

Adaptation and serial choice bias for low-level visual features are unaltered in autistic adolescents

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Autism spectrum disorder (ASD), or autism, is characterized by social and non-social symptoms, including sensory hyper- and hyposensitivities. A suggestion has been put forward that some of these symptoms could be explained by differences in how sensory information is integrated with its context, including a lower tendency to leverage the past in the processing of new perceptual input. At least two history-dependent effects of opposite directions have been described in the visual perception literature: a repulsive adaptation effect, where perception of a stimulus is biased away from an adaptor stimulus, and an attractive serial choice bias, where perceptual choices are biased toward the previous choice. In this study, we investigated whether autistic participants differed in either bias from typically developing controls (TDs). Sixty-four adolescent participants (31 with ASD, 33 TDs) were asked to categorize oriented line stimuli in two tasks that were designed so that we would induce either adaptation or serial choice bias. Although our tasks successfully induced both biases, in comparing the two groups we found no differences in the magnitude of adaptation nor in the modulation of perceptual choices by the previous choice. In conclusion, we find no

evidence of a decreased integration of the past in visual perception of low-level stimulus features in autistic adolescents.

Introduction

In typical perception, noisy sensory information is integrated with the spatial and temporal context in order to create a stable percept. In the case of temporal context, our environment tends to be temporally correlated or change in predictable ways. Because of this, perceptual systems, such as the visual system, can leverage the past in the processing of new sensory input (Schwartz, Hsu, & Dayan, 2007). However, a consequence of this is that perception is biased by the past. Specifically, temporal context can bias current visual processing in two directions: a repulsive bias, known as an adaptation bias, and an attractive bias, known as a serial choice bias. Adaptation is a long-known and widely found phenomenon in which perception of a stimulus feature is biased away from

Citation: Bosch, E., Fritsche, M., Utzerath, C., Buitelaar, J. K., & de Lange, F. P. (2022). Adaptation and serial choice bias for low-level visual features are unaltered in autistic adolescents. *Journal of Vision*, 22(6):1, 1–20, <https://doi.org/10.1167/jov.22.6.1>.



the previous input (Kohn, 2007; Thompson & Burr, 2009; Webster, 2003; Webster, 2012; Webster, 2015). In contrast, serial choice bias, also known as sequential choice bias or choice repetition, is a phenomenon where the decision about a stimulus is biased toward the previous decision (Abrahamyan, Silva, Dakin, Carandini, & Gardner, 2016; Akaishi, Umeda, Nagase, & Sakai, 2014; Bosch, Fritsche, Ehinger, & de Lange, 2020; Braun, Urai, & Donner, 2018; Fischer & Whitney, 2014; Fritsche, Mostert, & de Lange, 2017; Fründ, Wichmann, & Macke, 2014; St. John-Saaltink, Kok, Lau, & de Lange, 2016; Urai, Braun, & Donner, 2017; Urai, de Gee, Tsetsos, & Donner, 2019). These opposite biases may arise at different points of visual processing, with adaptation occurring during early stages of perception and serial choice bias occurring at later stages, possibly during decision-making (Bosch et al., 2020; Fritsche et al., 2017). Moreover, recent research suggests that they may be a reflection of distinct ways in which the visual system aims to optimize processing by increasing sensory sensitivity to changes of the environment while stabilizing percepts over time (Fischer & Whitney, 2014; Fritsche, Spaak, & de Lange, 2020).

A suggestion that has been put forward is that autistic individuals may underutilize context in perceptual processing. Autism spectrum disorder (ASD), or autism, is a developmental disorder that is most known for its social and behavioral symptoms, which feature prominently in the *Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition* (DSM-V) diagnostic criteria. The behavioral symptoms also include sensory atypicalities (i.e., hyper- or hyporeactivity to sensory input or unusual interests in sensory aspects of the environment). In recent decades, different hypotheses have been formulated that attempt to explain these sensory atypicalities by how autistic individuals differ from typically developing (TD) individuals in the way that perceptual input is processed (e.g., Happé & Frith, 2006; Lawson, Rees, & Friston, 2014; Mottron, Dawson, Soulières, Hubert, & Burack, 2006; Pellicano & Burr, 2012). For example, the weak central coherence theory (Happé & Frith, 2006) of autism conceptualizes a processing style that favors local processing over global, integrative processing, which may be observed as a reduction of the influence of the past in perceptual processing. Alternatively, work by Lawson, Aylward, Roiser, and Rees (2017) found that autistic individuals overestimate the volatility of the environment, which could lead them to underutilize the past when processing new perceptual input. Many of these theoretical accounts of perceptual processing in autism conceptualize the impairment, cognitive style, or atypicality in autism as one that is general (Happé & Frith, 2006; Mottron et al., 2006; Pellicano & Burr, 2012; Sinha et al., 2014) as opposed to specific to one particular domain or stimulus type. Whether due to a

processing style or an overestimation of the volatility of the environment, if autistic individuals indeed underutilize temporal context, then they would be expected to show decreased biases that stem from this integration of context in different domains and using different stimuli. Depending on where in the visual processing stream this occurs, they may show reduced adaptation, reduced serial choice bias, or both.

Evidence on adaptation in autism is mixed. Some research has indeed found evidence for reduced adaptation effects in autism using a variety of social and non-social visual stimuli, including faces (Ewing, Leach, Pellicano, Jeffery, & Rhodes, 2013; Ewing, Pellicano, & Rhodes, 2013; Pellicano, Jeffery, Burr, & Rhodes, 2007), social eye-gaze (Lawson et al., 2017), biological motion (Karaminis, Arrighi, Forth, Burr, & Pellicano, 2020; van Boxtel, Dapretto, & Lu, 2016), and number (Turi, Burr, Iglizzi, Aagten-Murphy, Muratori, & Pellicano, 2015). However, other studies have found no differences in adaptation to color (Maule, Stanworth, Pellicano, & Franklin, 2018) and causation (Karaminis, Turi, Neil, Badcock, Burr, & Pellicano, 2015). These differences in findings could be attributed to the use of different stimuli and designs, as well as differences in study populations. Notably, there is some evidence that a higher severity of autistic traits and social atypicalities may be associated with larger reductions in the magnitude of adaptation (Lawson et al., 2017; Pellicano et al., 2007), suggesting there may be variation in adaptation decrease across the autistic spectrum.

Few studies have investigated the serial choice bias in autism. One study has found increased, rather than reduced, attractive influence of prior choices in visual location discrimination and visual-vestibular heading discrimination in autism (Feigin, Shalom-Sperber, Zachor, & Zaidel, 2021). However, another study found that perceptual decisions are less strongly attracted toward the immediate past in autistic individuals (Lieder, Adam, Frenkel, Jaffe-Dax, Sahani, & Ahissar, 2019). Although these studies both investigate the influence of the past, they do so by probing different biases using vastly different designs and stimuli, which may explain the contrasting results. An alternative explanation for the contrasting results may be a difference in population: The sample of Feigin et al. (2021) consisted of children and adolescents, whereas the study population of Lieder et al. (2019) consisted of adults.

In summary, if the integration of temporal context is generally reduced in autism, we should find reduced biases that arise from this integration, such as adaptation and serial choice bias. Previous research on adaptation in autism has shown mixed results, and serial choice bias in autism has barely been investigated. Additionally, as no studies have looked into both biases, and studies widely differ from each other with regard

to their samples, designs, and stimuli, it is difficult to compare findings between studies. This leaves open questions on how the past influences perception and perceptual decision-making in autism.

In this study, we investigated whether autistic individuals differ from typically developing peers in the influence or use of prior information in perception and perceptual decision-making. To this end, we conducted two psychophysical tasks in a sample of adolescents with and without an ASD diagnosis. The tasks were optimized in their design to induce either an adaptation bias or a serial choice bias, and both used the same stimuli, which allowed for comparison between the tasks. We used oriented line stimuli for their simplicity and easy-to-control features. To preview the results, we successfully induced both biases, but we found no differences between groups in the magnitude of their adaptation effect or the influence of the previous on the current choice. These findings suggest that integration of temporal context in visual processing of simple features in autism may be typical for low-level features.

Methods

Data availability

All data and code used for stimulus presentation and analysis are available from the Donders Institute for Brain, Cognition and Behavior repository (<https://doi.org/10.34973/kqam-t325>).

Participants

The final sample consisted of 64 participants (31 with ASD, 33 TDs; see [Table 1](#)). Almost half of the sample was female (13 ASD, 16 TD). We tried to match participants in the groups as well as possible based on gender, age, and IQ.

The majority of participants with ASD were recruited from referrals to Karakter Child and Adolescent Psychiatry University Centre, Nijmegen, the Netherlands. The remainder of the participants were recruited through local schools, doctor offices, and recreational organizations such as sports clubs. Finally, some participants who had previously participated in local studies and given permission to be approached for other studies were recruited through local researchers (e.g., [Utzerath, Schmits, Buitelaar, & de Lange, 2018](#); [Utzerath, Schmits, Kok, Buitelaar, & de Lange, 2019](#)).

All participants and their parents or guardians provided written informed consent. No parental consent was required for participants who were legal adults. Participants understood that they could withdraw from the study at any time. We compensated participants

with gift vouchers. Participants were between 12 and 18 years old, were native Dutch speakers, had normal or corrected-to-normal vision based on parental and self-report, and had an IQ above 85. Exclusion criteria were (comorbid) major psychiatric or neurological disorders, current or recent alcohol or drug addiction, use of antipsychotic medication, claustrophobia, and pregnancy. An exception to the comorbid disorders was participants with an additional attention deficit hyperactivity disorder (ADHD) diagnosis, as this is a very frequent comorbidity (e.g., [Jang, Matson, Williams, Tureck, Goldin, & Cervantes, 2013](#)). However, importantly, we included only participants for whom ASD was their primary diagnosis and who did not require ADHD medication. All participants in the ASD group had a clinical diagnosis of autism spectrum disorder according to the DSM-5 criteria ([American Psychiatric Association, 2013](#)) or autistic disorder of Asperger's disorder according to the DSM-IV criteria ([American Psychiatric Association, 1994](#)). Additionally, we conducted a structured developmental interview, the Autism Diagnostic Interview–Revised (ADI-R) ([Lord, Rutter, & Le Couteur, 1994](#)), to verify that their symptomatology matched the diagnostic threshold for ASD. Members of the TD group had no history of neurological or psychiatric disorders. To screen for the presence of undiagnosed psychopathology, we conducted screening questionnaires (see below).

Based on the criteria described above, 12 participants were excluded from our sample for the following reasons. Two participants in the ASD group were excluded based on the ADI-R, as they did not meet the diagnostic threshold for ASD. Three participants in the TD group were excluded based on the screening questionnaires, as they scored within the clinical range on the DSM-oriented scales. One additional TD participant was excluded due to receiving a developmental disorder diagnosis after participation in the study. Two participants were excluded from the ASD group due to their total IQ (TIQ) being under the preregistered cut-off ($TIQ \leq 85$). Finally, two participants in the ASD group and two participants in the TD group were excluded due to poor performance on one of the experimental tasks. All excluded participants were replaced to reach the final sample size.

Recruitment and experimental procedures followed a protocol registered at and approved by and the local ethics committee (CCMO protocol NL60040.091.16, accessible at www.toetsingonline.nl).

General procedure

All participants underwent the same general procedure. Participation consisted of a single experimental session and a set of questionnaires that could be completed during the session or at home.

Measure	ASD	TD	Statistic	<i>p</i>
<i>N</i>	31	33	—	—
Gender (M:F), <i>n</i>	18:13	17:16	$\chi^2 = 0.277$	0.599
Age (year)				
Mean (<i>SD</i>)	15.55 (1.76)	15.65 (1.88)	$t(62) = 0.209$	0.835
Min–max	12.18–18.98	12.26–18.60	—	—
Handedness, mean (<i>SD</i>)	36.10 (8.32)	34.76 (8.16)	$t(61) = -0.646$	0.521
Wechsler Intelligence Scales, mean (<i>SD</i>)				
Picture completion	10.19 (1.618)	10.67 (2.245)	$t(58) = 0.933$	0.355
Block design	10.43 (3.213)	12.58 (2.424)	$t(53.740) = 2.965$	0.005
Vocabulary	10.90 (2.708)	11.79 (2.355)	$t(61) = 1.392$	0.169
Similarities	11.47 (3.360)	12.85 (2.563)	$t(61) = 1.845$	0.070
Performance IQ	100.74 (10.714)	110.21 (10.703)	$t(62) = 3.536$	0.001
Verbal IQ	107.35 (14.520)	113.24 (11.822)	$t(62) = 1.784$	0.079
Total IQ	104.06 (11.685)	112.00 (11.037)	$t(62) = 2.794$	0.007
Adolescent/Adult Sensory Profile, mean (<i>SD</i>)				
Low registration	34.50 (10.514)	28.42 (5.292)	$t(41.882) = -2.854$	0.007
Sensation seeking	35.77 (6.296)	45.48 (8.526)	$t(61) = 5.104$	<0.001
Sensory sensitivity	40.73 (12.123)	30.91 (6.844)	$t(44.828) = -3.909$	<0.001
Sensation avoiding	41.20 (11.631)	28.91 (6.779)	$t(45.728) = -5.059$	<0.001
AASP sum (seeking reverse scored)	155.67 (32.662)	117.76 (13.365)	$t(37.709) = -5.922$	<0.001
Autism Diagnostic Interview, Revised (ASD only)				
Social interaction				
Mean (<i>SD</i>)	18.07 (8.40)	—		
Min–max	6–37	—		
Communication and language				
Mean (<i>SD</i>)	14.16 (4.31)	—		
Min–max	4–21	—		
Restricted and repetitive behaviors				
Mean (<i>SD</i>)	4.13 (3.54)	—		
Min–max	0–17	—		
Child Behavior Checklist DSM-oriented scales (TD only)				
Affective problems				
Mean (<i>SD</i>)	—	1.667 (1.689)		
Min–max	—	0–6		
Anxiety problems				
Mean (<i>SD</i>)	—	1.000 (1.199)		
Min–max	—	0–4		
Somatic problems				
Mean (<i>SD</i>)	—	0.424 (0.867)		
Min–max	—	0–4		
Attention deficit hyperactivity problems				
Mean (<i>SD</i>)	—	1.667 (2.041)		
Min–max	—	0–7		
Oppositional defiant problems				
Mean (<i>SD</i>)	—	1.394 (1.499)		
Min–max	—	0–6		
Conduct problems				
Mean (<i>SD</i>)	—	0.606 (0.998)		
Min–max	—	0–4		

Table 1. Final sample characteristics.

After written informed consent was obtained, we first conducted a brief IQ test (see below) with the participant. If the participant was in the ASD group, we simultaneously conducted the ADI-R structured interview (Lord et al., 1994) with the participant's caregiver in a different room. Participants were then familiarized with the experimental setting in which they performed two behavioral tasks. The order of these tasks was fixed across participants due to an increase in response difficulty from the first to the second task. For each task, participants first received instructions, then performed practice blocks, and finally performed experimental blocks. This procedure was completed for the first task before introducing the second task. Participants were provided with several breaks during the session.

The IQ test consisted of four subtests of the Dutch translation of the Wechsler Intelligence Scale for Children or Adults (WISC-III or WAIS-III) (Kort et al., 2002; Kort, Schittekatte, Dekker, Verhaeghe, Compaan, & Bosman, 2005; Wechsler, 1991; Wechsler, Van der Steene, Vertommen, Bleichrodt, & Uiterwijk, 2002) based on their age at inclusion. The subtests included were picture completion, similarities, block design, and vocabulary, in this order. In order to estimate the participants' IQ, we calculated the norm scores obtained on the four subtests; extrapolated from these scores the verbal, performance, and total sum scores that a participant likely would have obtained had they completed all subtests with similar performance; and recoded these to the IQ scales. In case a participant had already completed the WISC or WAIS (third edition or later) within the 2 years before the inclusion date (e.g., as part of a clinical procedure or participation in a different scientific study), we did not conduct it again, as this would introduce retest effects, but instead requested and used their recent result.

The questionnaire set included, for all participants, Dutch translations of the self-report Edinburgh Handedness Inventory (Oldfield, 1971) and the Adolescent/Adult Sensory Profile (AASP) (Brown & Dunn, 2002). Parents of TD participants completed the Child Behavior Checklist (CBCL) (Achenbach, 1991) to control for the presence of psychopathology.

Apparatus and stimuli

Visual stimuli were generated with the Psychophysics Toolbox (Brainard, 1997; Kleiner, Brainard, Pelli, Ingling, Murray, & Broussard, 2007; Pelli, 1997) for MATLAB (MathWorks, 2018) and displayed on a 24-in. flat-panel display (BenQ XL2420T, resolution 1920 × 1080, refresh rate 60 Hz; BenQ Corporation, Taipei, Taiwan). Participants viewed the stimuli from a distance of approximately 53 cm in a dimly lit room. A chinrest was used to ensure a constant viewing distance.

We chose to use orientation stimuli, as these are simple stimuli with low-level features that can be well controlled. Orientation stimuli were generated by filtering white noise in the Fourier domain with a bandpass filter to create stimuli that had a predetermined, quantifiable amount of orientation information in them and would be more difficult to categorize (see task descriptions below). The passband of spatial frequencies was defined as a Gaussian with a mean of 0.75 $c/^\circ$ and standard deviation of 0.3 $c/^\circ$. The passband for orientations was defined as a von Mises distribution with location parameter μ and concentration parameter κ . The location parameter μ determined the mean orientation of a stimulus, and the concentration parameter κ effectively determined the amount of orientation noise. To introduce sensory uncertainty about the mean orientation of the stimulus, we chose a low concentration parameter κ of 2.3, leading to uncertain stimuli containing multiple orientations around their mean orientation (Figure 1a). After applying the inverse Fourier transform, the root-mean-square contrast of the stimuli was set to 11.76% of their mean luminance. All stimuli were windowed by a Gaussian envelope (2.3° SD). Stimuli and a white fixation dot were presented at the center of a gray-background screen.

In order to increase the participant's interest in and engagement with the stimuli, we used a cover story in which the participant went on safari and was searching by the river for drinking zebras, represented by orientation stimuli, using an old spyglass, explaining the poor resolution of the visual stimuli. The stripes of the zebra were rotated away from vertical in either direction depending on which way the zebra was leaning to drink from the river. This cover story was used only as part of instruction; no visual elements related to the cover story were incorporated into the tasks themselves to avoid introducing confounding factors.

Task 1: Adaptation task

In each trial of task 1 (Figure 1a), two successive stimuli were presented on top of the fixation dot and separated by a 500-ms interstimulus interval. The first stimulus was oriented 20° clockwise or counterclockwise from vertical, with each orientation equally frequent, and was presented for 1000 ms. We term this first stimulus the “adaptor,” as it was meant to induce a repulsive adaptation bias. The adaptor was instructed to be irrelevant (reeds growing by the river, according to the cover story) and had to be merely viewed. The second stimulus was oriented at or around vertical (−12°, −6°, 0°, 6°, or 12°), with each orientation equally frequent, and was presented for 100 ms. We term this second stimulus the “test” stimulus, as it was meant to measure the biasing effect

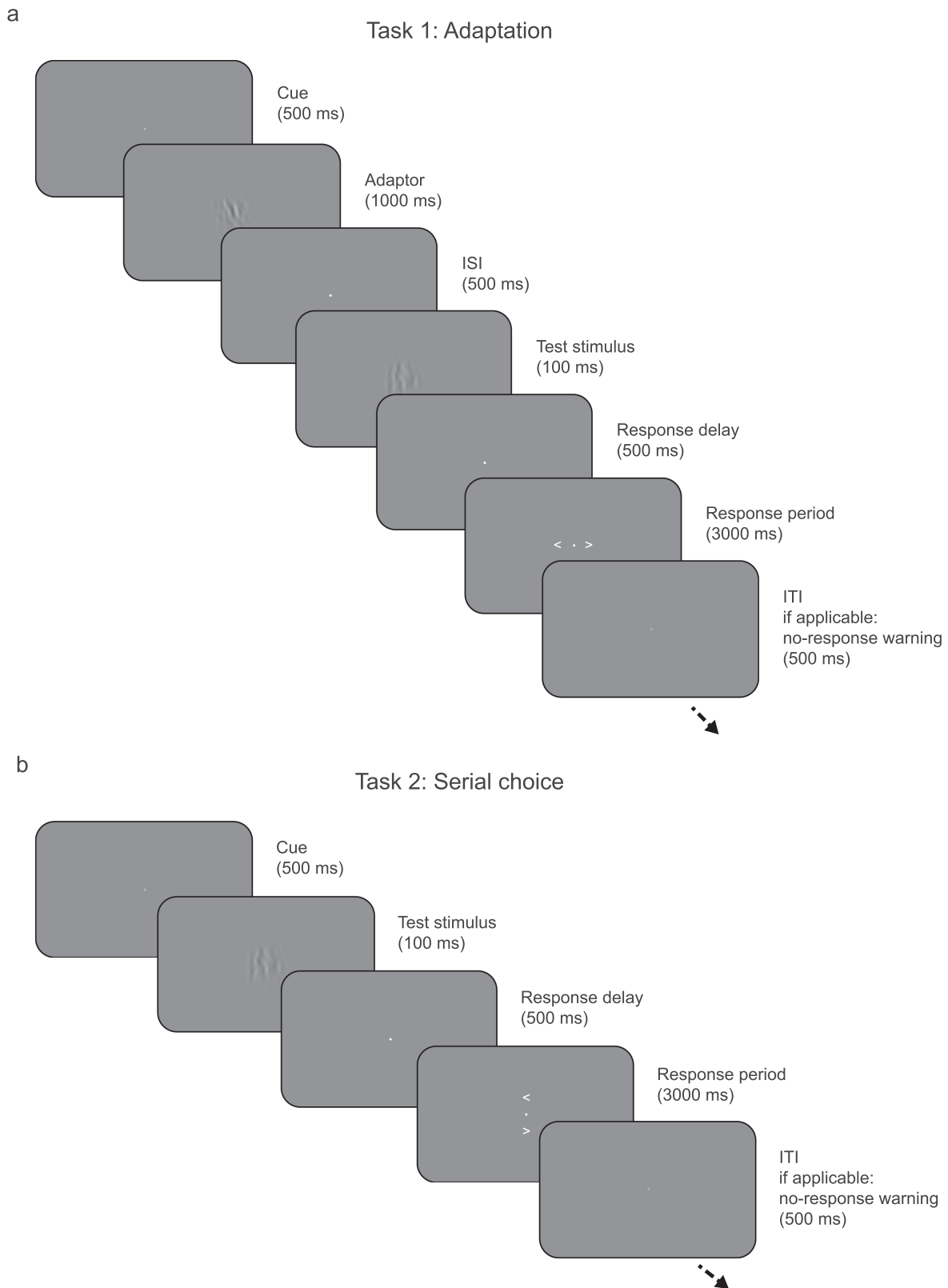


Figure 1. A single trial of task 1 (a) and task 2 (b). In both tasks, participants were presented with ambiguous orientation stimuli and categorized the orientation of a test stimulus compared with vertical. (a) Task 1 was an adaptation task in which the test stimulus was preceded by an adaptor stimulus that participants were instructed was irrelevant. (b) In task 2, the serial choice task, the button mapping was pseudorandomized and communicated with a post-cue, after stimulus presentation.

of the preceding adaptor. Participants were instructed to report the orientation of the test stimulus compared to vertical during the response period that followed the presentation of the test stimulus. During this response period, arrows pointing left and right were presented to the left and right of the fixation dot, respectively, for 3 seconds or until a response was given. Participants used the left and right arrow keys on the keyboard to give their answer, where the left and right keys indicated the stimulus was rotated counterclockwise (or “left” starting from the top) or clockwise (or “right” starting from the top), respectively. If participants did not respond within 3 seconds, the fixation dot would briefly turn orange to remind them to respond within the designated time.

Each practice block and experimental block consisted of 40 trials. Within each block, each combination of adaptor orientation and test stimulus orientation was equally likely, and the order of trials was randomized. Participants completed at least one practice block and exactly four experimental blocks. After each block, participants received on-screen feedback on their performance on the easiest trials (i.e., the trials with the largest rotation away from vertical), although it was framed as general performance. Participants completed practice blocks until their performance on these easiest trials reached 75% (which was achieved after only one practice block for the majority of participants), with a reasonable distribution of left and right responses.

Task 2: Serial choice task

Task 2 (Figure 1b) was similar to task 1, with the exception of the response configuration and the absence of an adaptor stimulus. In each trial of task 2, a single test stimulus was presented on top of the fixation dot. This stimulus was oriented at or around vertical (-5° , 0° , or 5°), with the vertical orientation being the most frequent (occurring on 50% of trials). Participants were instructed to report the orientation of the test stimulus compared to vertical during the subsequent response period. During this response period, arrows pointing left and right were presented above and below the fixation dot for 3 seconds or until a response was given. Participants gave their answer using the up and down arrow keys on the keyboard, with the on-screen arrows indicating which key signified the direction of rotation (with left being rotated counterclockwise or “left” starting from the top and right being rotated clockwise or “right” starting from the top). For this task, button mapping was pseudorandomized, with a 50% chance that the button mapping would flip between one trial and the next. If participants did not respond within 3 seconds, the fixation dot would briefly turn orange to remind them to respond within the designated time.

Each practice block consisted of 41 trials, and each experimental block consisted of 81 trials. Within each block, each combination of test stimulus orientation and button mapping within a trial was equally likely. The order of trials was randomized in practice blocks and pseudorandomized within experimental blocks so that the frequency of stimulus orientation within successive trials (t and $t + 1$) was balanced as would be expected based on the frequency of each orientation. Participants completed at least one practice block and exactly three experimental blocks. After each block, participants received on-screen feedback on their performance, with vertical trials always being counted as correct, as there was no correct answer on these trials. Participants completed practice blocks until their performance on these trials exceeded 75% (which was achieved after only one practice block for the majority of participants), with a reasonable distribution of left and right responses.

Data cleaning

For both tasks, trials in which no response was given were removed from the data before analysis. In addition, for task 2, the serial choice task, trials with premature responses (≤ 200 ms from the onset of the button mapping) were removed. As a result, for task 1 (the adaptation task), 36 out of 10,202 total trials were removed (0.35%); for task 2 (the serial choice task), 115 of 15,552 total trials were removed (0.74%), of which 73 were due to no response and 42 were due to being below the response time cut-off. Trial removals from participants in the ASD group accounted for the majority of the removals: 63.9% and 70.4% of removed trials for tasks 1 and 2, respectively.

Analysis

For both tasks, response accuracy was calculated as

$$accuracy = P(r = s)$$

where r is the direction of the response, and s the direction of the stimulus, with s constrained to be non-zero (i.e., non-vertical), leaving a counterclockwise versus clockwise binary for both variables.

We analyzed adaptation and choice repetition biases in three different ways: (1) by conditioning the current response on the preceding adaptor orientation or previous response (model-free analysis); (2) by fitting psychometric functions to the response data and quantifying shifts in the psychometric functions depending on preceding adaptor or previous response (psychometric analysis); and (3) by fitting a hierarchical

multiple logistic regression model to the data, accounting for the influence of both previous stimuli and responses (history-dependent multiple regression model).

Model-free analysis

For task 1, we calculated the bias induced by the adaptor by calculating the difference in the proportion for clockwise responses for trials that had a counterclockwise adaptor versus trials that had a clockwise adaptor:

$$\text{bias} = P(r = 1|a = -1) - P(r = 1|a = 1)$$

where r is the direction of the response, and a is the direction of the adaptor, with both variables representing either a counterclockwise (-1) or a clockwise ($+1$) direction.

For task 2, we then calculated the choice repetition probability as the mean of the probability to repeat a counterclockwise response and the probability to repeat a clockwise response:

$$P(\text{repeat}) = (P(r_t = -1|r_{t-1} = -1) + P(r_t = 1|r_{t-1} = 1))/2$$

where r_t and r_{t-1} indicate the direction of the response on the current and previous trial, respectively. The probability was calculated per response direction to prevent a general response bias in either direction—in other words, a tendency to respond either counterclockwise or clockwise more often throughout the task—to influence $p(\text{repeat})$. The variables bias and $p(\text{repeat})$ were visualized using code for violin plots by [Bechtold \(2016\)](#).

Next, we conducted independent samples t -tests and Bayesian independent samples t -tests in JASP ([JASP Team, 2020](#)) to test for differences between the ASD group and the TD group in the calculated measures and to quantify evidence in favor of and against the null hypotheses of no effect—no difference from 0 for bias and no difference from 0.5 for $p(\text{repeat})$ —or no difference between groups. We used default Cauchy priors (scale 0.707) for all Bayesian t -tests. Additionally, to investigate possible relationships between the behavioral measures and sensory characteristics, we conducted frequentist and Bayesian Pearson's correlations in JASP ([JASP Team, 2020](#)) between the size of the adaptation and the AASP sum scores, both within the ASD group as across the full participant pool. We used default prior widths of 1 for the Bayesian correlations. The relationship between choice repetition and sensory characteristics was investigated using a history-dependent multiple regression model approach (see below).

Psychometric analysis

Next, we conducted an analysis that involved fitting a psychometric function to the data. Specifically, we employed a psychometric function-fitting approach in order to quantify the effect of the adaptor on the response direction. As the limited number of trials per stimulus orientation did not allow for a good psychometric fit for all participants, we applied this method to pooled data of all participants within each group instead of single-subject data.

We first expressed the probability of a clockwise response, $P(r_t = 1)$, as a function of the stimulus evidence (\tilde{s}_t) and fit a psychometric function ([Wichmann & Hill, 2001](#)) (Figure 2a) of the form

$$P(r_t = 1|\tilde{s}_t) = \lambda + (1 - 2\lambda)g(\delta + \alpha\tilde{s}_t)$$

where λ is the probability of stimulus-independent errors (“lapses”), g is the cumulative normal function, δ is a bias term corresponding to a general bias, and parameter α reflects perceptual sensitivity. The free parameters λ , α , and δ were estimated by using the Palamedes Toolbox for analyzing psychophysical data ([Prins & Kingdom, 2018](#)) using a maximum-likelihood criterion.

For the quantification of adaptation bias, we split the data into two bins based on the direction of the adaptor and then fit a psychometric curve to data in each bin. We then calculated the difference between the points of subjective equality (PSEs) of each curve. This difference corresponds to the bias induced by the adaptor.

To test for differences between groups in lapse rate, perceptual sensitivity, general response bias, perceptual sensitivity, and bias induced by the adaptor, we used permutation tests. For each permutation, we randomly shuffled the group labels across participants, thereby permuting ASD and TD assignments. We then applied the same psychometric fitting method described above. We repeated this method for 10,000 permutations. For each permutation, we computed the differences between groups of the lapse, perceptual sensitivity, and bias terms, as well as the bias induced by the adaptor. For p values, we report the percentage of permutations that led to more extreme values than those estimated on the empirical data. As we conducted a two-sided test, we multiplied this p value by 2 and set the significance level to $\alpha = 0.05$.

History-dependent multiple regression model

The approaches described above allowed us to estimate biases induced by the adaptor (task 1) and previous decision (task 2) by splitting the data according to these variables. However, previous research (e.g., [Bosch et al., 2020](#)) has shown that this method of splitting data can partition meaningful variance and

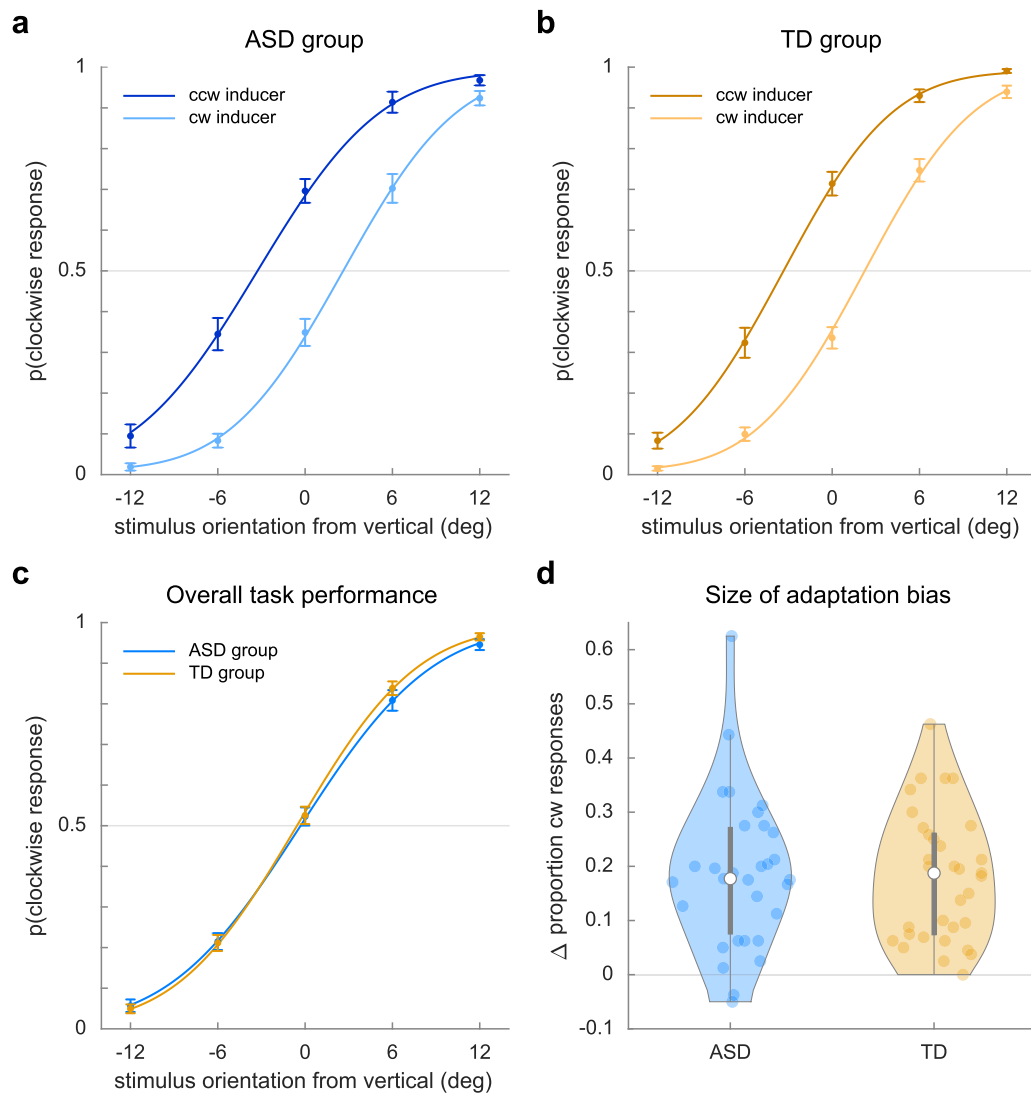


Figure 2. Adaptation task responses. Parts (a) and (b) show the proportion of clockwise responses to stimuli following a counterclockwise (ccw) or clockwise (cw) adaptor for the ASD and TD groups, respectively. Part (c) shows the proportion of clockwise responses to stimuli, regardless of the direction of the adaptor, of the ASD group (blue) and the TD group (orange). Part (d) shows the magnitude of the adaptation bias, expressed as the difference in the proportion of clockwise responses after a clockwise or counterclockwise adaptor. Positive values indicate a repulsion away from the adaptor stimulus.

introduce or mask influences of other variables. For example, splitting by previous response can obscure a potential effect of the previous stimulus, which contributes to the serial choice patterns in the data of task 2. In order to estimate separate influences of different current-trial variables and previous-trial variables on the current decision, we constructed a generalized linear mixed model (GLMM) for task 2.

The GLMM contained a binomial link function to predict the current decision (counterclockwise or clockwise) based on the previous decision and other trial characteristics, as well as interactions between these factors. The factors in this regression model can be conceptually split into current-trial factors, history factors, and the group factor. The current-trial factors

consist of the stimulus information (i.e., evidence direction) and button mapping on the current trial. The history factors consist of the stimulus information (i.e., evidence direction) and response characteristics (i.e., decision, button pressed, response time) of the previous trial. The group factor identifies the observer's group. An overview of the GLMM with group factor can be found in Table 2 and is described below.

As we were interested in serial choice effects, we were interested in the influence of the previous decision on the current decision. Accordingly, we added the effect of previous decision ($pDecision$; clockwise or counterclockwise) as a factor to the model. In order to compare the effect of the previous decision with that of the stimulus information on the previous trial, we also

	Estimate (<i>b</i>)	SE	95% CI	<i>z</i>	<i>p</i>
Single factors					
Intercept	0.1738	0.0494	0.0935 to 0.2776	3.519	4.33e-4
<i>group</i>	−0.0800	0.0494	−0.1630 to 0.0170	−1.620	0.105
<i>cStimIdent</i>	1.4839	0.0817	1.3643 to −1.6486	18.171	< 2e-16
<i>pDecision</i>	0.0686	0.0328	0.0094 to 0.1237	2.095	0.036
<i>pStimIdent</i>	−0.0102	0.0346	−0.0761 to 0.0578	−0.294	0.769
<i>pRt</i>	−0.0013	0.0149	−0.0299 to 0.0277	−0.085	0.932
Interactions with <i>pRt</i>					
<i>pDecision</i> × <i>pRt</i>	−0.0622	0.0156	−0.0934 to −0.0314	−3.992	6.56e-5
<i>pStimIdent</i> × <i>pRt</i>	0.0069	0.0227	−0.0352 to 0.0552	0.302	0.762
Interactions with <i>group</i> (and <i>pRt</i>)					
<i>cStimIdent</i> × <i>group</i>	−0.1197	0.0814	−0.2307 to 0.0562	−1.471	0.141
<i>pDecision</i> × <i>group</i>	0.0341	0.0327	−0.0255 to 0.1056	1.043	0.297
<i>pStimIdent</i> × <i>group</i>	0.0464	0.0346	−0.0179 to 0.1115	1.340	0.180
<i>pRt</i> × <i>group</i>	0.0060	0.0149	−0.0252 to 0.0374	0.401	0.689
<i>pDecision</i> × <i>pRt</i> × <i>group</i>	−0.0212	0.0156	−0.0536 to 0.0090	−1.362	0.173
<i>pStimIdent</i> × <i>pRt</i> × <i>group</i>	−0.0169	0.0227	−0.0609 to 0.0259	−0.745	0.456
Button mapping					
<i>cButtonMapping</i>	0.0683	0.0185	0.0314 to 0.1052	3.685	2.29e-4
<i>cButtonMapping</i> × <i>group</i>	0.0172	0.0185	−0.0159 to 0.0533	0.926	0.354
<i>pButtonXcButtonMapping</i>	−0.0784	0.0222	−0.1228 to −0.0325	−3.538	4.03e-4
<i>pButtonXcButtonMapping</i> × <i>group</i>	−0.0176	0.0222	−0.0542 to 0.0266	−0.796	0.426

Table 2. GLMM fixed factors for a model over all participants ($N = 64$) that predicts the current decision based on current and previous trial factors and group (ASD vs. TD). *p* values < 0.05 are bolded.

added the identity (clockwise or counterclockwise from vertical) of the previous stimulus (*pStimIdent*). Next, to examine whether the influence of the previous decision or previous stimulus identity was modulated by the previous response time (*pRt*), we added interaction factors (*pDecision* × *pRt* and *pStimIdent* × *pRt*). Crucially, in order to investigate any group difference between these effects, we added further interaction effects between all aforementioned factors and the *group* factor.

All factors described thus far reflect history effects; however, observers' decisions were primarily based on the stimulus information present in the current trial. Therefore, we included the orientation of the stimulus on the current trial to the model (*cStimIdent*) and allowed for the influence of the current stimulus to be modulated by *group* (*cStimIdent* × *group*). To account for the possibility of a difference in general response bias between groups, we also added *group* as a single factor to the model (the group-independent general response bias was reflected by the intercept of the model).

Additionally, we added factors to account for effects of button- and/or motor preferences. First, to account for a preference for responding with one button over the other and consequently for an effect of the button mapping on the perceptual

decision, we added the button mapping as a factor to the model (*cButtonMapping*). Second, we added a factor to account for a possible motor repetition or alternation effect (*pButtonXcButtonMapping*). As with all other factors, we accounted for possible group differences in these effects by adding their interactions with *group* (*cButtonMapping* × *group* and *pButtonXcButtonMapping* × *group*).

Finally, we included the main effect of the previous response time (*pRt*) and its interaction with *group* (*pRt* × *group*). As these variables on their own provide no directional information, whether it be about the previous response or the stimulus information on the previous or current trial, they were unlikely to predict the decision on the current trial and were thus not expected to be significant factors in the model. We nevertheless added them to prevent an unexpected modulation by these variables showing up in any of the interaction effects and hence being misinterpreted as such.

Considering our groups were not matched based on IQ (see Table 1), we also constructed a variation of the model described below that included total IQ as an additional factor. This allowed us to check whether any potential group differences could instead be explained away by the difference in total IQ. The factor (*TIQ*) was implemented in a similar way to

	Estimate (<i>b</i>)	SE	95% CI	<i>z</i>	<i>p</i>
Single factors					
<i>Intercept</i>	0.0967	0.0657	−0.0125 to 0.2307	1.472	0.141
<i>AASP</i>	0.1171	0.0648	0.0163 to 0.2451	1.808	0.071
<i>cStimIdent</i>	1.3748	0.1274	1.1859 to 1.6140	10.791	<2e-16
<i>pDecision</i>	0.0970	0.0519	−0.0072 to 0.2103	1.869	0.062
<i>pStimIdent</i>	0.0473	0.0518	−0.0355 to 0.1509	0.912	0.362
<i>pRt</i>	0.0063	0.0218	−0.0319 to 0.0469	0.287	0.774
Interactions with <i>pRt</i>					
<i>pDecision</i> × <i>pRt</i>	−0.0829	0.0226	−0.1261 to −0.0377	−3.669	2.44e-4
<i>pStimIdent</i> × <i>pRt</i>	−0.0093	0.0358	−0.0747 to 0.0602	−0.261	0.794
Interactions with AASP sum (and <i>pRt</i>)					
<i>cStimIdent</i> × <i>AASP</i>	0.1603	0.1255	−0.0380 to 0.4131	1.278	0.201
<i>pDecision</i> × <i>AASP</i>	−0.0862	0.0515	−0.1811 to 0.0173	−1.673	0.094
<i>pStimIdent</i> × <i>AASP</i>	0.0211	0.0521	−0.0697 to 0.1206	0.406	0.685
<i>pRt</i> × <i>AASP</i>	−0.0079	0.0211	−0.0489 to 0.0330	−0.374	0.708
<i>pDecision</i> × <i>pRt</i> × <i>AASP</i>	0.0449	0.0219	−0.0068 to 0.0896	2.050	0.040
<i>pStimIdent</i> × <i>pRt</i> × <i>AASP</i>	−0.0120	0.0345	−0.0879 to 0.0475	−0.577	0.564
Button mapping					
<i>cButtonMapping</i>	0.0854	0.0283	0.0338 to 0.1393	3.019	2.53e-3
<i>pButtonXcButtonMapping</i>	−0.0916	0.0301	−0.1507 to −0.0307	−3.049	2.30e-3

Table 3. GLMM fixed factors for a model within the ASD group ($n = 30$) that predicts the current decision based on current and previous trial factors and the participant's AASP sum score. *p* values < 0.05 are bolded.

group in the sense that we included *TIQ* and its interactions with *pDecision*, *pStimIdent*, *pDecision* × *pRt*, *pStimIdent* × *pRt*, *cStimIdent*, *cButtonMapping*, and *pButtonXcButtonMapping*.

To investigate how variability in the strength of sensory atypicalities may affect perceptual decision-making, we constructed a second GLMM within the ASD group ($n = 30$; one subject was excluded due to missing AASP score). The factors included in this second GLMM were similar to those described above. The main difference was that the categorical *group* factor was replaced by a continuous *AASP* factor, which reflected the subjects' AASP sum scores, both as a main factor and in all interactions that included *group*. See Table 3 for a full overview of the GLMM with AASP.

Before constructing the models, variables were (re-)coded as follows. Categorical predictors (*pDecision*, *pStimIdent*, *cStimIdent*, *pButton*, *cButtonMapping*, *pButtonXcButtonMapping*, and *group*) were coded using effect coding (−1/1). For *pDecision*, *pStimIdent*, and *cStimIdent*, −1 coded for the counterclockwise direction and 1 for the clockwise direction. For *pButton*, −1 coded for the down button and 1 coded for the up button. For *cButtonMapping*, −1 coded for a configuration where the up button indicated the counterclockwise direction and the bottom button indicated the clockwise direction, whereas 1 coded for the reverse configuration.

For *pButtonXcButtonMapping*, a value of 1 indicated that pressing the same button as on the previous trial resulted in a clockwise response on the current trial, whereas −1 indicated that a repeated button press resulted in a counterclockwise response. Finally, for *group*, the ASD group was coded as 1 and the TD group as −1. Non-categorical predictors were (re-)coded in the following ways. Response times (*pRt*) were transformed to robust *z*-scores by removing the subject-wise median and scaling the result by the subject-wise median absolute deviation (constant = 1.48). AASP scores were *z*-scored.

We used the R-package *lme4* (Bates, Mächler, Bolker, & Walker, 2015) to fit a generalized linear model from the binomial family. We fitted both models with “subjects” as the only random grouping factor. For each fixed effect, we included its corresponding random slope coefficient but without random correlations, as the model did not converge.

For significance testing we report the Wald *z*-test, which is valid only in the asymptotic regime assuming a multivariate normal sampling distribution of parameters and a proportional sampling distribution of the log likelihood to χ^2 . Therefore, we must be very conservative in our interpretation of the reported *p* values if the effects are not obvious from effect sizes alone. An overview of the model outputs can be found in Tables 2 and 3.

Results

Sample characteristics

An overview of sample characteristics after exclusions can be found in [Table 1](#). The ASD group and TD group were comparable with regard to gender ($\chi^2 = 0.277, p = 0.599$). On average, participants were 15 years, 7 months of age on the day of inclusion, with no age difference between groups, $t(62) = 0.209, p = 0.835$. On average, the TD group scored higher on the Wechsler Intelligence Scale than the ASD group. Specifically, there was a 7.94-point difference on the TIQ scale, $t(62) = 2.794, p = 0.007$; 9.47-point difference on the performance IQ scale (PIQ), $t(62) = 3.536, p = 0.001$; and a 5.89-point difference on the verbal scale (VIQ), although the last difference did not reach significance, $t(62) = 1.784, p = 0.079$.

The ASD group and TD group differed significantly with regard to their sensory symptomatology as measured by the AASP. The ASD group self-reported higher scores on the subscales of low registration, $t(41.882) = -2.854, p = 0.007$; sensory sensitivity, $t(44.828) = -3.909, p < 0.001$; and sensation avoiding, $t(45.728) = -5.059, p < 0.001$. This group self-reported lower scores on the sensation seeking subscale, $t(61) = 5.104, p < 0.001$. A sum score was calculated by adding the values for each subscale, with the sensation seeking subscale reverse scored. The groups differed significantly on this sum score, as well, $t(37.709) = -5.922, p < 0.001$.

The ASD diagnoses for participants in the ASD group were confirmed by the ADI-R (see Supplemental Table S1 for individual scores). TD participants scored below clinical range on the CBCL ([Achenbach, 1991](#)) according to the Edition 208 criteria for DSM-oriented scales for ages 12 to 18: for boys, affective problems < 8 , anxiety problems < 5 , somatic problems < 5 , attention deficit/hyperactivity problems < 11 , oppositional defiant problems < 8 , and conduct problems < 13 ; for girls, affective problems < 9 , anxiety problems < 6 , somatic problems < 5 , attention deficit/hyperactivity problems < 9 , oppositional defiant problems < 8 , and conduct problems < 11 .

Adaptation task

First, we established that participants were able to discriminate counterclockwise from clockwise stimuli in task 1 (adaptation task). Both the ASD group and the TD group were well able to discriminate between counterclockwise and clockwise stimuli in task 1 ([Figure 2c](#)), with mean performance of $87.1\% \pm 7.9\%$ (range, 65.6%–96.1%) in the ASD group and $88.6\% \pm$

5.2% (range, 74.8%–95.3% range) in the TD group. We found no differences in overall response accuracy on the adaptation task between the ASD and TD groups; for accuracy, $t(62) = 0.924, p = 0.359, BF_{10} = 0.367$, error % = $3.898e-4$. Average response times were fast (ASD: mean = 408.3 ms, $SD = 156.5$ ms; TD: mean = 434.1 ms, $SD = 197.4$ ms) and did not differ between groups, $t(62) = -0.5761, p = 0.567, BF_{10} = 0.294$, error % = 0.002.

Next, we looked at whether the direction of the adaptor influenced participants' responses using a model-free analysis. We observed a clear effect of the adaptor in both groups ([Figures 2a and 2b](#)), with the probability of a clockwise response after a counterclockwise versus clockwise adaptor increasing numerically for all but two participants in the ASD group and all but one participant in the TD group. The induced bias was statistically significant in both groups ([Figure 2d](#)): for ASD, $t(30) = 7.407, p < 0.001, BF_{10} = 4.66e5$, and error % = $1.19e-8$; for TD, $t(32) = 8.734, p < 0.001, BF_{10} = 1.98e7$, and error % = $5.74e-10$. On average, the proportion of clockwise responses differed between adaptor conditions by $18.7\% \pm 14.1\%$ in the ASD group and $18.1 \pm 11.9\%$ in the TD group.

Finally, we looked at whether the influence of the adaptor was altered in ASD by comparing the magnitude of the induced bias between the ASD and TD groups. We found that the magnitude of the bias did not differ between groups, with moderate evidence for a lack of difference ([Figure 2d](#)): $t(63) = -0.206, p = 0.837, BF_{10} = 0.260$, error % = 0.002. This suggests that the repulsive adaptation bias was similar across groups. We also did not find a relationship between the size of the adaptation bias and sensory characteristics (as measured by the AASP), neither within the ASD group ($r = 0.249, p = 0.185, BF_{10} = 0.525$) nor across the full participant pool ($r = 0.156, p = 0.221, BF_{10} = 0.327$), suggesting that there may be no relationship between sensory symptomatology and adaptation, although the evidence is largely inconclusive.

Our psychometric fitting approach with permutation testing showed similar results. We found no difference between the ASD group and the TD group in overall bias ($p = 0.6152$), slope ($p = 0.6724$), lapses ($p = 0.6298$), or bias induced by the adaptor ($p = 0.7086$), suggesting that the groups exhibited similarly large adaptation biases.

Note that in the psychometric fits observed in [Figure 1](#), the absolute shift from 0 in the PSE is numerically larger for counterclockwise adaptors (ASD PSE = 3.34° ; TD PSE = 3.32°) than for clockwise adaptors (ASD PSE = 2.62° , TD PSE = 2.23°) ([Figures 1b and 1c](#)), reflecting either a larger bias from vertical by counterclockwise compared to clockwise adaptors or, more likely, a general response bias favoring clockwise responses.

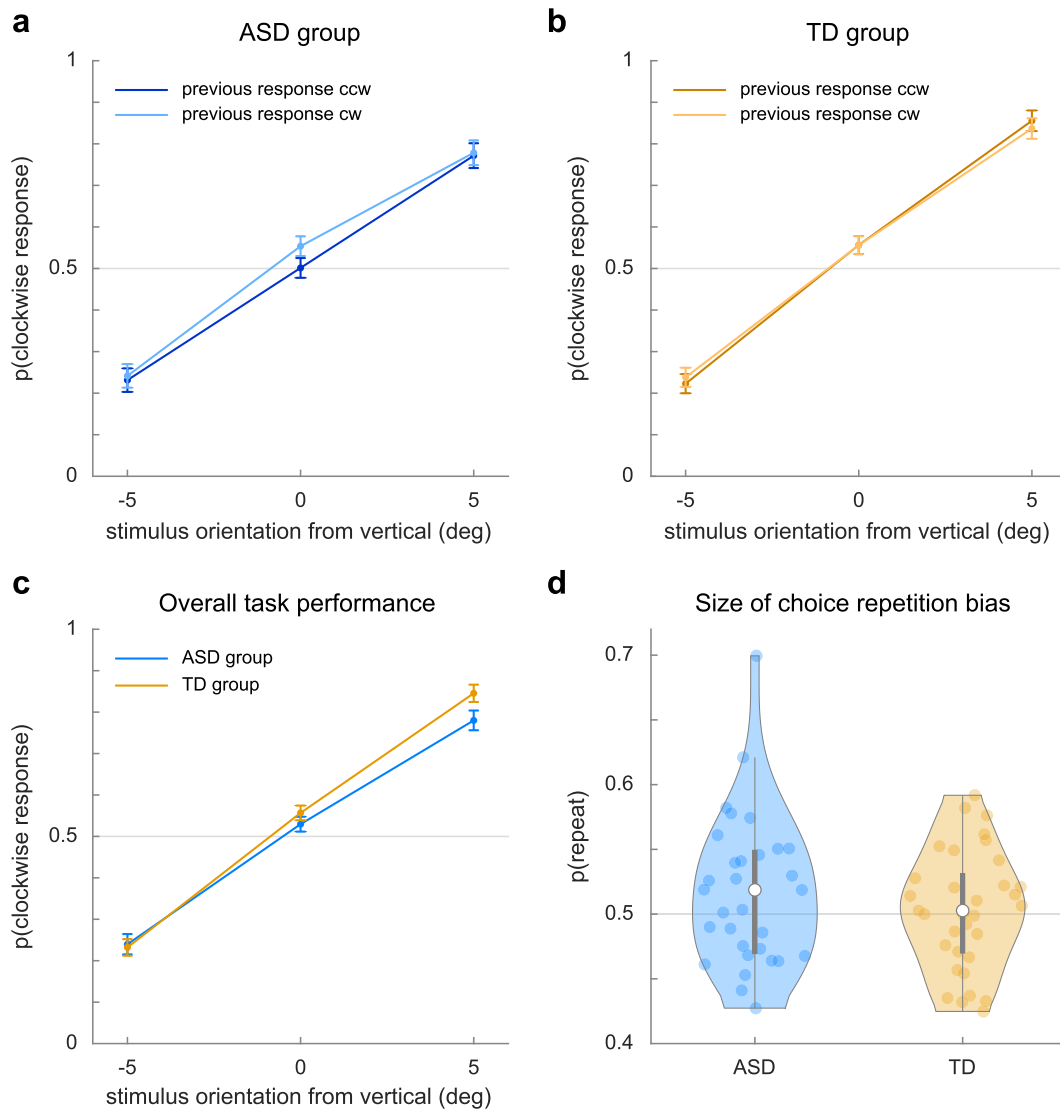


Figure 3. Serial choice task responses. Parts (a) and (b) show the proportion of clockwise responses to stimuli after a counterclockwise (ccw) or clockwise (cw) response on the previous trial for the ASD and TD groups, respectively. Part (c) shows the proportion of clockwise responses to stimuli, regardless of the previous response, of the ASD group (blue) and the TD group (orange). Part (d) shows the magnitude of the choice repetition probability, $p(\text{repeat})$.

Serial choice task

For the serial choice task, we first established that participants were able to discriminate counterclockwise from clockwise stimuli. Both the ASD group and the TD group were able to do this discrimination (Figure 3c), with mean response accuracy of $77.0\% \pm 11.2\%$ (range, 55.9%–95.0%) in the ASD group and $80.7\% \pm 9.3\%$ (range, 60.7%–93.3%) in the TD group. We found no significant differences in response accuracy on this serial choice task between the groups; for accuracy, $t(62) = 1.432$, $p = 0.157$, $BF_{10} = 0.606$, and error % = 0.003. Mean response times did not differ between groups (ASD: mean = 1039.4 ms, SD

= 195.3 ms; TD: mean = 1065.3 ms, $SD = 157.9$ ms), $t(62) = -0.5831$, $p = 0.5619$, $BF_{10} = 0.295$, error % = 0.001.

Next, we looked at whether participants' previous choice influenced their current choice using a model-free analysis. We did not observe an apparent effect of the previous choice in either group (Figures 3a and 3b). We quantified the effect by calculating the probability that participants repeated the previous choice (choice repetition). On average, choice repetition probability was $51.7\% \pm 5.8\%$ (range, 42.7%–69.9%) in the ASD group and $50.3\% \pm 4.6\%$ (range, 42.5%–59.2%) in the TD group (Figure 3d). For neither group did this probability differ convincingly from chance: for ASD,

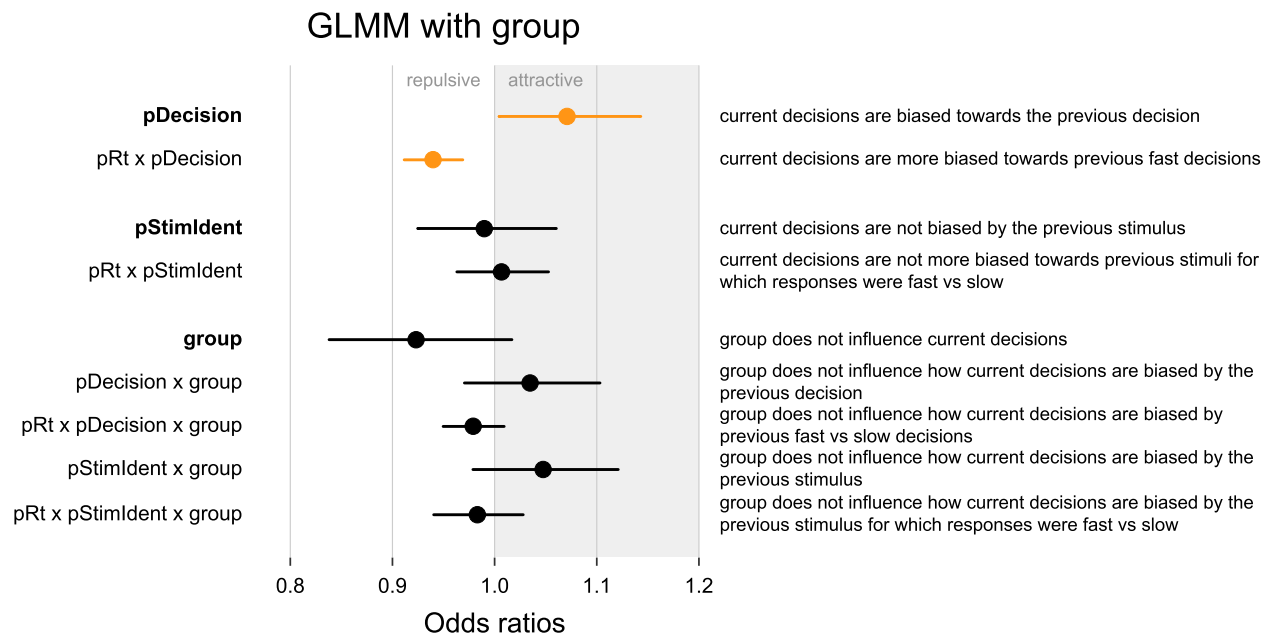


Figure 4. GLMM results for a model over all participants ($N = 64$) that predicts the current decision based on current and previous trial factors and group (ASD vs. TD). Not all factors are shown (see Table 2 for a full model overview); significant factors are marked in orange. Results show that decisions were biased toward the previous decision and more biased toward previous fast decisions than slow decisions. No group differences were found.

$t(30) = 1.642$, $p = 0.111$, $BF_{10} = 0.637$, and error % = 0.008; for TD, $t(32) = 0.380$, $p = 0.707$; $BF_{10} = 0.199$, and error % = $1.90e-6$. Although we hypothesized differences in choice repetition probability between the groups, we did not find this, $t(62) = -1.077$, $p = 0.286$, nor did we find convincing evidence against the null hypothesis ($BF_{10} = 0.417$, error % = $1.456e-4$).

As we set out to investigate how the previous choice influences the current choice and how this may differ between autistic and non-autistic individuals, the fact that we did not find a serial choice bias may seem problematic. However, research in a typical population has shown that serial choice bias may be obscured across trials by simultaneous but oppositely signed effects—for example, a repulsive effect of the stimulus of the previous trial (sensory adaptation) and an attractive effect of the response on said trial (Bosch et al., 2020). Therefore, in order to study the effect of the previous response while controlling for concurrent stimulus-related effects, we used an analytical method that can identify these separate effects. We applied a history-dependent multiple regression model (i.e., GLMM) method for this reason.

Indeed, the GLMM (Figure 4; for a full model overview, see Table 2) revealed a small yet reliable attractive effect of the previous decision on the current decision ($pDecision$: $b = 0.0686$, $SE = 0.0328$, $p = 0.036$). We also found that people were more likely to repeat fast trials ($pDecision \times pRT$: $b = -0.0622$, $SE = 0.0156$, $p = 6.56e-5$). Both effects have been found in

a previous study using a comparable analysis (Bosch et al., 2020). Interestingly, the repulsive effect of the previous stimulus on the current decision was not replicated in this dataset ($pStimIdent$: $b = -0.0102$, $SE = 0.0346$, $p = 0.769$), perhaps because the orientation information in the current stimuli was much weaker and noisier, reducing or even removing the influence of this information on the current decision.

We then looked at whether the effects involving the previous decision were modulated by group and found that they were not ($pDecision \times group$: $b = 0.0341$, $SE = 0.0327$, $p = 0.297$; $pDecision \times pRT \times group$: $b = -0.0212$, $SE = 0.0156$, $p = 0.173$). When we incorporated IQ into the model to account for the difference in IQ between the groups, the results did not change (see Supplemental Table S2). This suggests that group did not alter the effect of the previous decision on the previous trial, nor did it alter the modulation of this effect by previous response time.

The failure to find group differences in our data may be due to heterogeneity within the ASD and typical population. ASD is described as a spectrum, with social, behavioral, and sensory characteristics varying between individuals on this spectrum. It is possible that investigating the magnitude of choice repetition bias not between diagnostic groups but instead along the dimension of sensory atypicality may reveal an effect of this symptomatology specifically. For this reason, we created a separate GLMM within the ASD group and included the sum score on the AASP as a factor

GLMM with AASP

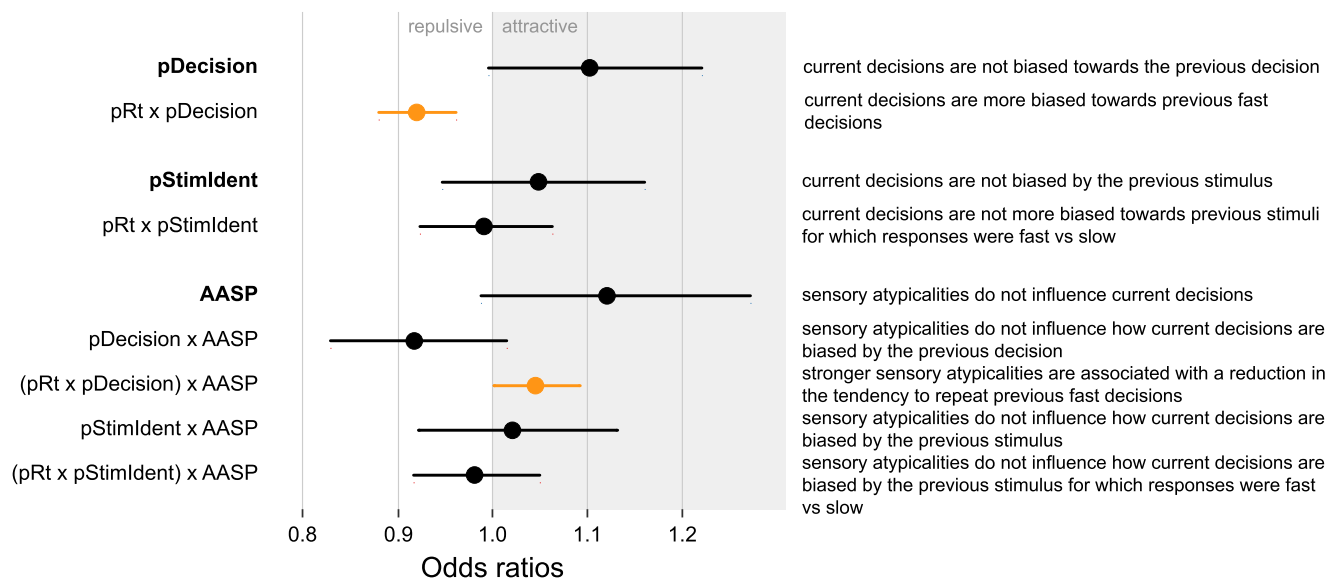


Figure 5. GLMM results for a model within the ASD group ($n = 30$) that predicts the current decision based on current and previous trial factors and the participant's AASP sum score. Not all factors are shown (see Table 3 for a full model overview); significant factors are marked in orange. Results show that decisions were more biased toward fast than slow previous decisions and that this bias was weaker for participants with higher AASP sum scores.

(Figure 5; for a full model overview, see Table 3). As in the previous model, observers were more likely to repeat a previous decision, although this effect did not reach significance ($pDecision$: $b = 0.0970$, $SE = 0.0519$, $p = 0.062$), and observers were more likely to repeat previous fast decisions ($pDecision \times pRt$: $b = -0.0829$, $SE = 0.0226$, $p = 2.44e-4$). There was a lower tendency of observers with stronger sensory atypicalities (reflected by high AASP scores) to repeat previous decisions, although this effect did not reach significance ($pDecision \times AASP$: $b = -0.0862$, $SE = 0.0515$, $p = 0.094$). Moreover, observers with stronger sensory atypicalities were less likely to repeat fast decisions ($pDecision \times pRt \times AASP$: $b = 0.0449$, $SE = 0.0219$, $p = 0.040$). However, we found the model predictions from this model did not closely fit the data except for participants with AASP scores closest to the mean, bringing into question the reliability of the model results. We therefore choose to remain cautious in our interpretation of these findings and emphasize that these potential subtle effects require replication in future studies.

Discussion

An open question in the literature is whether autistic people underutilize prior experience when processing new sensory input. In this study, we investigated

whether adaptation and serial choice bias, two biases induced by previous sensory input and previous perceptual decisions, respectively, are reduced in autism. To this end, we tested adolescents with and without ASD in two tasks that both used line orientation stimuli but were designed to induce either adaptation or serial choice bias. Importantly, in contrast to and in advance of previous studies, we probed adaptation and serial choice biases using the same stimuli, similar task designs, and a single sample of subjects, allowing for a more direct comparison of biases believed to arise at different stages of perceptual processing. Although we successfully induced both biases, we found no differences between the groups in the magnitude of the biases, reflecting preserved influence of previous stimuli in perception and preserved influence of previous choices in perceptual decision-making and suggesting that the past is not underutilized in autism.

Our finding that adaptation is preserved in autism may be surprising, as it conflicts with several studies that observed decreased adaptation in autism (Ewing, Leach et al., 2013; Ewing, Pellicano et al., 2013; Karaminis et al., 2020; Lawson et al., 2017; Pellicano et al., 2007; Turi et al., 2015; van Boxtel et al., 2016). However, there is also existing literature that has found preserved adaptation (Karaminis et al., 2015; Lawson et al., 2017; Maule et al., 2018). These diverging conclusions may be explained by the type of stimulus used in these studies—specifically, whether the stimuli are social and/or complex. One possibility is that

adaptation in autism is reduced for social but not for non-social stimuli. Indeed, many studies that have used social stimuli, such as faces (Ewing, Leach et al., 2013; Ewing, Pellicano et al., 2013; Pellicano et al., 2007) or biological motion (van Boxtel et al., 2016), have found reduced adaptation, whereas several studies that used non-social stimuli, such as color (Maule et al., 2018) and causality (Karaminis et al., 2015), have found preserved adaptation. Although it has been suggested that this could be due to differences in the amount of attention paid to these stimuli, as attention can boost the magnitude of adaptation (e.g., Alais & Blake, 1999; Kreutzer, Fink, & Weidner, 2015; Lankheet & Verstraten, 1995; Raymond, 2000; Rhodes, Jeffery, Evangelista, Ewing, Peters, & Taylor, 2011), and autistic individuals may attend less to social stimuli (e.g., for an overview, see Simmons, Robertson, McKay, Toal, McAleer, & Pollick, 2009), several studies that controlled for attention found that this does not explain the difference (Ewing, Leach et al., 2013; Ewing, Pellicano et al., 2013). If it is the case that adaptation is affected only for social stimuli, this may suggest domain specificity.

However, studies that have found reduced adaptation for non-social, complex stimuli, such as visual number (Turi et al., 2015) and audiovisual stimuli (Turi, Karaminis, Pellicano, & Burr, 2016), and a study that—in contrast to van Boxtel et al. (2016)—found intact adaptation for biological motion (Karaminis et al., 2020) are in opposition to the theory that reduced adaptation in autism is specific to social stimuli. These studies suggest that adaptation in autism may be reduced for complex stimuli and intact for simple stimuli. As social stimuli such as faces tend to be complex, this could explain why reduced adaptation is found in most studies that used such stimuli. It also suggests that reduced adaptation in autism may only arise at higher levels of processing. As our stimuli were both simple and non-social, our experiment cannot differentiate between these two explanations.

With regard to the serial choice bias, we found that perceptual decisions are biased toward the previous perceptual decision, with no differences between the groups. This is not in line with expectations following the weak central coherence account, which hypothesizes that perceptual integration is impacted and from which would follow that serial choice bias may be reduced in autism (Happé & Frith, 2006), nor is it in line with the idea that an overestimation of the volatility of the environment, as found in autism (Lawson et al., 2017), may lead to a reduced leveraging of the past and thus a reduction in serial choice bias. Our finding is also in contrast with a study that found increased influence of recent choices (Feigin et al., 2021) and with a study that found decreased influence of the past (Lieder et al., 2019).

Feigin et al. (2021) conducted a location discrimination task and heading discrimination task with two-alternative forced choice (2AFC) responses in a sample consisting of autistic and non-autistic children and adolescents. In both tasks, they found that participants' choices were biased toward the preceding trial (in the heading discrimination task) or set of trials (in the case of the heading discrimination task) and that this effect was larger for the ASD group than for the control group. When discriminating between the influence of previous choices and previous stimuli, they determined that the effect of the previous stimuli was similar between groups, whereas the effect of previous choices was larger for the ASD group, suggesting an increased choice bias. However, notably, in a separate location discrimination task where the previous choice was dissociated from the previous motor response by changing which keys participants pressed to respond between preceding trials and target trials, there was no difference between the groups in the effect of the previous choice. This is in agreement with the lack of group differences in the current experiment, in which we varied the mapping between perceptual choices and motor responses across trials. Feigin et al. (2021) considered, and could not rule out, group differences in motor perseveration as a possible explanation for their findings. In contrast, we found no group differences in the influence of previous button presses, arguing against this explanation. Although the cause for the contradicting findings remains unclear, it remains possible that altered choice repetition in autism could arise under a fixed mapping between perceptual choices and motor actions.

Lieder et al. (2019) conducted a two-tone frequency discrimination task with 2AFC responses using non-natural auditory stimuli in a sample of autistic and neurotypical adults. They found that, in general, autistic individuals show a reduced contraction bias, indicating a weaker influence of the past. Interestingly, they separately quantified the influence of not just the previous trial but also the preceding trials up to four back individually, as well as the mean frequency across trials. Specifically, the influence of the previous trial was smaller for autistic participants, in contrast to our own study, which does not find differences in the influence of (elements of) the previous trial. However, this may be due to a difference in analysis; where this study conceptualized history effects based on trial(s), we separated the influence of different elements of the previous trial, such as the choice and stimulus. This may be an important distinction when these elements exert separate and potentially opposing influences (Bosch et al., 2020). Also, we may consider differences in the age of the sample as well as potential differences in temporal integration between the auditory and the visual domain as factors contributing to a difference in results.

Some previous research has investigated differences in perception as something that varies across the autism spectrum. For example, Pellicano et al. (2007) found that adaptation magnitude was more decreased in an autistic children sample that scored higher on social atypicalities in comparison with the overall ASD group. Similarly, Lawson et al. (2017) found that adaptation magnitude decreased with autistic traits in an autistic adult sample and with autistic traits and sensory sensitivity in a non-autistic adult sample. Following this, we explored whether perceptual choice patterns vary with the severity of sensory symptomatology. Although we found some evidence of an effect, with autistic participants with more severe sensory atypicalities showing reduced influence of previous fast decisions on subsequent decisions compared with autistic participants with weaker sensory atypicalities, upon visual inspection the general linear model did not provide an adequate fit to the data, prompting caution when interpreting this finding. More research is needed to determine if there are indeed (subtle) effects.

In conclusion, we found that autistic adolescents show similar visual adaptation and leverage previous decisions similarly to their non-autistic peers when making perceptual decisions about low-level stimulus features, suggesting that the influence and use of the past may be preserved in autism. This contradicts hypotheses that describe sensory atypicalities in autism as a result of a reduced integration of perceptual input with its temporal context.

Keywords: adaptation, serial choice, serial dependence, autism spectrum disorder, autism

Acknowledgments

We extend our gratitude to our participants and their parents for supporting this research. We also thank Christian Utzerath, Amy Abelmann, and Iris C. Schmits for assistance in recruitment (CU, AA), data collection (CU, AA, ICS), and cover story development (ICS). This study was financed by the European Research Council (ERC Starting Grant 678286 CONTEXTVISION). JB has been supported by the EU-AIMS (European Autism Interventions) and AIMS-2-TRIALS programs, which receive support from grants from Innovative Medicines Initiative Joint Undertaking (115300 and 777394), the resources of which include financial contributions from the European Union's 7th Framework Programme for Research (FP7) and the Horizon 2020 program; the European Federation of Pharmaceutical Industries and Associations companies' in-kind contributions; AUTISM SPEAKS; Autistica; Simons Foundation Autism Research Initiative (SFARI); and by a grant

from the Horizon 2020-supported program Comorbid Analysis of Neurodevelopmental Disorders and Epilepsy (CANDY; 847818).

Commercial relationships: none.

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