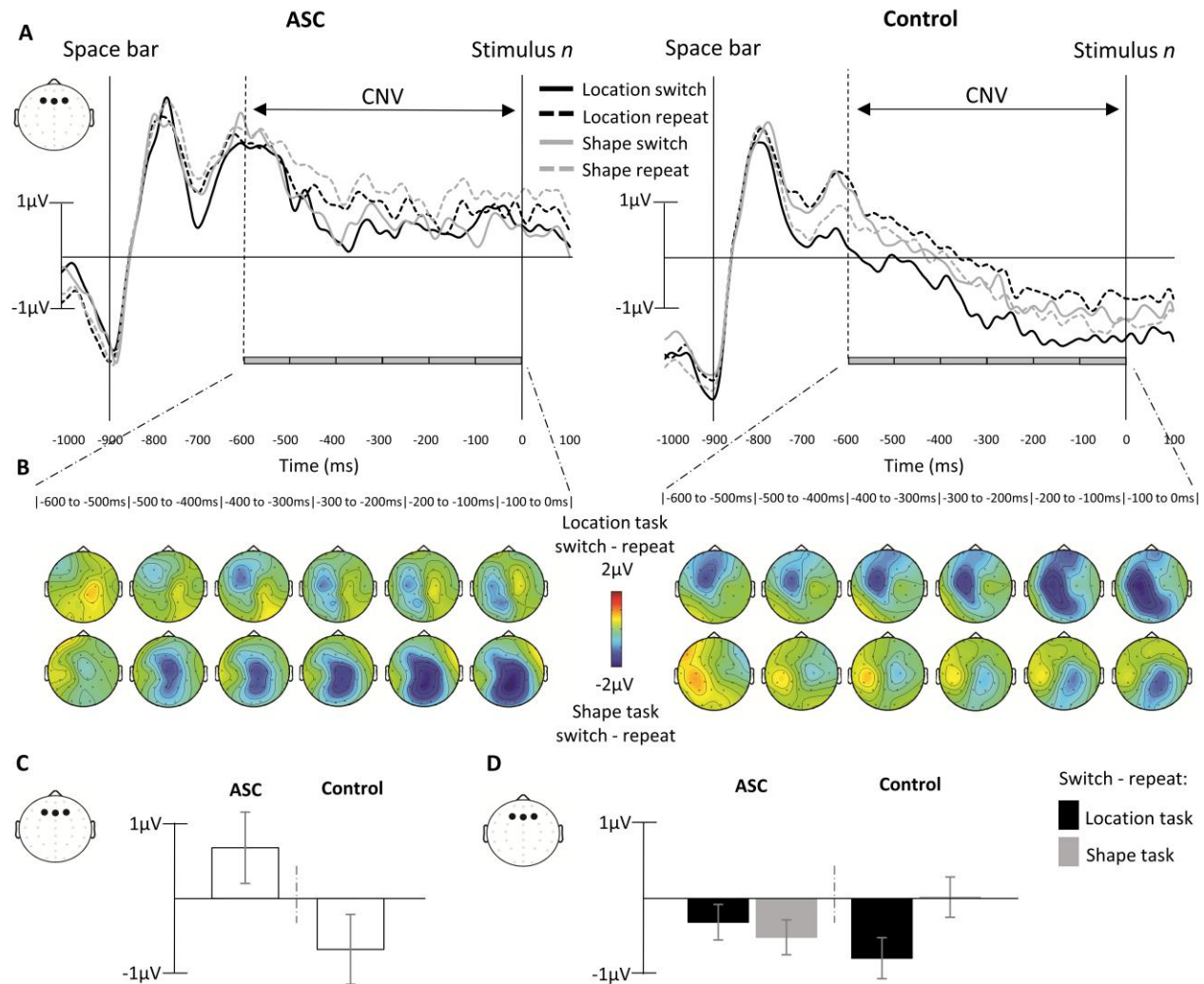
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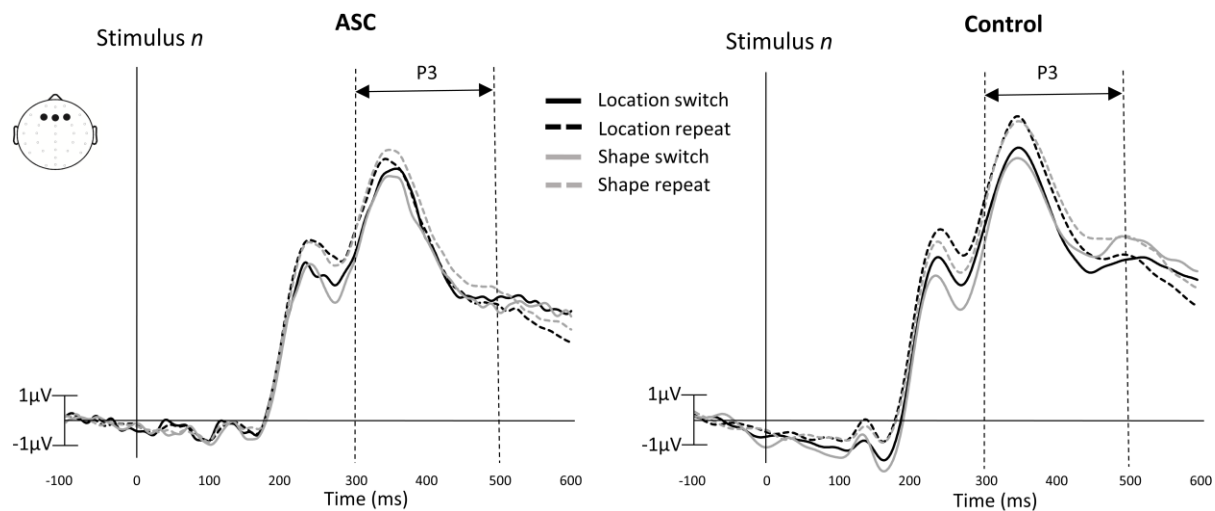


Table 1 Descriptive data for the ASC group and the control group.

	ASC (n = 31)		Control (n = 32)			
	<i>M</i>	Range	<i>M</i>	Range	<i>t</i> (61)	<i>p</i>
Age (in years)	23.3 (.54)	17.8 - 28.8	23.4 (.55)	17.3 - 28.8	-0.02	.982
IQ						
Full Scale	110 (1.68)	97 - 131	111 (1.55)	85 - 131	-0.37	.710
Verbal Scale	111 (1.75)	92 - 129	113 (1.58)	92 - 137	-0.96	.341
Performance Scale	109 (2.28)	86 - 134	109 (2.28)	77 - 134	0.18	.861
AQ	28.2 (1.56)	9 - 42	13.4 (.96)	3 - 25	8.15	<.001
Handedness	25.3 (1.54)	0 - 32	27.3 (1.36)	2 - 32	-0.99	.328

Note. ASC = Autism Spectrum Conditions, AQ = autism spectrum quotient, SE = standard error.

Values in parentheses represent SE of the means.

Table 2 (A) Mean voltage of CNV for the ASC and the control group across 100ms intervals.

Statistical testing was performed for each interval's Group main effect, and (B) Task x Transition

x Group interaction effect.

## A

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Interval (ms)	<i>M</i> ASC ( $\mu$ V)	<i>M</i> CON ( $\mu$ V)	<i>F</i> (1,61)	<i>p</i>	$\eta^2_p$
600-500	1.71(.46)	.24(.39)	6.08	.017	.091
500-400	.70(.51)	-.17(.42)	1.76	.190	.028
400-300	.45(.51)	-.66(.45)	2.65	.109	.042
300-200	.39(.55)	-1.03(.49)	3.76	.057	.058
200-100	.34(.58)	-1.22(.55)	3.84	.055	.059
100-0	.50(.60)	-1.26(.60)	4.32	.042	.066

**B**

Interval (ms)	<i>F</i> (1,61)	<i>p</i>	$\eta^2_p$
600-500	3.25	.077	.050
500-400	2.16	.147	.034
400-300	1.04	.311	.017
300-200	2.08	.154	.033
200-100	4.53	.037	.069
100-0	4.43	.039	.068

Note. CNV = contingent negative variation, ASC = Autism Spectrum Conditions, CON = control.

Values in parentheses represent SE of the means.

## Highlights:

- Participants with autism and matched controls performed voluntary task switching
- The CNV was attenuated and less contextually discriminative in the autism group
- The P3 showed no differences between groups
- Altered intention formation seems to underlie the cognitive inflexibility in autism
- In contrast, translation from intentions into actions seems intact in autism