# The effect of autism on information sampling during decision-making: An eye-tracking study

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## Abstract

Recent research has highlighted a tendency for more rational and deliberative decision-making in individuals with autism. We tested this hypothesis by using eye-tracking to investigate the information processing strategies that underpin multi-attribute choice in a sample of adults diagnosed with autism spectrum condition. We found that, as the number of attributes defining each option increased, autistic decision-makers were speedier, examined less of the available information, and spent a greater proportion of their time examining the option they eventually chose. Rather than indicating a more deliberative style, our results are consistent with a tendency for individuals with autism to narrow down the decision-space more quickly than does the neurotypical population.

Keywords: autism, decision-making, eye-tracking, rational choice, deliberation

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# 1   Introduction

Adults with autism spectrum conditions (hereafter autism) often report having difficulty making decisions, with potentially negative socio-economic consequences (Luke et al., 2012; Mussey et al., 2015; Skylark & Baron-Cohen, 2017). Whereas a large body of research has examined the cognitive and social atypicalities associated with autism, the cognitive processes involved in decision-making have received relatively little attention. However, the past few years have seen a surge of research activity in this area. These studies have used a wide variety of tasks, samples, and analytic strategies, and have often produced rather mixed results (e.g., Johnson et al., 2006; Minassian et al., 2007; Robic et al., 2015). One emerging idea is that people with autism take a more deliberative, systematic approach to decision-making than do neurotypical individuals, resulting in more consistent and conventionally-rational behaviour (e.g., Brosnan et al., 2016; Levin et al., 2015; Vella et al., 2018). Three lines of research underlie this proposition.

First, autism and high levels of autistic traits are associated with lower scores on the "experiential" (intuitive) component of the Rational Experiential Inventory (REI: Epstein et al., 1996; Gaeth et al., 2016) and, in some studies, with higher scores on the rational (deliberative) component (Gaeth et al., 2016). Similarly, autistic people have been found to make more deliberative, less intuitive responses on the "Cognitive Reflection Task" (Brosnan et al., 2016). A study using the Generalized Decision Making Style Inventory (Scott & Bruce, 1995) found that autistic people report a more avoidant decision style but not a more rational one (Luke et al., 2012) (see also Fujino, Tei, Itahashi, Aoki & Ohta, 2019); however, such avoidance may reflect a feeling of being overwhelmed with information and "overthinking" the problem (Luke et al., 2012, p.614) (see also Fujino, Tei, Itahashi, Aoki & Ohta, 2019) consistent with increased deliberation when decisions are not avoided.

The second line of evidence comes from studies investigating how people sample information when they must make decisions under uncertainty. Brosnan et al. (2014) had people complete a "jumping to conclusions" task in which a decision maker must sample beads to decide whether they are being drawn from an urn that contains 60% black beads and 40% white or vice-versa. Autistic participants drew more beads before making their decision. Jänsch and Hare (2014) found the opposite result, but Vella et al. (2018) also found that autism was associated with greater sampling in a similar task, and Brosnan et al. (2013) found evidence for greater sampling among people with high levels of autistic traits in a non-clinical sample. Lu et al. (2019) also found that high levels of autistic traits predicted greater sampling, although this depended on there being no cost associated with sampling. There is also some evidence that people with autism engage in more exploratory sampling in the "Iowa Gambling Task", wherein the participant must repeatedly sample from four options that differ in the probabilities and magnitudes of the wins and losses that they afford (Mussey et al., 2015; Yechiam et al., 2010) – although data from this task are mixed (e.g., South et al., 2014; Vella et al., 2018; Zhang et al., 2015). The reasons for the conflicting findings in some of these studies are unclear, but differences in participant sampling strategy

might be one factor. For instance, Brosnan et al., (2014) recruited adolescents while Jänsch and Hare (2014) used an adult sample.

The third body of work to suggest that autism entails a more systematic approach to decision-making consists of studies showing that autistic people are often less susceptible than are neurotypical individuals to "irrational" reasoning and decision-making biases (Lewton et al., 2019; Morsanyi et al., 2009). De Martino and colleagues (2008) had people choose between a sure thing and a risky option, where the outcomes associated with each option were described in one of two logically-equivalent ways: as a gain (e.g., "Start with £50 and keep £30") or a loss (e.g., "Start with £50 and lose £20"). Neurotypical adults usually switch from preferring sure-things when the outcomes are framed as gains to favouring risky options when the outcomes are presented as losses, a preference reversal that violates conventional assumptions about rational economic behaviour (Tversky & Kahneman, 1974). This tendency was reduced in people with autism, indicating "enhanced logical consistency" (De Martino et al., 2008, p.10746). This difference has been replicated by Shah et al. (2016), although it may depend on the specific experimental procedure (Gosling & Moutier, 2018; Levin et al., 2015). Elsewhere, people with autism have been found to be less prone to the sunk cost fallacy – that is, less likely to stick with a sub-optimal decision in which they have invested (Fujino et al., 2019) – and less susceptible to the attraction effect, wherein a decision-maker's preference between two items reverses when a third, decoy option is added to the choice set (Farmer et al., 2017).

Taken together, these lines of research suggest that autistic people are more "deliberative" (Brosnan et al., 2016, p.2120) and "analytic" (De Martino et al., 2008, p.10749), and that they take "a more logical approach to, and care in, decision-making" (Vella et al., 2018, p.549). This view accords with the more general proposal that autism often entails a strong "systemizing" tendency – a desire to analyse and construct systems that follow lawful rules (Baron-Cohen et al., 2003).

We undertook a new test of this idea by using gaze tracking to examine the decision process. In neurotypical populations, gaze tracking has helped illuminate how the allocation of visual attention across an array of objects is linked to emerging preference between the items (e.g., Krajbich et al., 2010), and how people sample and compare options that differ in two or more explicitly-stated attributes such as price, probability, or payoff (e.g., Ashby et al., 2018; Glöckner & Herbold, 2011; Reisen et al., 2008; Stewart et al., 2016; see Orquin & Mueller Loose, 2013, for a review). Although eye tracking has been extensively used to study various aspects of autism, including social interaction (e.g., Barzy et al., 2020), language processing (e.g., Black et al., 2018), and basic neurological functioning (e.g., Schmitt et al., 2014; see Howard et al., 2019, for a review), it has not been widely used to investigate the effects of autism on decision making. Gharib et al. (2015) provide a rare exception: they tracked gaze while participants chose between pairs of objects (e.g., two faces) and found that, although autistic participants chose more quickly, there was no effect of autism on the "gaze cascade" (the emerging tendency to fixate the ultimately chosen

object; e.g., Shimojo et al., 2003).

In the present paper, we used a different gaze-tracking paradigm to examine whether people with autism show a pattern of information search consistent with a more systematic, "deliberative" decision style, as conjectured in the literature reviewed above. Building on classic work with neurotypical populations (Lohse & Johnson, 1996; Payne, 1976), we used a naturalistic task in which people choose an apartment, where the possible apartments are represented as a grid of attribute values and the decision-maker's gaze is tracked while they inspect and evaluate the options. This generates multiple eye-movement metrics that illuminate the processes by which the decision-maker is sampling, comparing, and integrating information to reach their decisions. In particular, these metrics indicate the extent to which the decision-maker is engaged in a systematic search and combination of all information rather than a simpler, more heuristic strategy. By varying the number of options and the number of attributes defining each option, we also probed whether differences in the level of systematic information search depend on the complexity of the decision. Based on the literature surveyed above, we hypothesised that autistic participants would engage in more deliberative and rational decision-making. Thus, measures such as decision time and the proportion of information sampled would be greater in the autistic sample. We also expected that the patterns of information acquisition by people with autism would follow a less heuristic pattern than neurotypicals, and that this would be evidenced by having a greater proportion of within-alternative, as opposed to within-attribute, transitions.

# 2  Method

## 2.1  Participants

The sample size was determined by the maximum number of autistic participants that we could test within the funding period of this project, with an equal number of neurotypical adults. Both autistic and neurotypical participants were recruited via the Cambridge Autism Research Database (CARD) at the Autism Research Centre, and from adverts placed with local community groups. We recruited 46 participants with a documented diagnosis of autism; of these, 4 did not complete the study and a further 7 produced eye-movement data that did not pass a pre-specified data quality check (see below). We tested a total of 37 neurotypical participants (after pre-screening for age and gender and having English as their first language); one was discarded because of equipment failure and one did not meet the data-quality criteria. Our final sample of 35 participants per group gives 90% power to detect a "large" (d = 0.8) main effect of participant group, 54% power to detect a "medium" (d = 0.5) effect, and only 13% power to detect a "small" (d = 0.2) effect. Ideally, the study would be more highly powered; however, clinical conditions might be expected to produce substantial effects, and effects sizes in previous studies of decision-making by people with autism are frequently reported to be quite large (e.g., Mussey et al., 2015; Shah et al., 2016).

TABLE 1: Participant demographics

|  | ASC | NT | Test |
|---|---|---|---|
| Gender (M:F) | 19:16 | 16:19 | $\chi^2(1) = 0.51$, $p = .473$ |
| Full Scale IQ | 118.5 (11.8) | 121.1 (9.7) | $t(65.33) = -1.01$, $p = .318$ |
| Verbal IQ | 119.7 (12.0) | 120.1 (10.2) | $t(66.22) = -0.15$, $p = .881$ |
| Performance IQ | 113.2 (12.8) | 117.0 (10.9) | $t(66.36) = -1.32$, $p = 0.193$ |
| Age | 36.3 (13.2) | 35.3 (13.3) | $t(68.00) = 0.32$ , $p = .754$ |
| AQ Short | 90.6 (10.7) | 57.2 (11.8) | $t(67.34) = 12.41$, $p < .001$ |

Note: For Gender, the values shown in the ASC and NT columns are the numbers of males and females in each group; for all other variables, the numbers indicate the means with SD in parentheses. Test = the results of a test of the difference between the ASC and NT groups.

The samples are described in Table 1. None of the final sample reported having Obsessive Compulsive Disorder (OCD) or Attention Deficit Hyperactivity Disorder (ADHD).

## 2.2 Stimuli, Design and Procedure

Participants were tested individually in quiet testing cubicles. The experimenter was present throughout the session, which comprised several tasks with the opportunity to take breaks between each task.

After initial briefing and providing informed consent, participants completed the Wechsler Abbreviated Scale of Intelligence (WAIS; Wechsler, 1999). They then completed a choice task modelled on previous studies of multi-attribute choice, particularly that of Lohse and Johnson (1996). On each trial participants inspected a table of apartments described by several attributes, and chose their preferred apartment. The number of apartments ("options") and the number of attributes were both varied within subjects to give a 4 (number of options: 2,3,5, or 7) x 4 (number of attributes: 2,3,5, or 7) x 2 (participant group: autistic or neurotypical) mixed design. The stimuli were displayed on a 27-inch monitor with a resolution of 2560 by 1440 pixels viewed from approximately 80 cm. Each cell of the decision matrix (the grid listing the options and attribute values) measured 180 by 180 pixels; the attribute labels and values were displayed in 22-point font. The centre of the decision matrix was always the centre of the screen. Immediately outside the grid, each row and column was labelled with the name of the corresponding option or attribute. Each row label was centred in a 200 x 180 pixel box to the left of the decision matrix; the column labels were horizontally centred directly above the columns. Example stimuli are shown in Figure 1.

The choice task began with on-screen instructions that included a description of the 7 possible attributes (e.g., "Space: How large the apartment is"). They then completed 48

|  | Noise | Distance | Rent | Space | Notice |
|---|---|---|---|---|---|
| Apartment 1 | Quiet | 2 miles | 80% | Large | 2 months |
| Apartment 2 | Noisy | 0.25 miles | 90% | Very large | 2 months |
| Apartment 3 | Very quiet | 4 miles | 60% | Small | 1 month |

FIGURE 1: Example stimuli for a trial with 3 options and 5 attributes.

trials, three for each of the 16 possible combinations of the number of options and number of attributes. The set of 7 attributes and their possible values are listed in Table 2; on each trial, we randomly selected the requisite number of attributes from this set, randomized the order in which those attributes were listed on-screen, and randomly selected (with replacement) the value of each attribute for each apartment. For each participant, we alternated whether the apartments were listed horizontally and the attributes listed vertically or vice-versa, and randomized the trial order. The apartments were always numbered successively.

TABLE 2: Attributes and values used to describe apartments in the experiment

| Attribute | Values | | | | | | |
|---|---|---|---|---|---|---|---|
| Rent | 40% | 50% | 60% | 70% | 80% | 90% | 100% |
| Distance | 0.25 miles | 0.5 miles | 1 mile | 2 miles | 4 miles | 8 miles | |
| Cleanliness | Very clean | Clean | Acceptable | Dirty | Very dirty | | |
| Space | Very large | Large | Medium | Small | Very small | | |
| Notice Period | 1 month | 2 months | 3 months | 6 months | 12 months | | |
| Noise | Very quiet | Quiet | Noisy | Very noisy | | | |
| Landlord | Very easy | Easy | Difficult | Very difficult | | | |

 Note: Rent = Rent as % of budget; Distance = Distance from town centre; Landlord = Ease of contacting landlord. The number of levels for each attribute varied from 4 (e.g., Noise) to 7 (Rent).

During the choice task, participants' gaze was tracked at 500Hz using an Eyelink 1000+ (SR Research) with remote camera mount, which permits and corrects for small head movements. Prior to reading the choice-task instructions, participants completed a 9-point calibration and validation procedure. They took self-paced breaks after 16 and 32 trials, with recalibration and validation after each break. Each trial began with a drift check; if

an error was raised the calibration was performed again. When gaze was stably fixated on a central point, the experimenter initiated the display of the decision matrix for that trial. Participants indicated their preferred option by vocalizing its number; we used vocal responses so that participants did not divert their gaze from the screen to the response buttons. The experimenter immediately registered the participant's choice with a button press that terminated the trial, at which point a message appeared notifying the participant that their choice had been recorded.

After the choice task, participants ranked the importance of the 7 attributes to their decisions. They also indicated their direction of preference for each attribute (e.g., whether they regarded a longer or shorter notice period as more preferable). This information would be needed if future work were to try to model the extent to which participants made "optimal" decisions, although we have not attempted such analyses.

Finally, participants completed the Autism Quotient Short (AQS; Hoekstra et al., 2011) to assess their level of autistic traits, and the General Decision Making Style inventory (GDMS; Scott & Bruce, 1995) which scores participants on five decision-making styles (Rational, Intuitive, Avoidant, Spontaneous, Dependent); the order of the questionnaires was alternated from one participant to the next.

## 2.3   Eye movement data processing

We decided and applied data-quality inclusion criteria prior to running any inferential analyses. We defined a "calibration zone" consisting of (a) the central 75% of each cell of the decision matrix, (b) the central 75% of the invisible boxes holding the row labels, and (c) a strip 80 pixels high extending across the top of the decision matrix and encompassing the column labels. We excluded trials on which more than 25% of fixations were outside this zone, on the basis that it was likely that the eye tracker was poorly calibrated on such trials and classification of fixations as belonging inside a particular cell would be error-prone. We also excluded trials on which tracking was lost (e.g., because of blinks) for more than 5% of the total duration of the trial, and one trial from one participant on which no response was recorded. Finally, we excluded participants for whom more than 25% of trials were excluded (as noted above this resulted in excluding 7 people in the ASC group and 1 in the neurotypical group) or for whom the trial exclusions resulted in empty cells in the experimental design (in practice, this was no-one). For the final participant sample, 3.5% of trials were excluded for the reasons listed above (3.7% in ASC group and 3.4% in the NT group). For the remaining trials, we assumed the eye tracker was well-calibrated and therefore defined areas of interest to be the entirety of each cell of the decision matrix; we classified fixations according to the cell into which they fell, and grouped consecutive fixations within a given area to form "dwells" – continuous periods of inspection of a particular piece of information.

TABLE 3: Comparison of self-reported decision styles.

| Decision Style | ASC | NT | $t$(df) | $p$ | $d$ | CI |
|---|---|---|---|---|---|---|
| Avoidant | 3.14 (1.07) | 2.62 (1.04) | 2.06 (67.94) | .043 | 0.49 | 0.01, 0.97 |
| Rational | 4.23 (0.65) | 4.03 (0.51) | 1.43 (64.67) | .158 | 0.34 | -0.13, 0.81 |
| Dependent | 3.76 (0.96) | 3.55 (0.82) | 0.96 (66.50) | .339 | 0.23 | -0.24, 0.70 |
| Intuitive | 3.32 (0.89) | 3.47 (0.75) | -0.75 (66.08) | .453 | -0.18 | -0.65, 0.29 |
| Spontaneous | 2.53 (0.83) | 2.70 (0.66) | -0.95 (64.44) | .343 | -0.23 | -0.70, 0.24 |

Note: The ASC and NT columns show the group means, with $SD$ in parentheses. $d$ values used pooled variance. CI = 95% confidence interval.

# 3 Results

We computed several variables that allow us to answer specific questions about the decision process employed by the autistic and neurotypical groups. These variables reflect different aspects of the decision process which might or might not reflect the same underlying tendencies. Unless otherwise stated, each variable was analysed with a 2 (participant group: autistic vs neurotypical) x 4 (number of attributes: 2, 3, 5, or 7) x 4 (number of options: 2, 3, 5, or 7) mixed ANOVA with Greenhouse-Geisser correction and partial eta-squared as the indicator of effect size (reported with 90% confidence intervals, as per convention; Lakens, 2013). The data are available from: https://doi.org/10.17605/OSF.IO/K7N58

## 3.1 Did autistic participants report differences in their approach to decision-making?

Table 3 shows the mean scores for each of the 5 "decision styles" assessed by the GDMS questionnaire, along with the results of Welch-corrected t-tests comparing the autistic and neurotypical participants. Like in Luke et al. (2012), our autistic participants reported a more avoidant decision-style, with a conventionally "medium" effect size – although the test of this effect would not survive a Bonferroni correction – and none of the other dimensions show a substantial difference between the groups.

## 3.2 Did autistic participants take longer over their decisions?

The time taken to reach a decision is widely assumed to indicate the extent to which the decision was based on deliberative processing and integration of all relevant information (Payne et al., 1993). We computed the latency between the appearance of the choice matrix and the experimenter's button-press to indicate the participant's response, and took the natural logarithm of these values to improve normality and reduce the effect of extreme

values. For each participant, we calculated the mean log-transformed decision time for each cell of the design; the exponentiated means of these values are shown in the top left and top centre panels of Figure 2, and the results of the corresponding ANOVA are reported in Table 4.

Decisions took longer when there were more options and when there were more attributes per option. Contrary to the hypothesis that there is a generalized increase in deliberation amongst people with autism, the only effect involving autism is a two-way interaction between participant group and number of attributes. This interaction is plotted in the top right panel of Figure 2 and shows that the autistic group are less affected than the neurotypical by an increase in the number of attributes: for decisions that involve just two or three attributes per option, the two groups are similar; for decisions involving 5 or 7 attributes, the autistic group are notably faster to make their choices. Note that this effect does not extend to increases in the number of options, which influence both groups of participants to a similar extent (Table 4; the non-significant two-way interactions between group and number of options for this and subsequent variables are plotted in the Supplementary Materials.).

We decomposed the total decision time on each trial into the inspection time (during which gaze fell within the grid of attribute values) and the non-inspection time (during which gaze was elsewhere — mostly on the attribute or option labels at the edge of the decision matrix — or not recorded because the tracking was temporarily lost, which happened rarely). The pattern for inspection time was very similar to that for total decision time; that for non-inspection time (which comprised an average of 25% of each trial) was similar but somewhat noisier (Supplemental Materials).

## 3.3  Did autistic participants sample more information?

We defined a dwell as a continuous period of gaze within a single cell of the choice matrix (a dwell might consist of several fixations if the decision-maker moved their gaze within a cell – e.g., because they were reading the text). Again, we log-transformed the values to improve normality. The number of dwells is plotted in Figure 2 and the ANOVA results are shown in Table 4. The effect of autism is the same as for decision time: autistic participants were less affected by increases in the number of attributes such that, for decisions involving large number of attributes, they engaged in less sampling than did neurotypical adults.

## 3.4  Did autistic participants sample a greater proportion of the available information?

Search depth is the proportion of cells in the choice matrix that were inspected at least once and is typically greater for more deliberative decision-makers (Lohse & Johnson, 1996). The means are plotted in Figure 2 and the ANOVA results are shown in Table 4. (Some caution is needed because these data violate the assumption of variance homogeneity
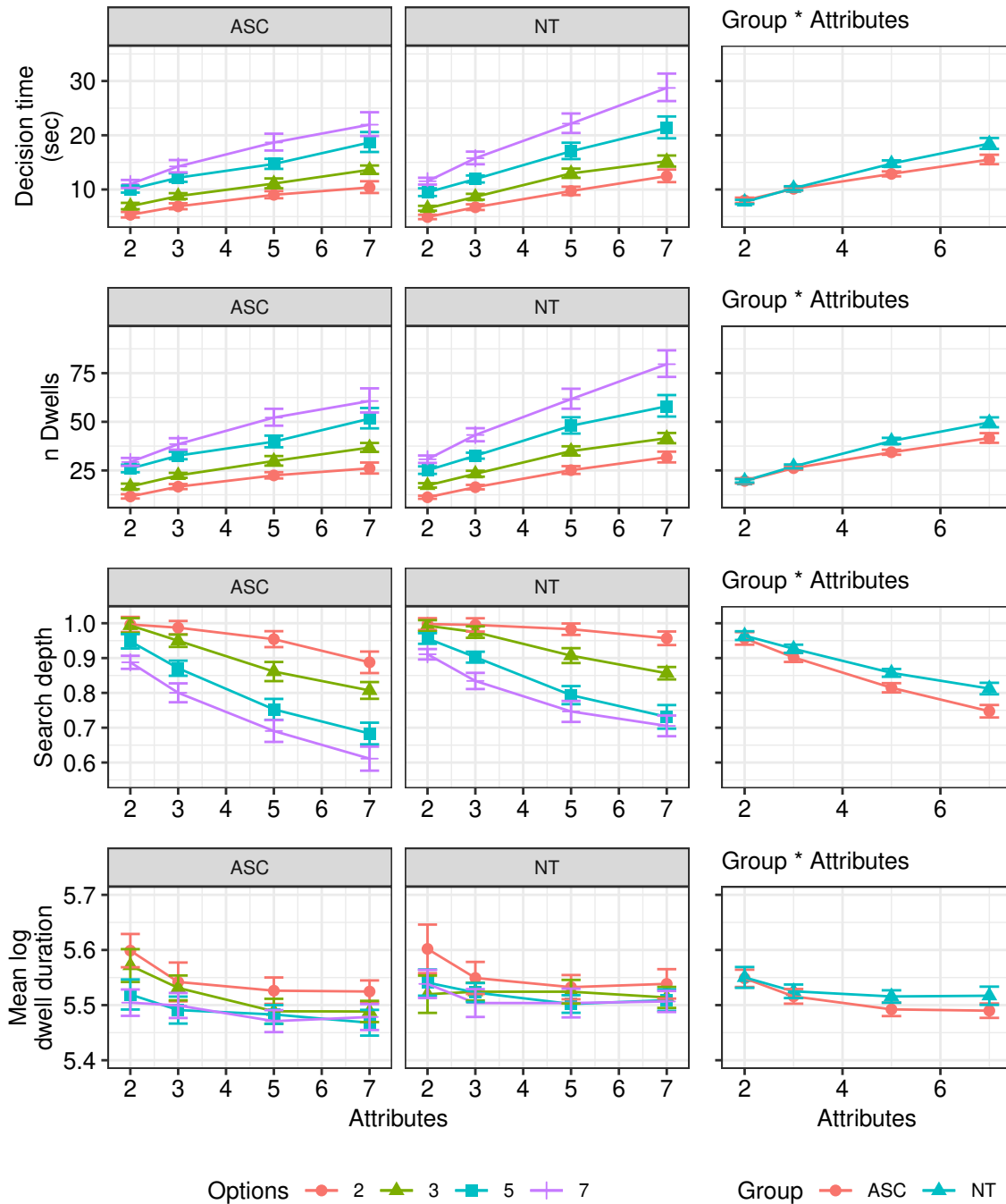
FIGURE 2: The first two columns show the effect of number of attributes and options on our dependent variables for the autism and neurotypical groups respectively. The third column shows the same data collapsed over the number of options with separate lines for the autism and NT groups. The rows are trial duration (time to reach a decision), number of dwells, search depth (the proportion of cells in the grid that were looked at) and logged dwell durations. Error bars are 95% C.I.'s with a within-subjects correction (Morey, 2008).

because search depth is close to one for all simple decisions, but with equal group sizes this is arguably not too problematic). As one would expect, search depth declined as the complexity of the choice increased. More importantly, autistic participants on average inspected a smaller proportion of the available information, and this tendency became more pronounced with increases in the number of attributes (but not with changes to the number of options).

## 3.5    Did autistic participants take longer over each sample?

For each trial, we computed the mean of the (log-transformed) duration of each dwell. The results are plotted in Figure 2. Although the plot indicates some tendency for autistic participants to spend less time sampling each attribute, none of the ANOVA results involving participant group involve a substantial or "significant" effect (Table 4). That is, we found very little indication that people with autism spent more time cogitating over the attribute value they were currently inspecting.

## 3.6    Did autistic participants engage in more integrative search?

When a decision-maker shifts their gaze from one cell of the choice matrix to another, they usually make either a within-option transition (e.g., from the rent of an apartment to its noise level) or a within-attribute transition (e.g., comparing the rent of one apartment with that of another). Following the example of previous work, we computed the Search Index defined as:

$$SearchIndex = \frac{N_{within-option} - N_{within-attribute}}{N_{within-option} + N_{within-attribute}}$$

where more positive values are taken to indicate a more deliberative, integrative decision process (e.g., one in which the decision-maker attempts to weight each attribute value by its relative importance in order to form a global assessment of an option's utility that can then be compared with that of the other options; Payne, 1976). The results are plotted in Figure 3 and the corresponding ANOVA results are shown in Table 4; there is no effect for any of the terms involving participant group. Böckenholt and Hynan (1994) proposed a Modified Search Index that seeks to eliminate bias in the original measure; analysis of this index likewise revealed no effects involving participant group (Supplemental Materials). In short, we found little indication that autism was associated with a more systematic, integrative decision process.

## 3.7    Did the participant groups differ in the attention allocated to the chosen option?

People usually spend more time looking at the option that they ultimately choose than at other options, and their merely looking at an option increases the probability of choosing it

TABLE 4: ANOVA Results

| | | Group | Natt | Nopt | Group* Natt | Group* Nopt | Natt* Nopt | Group* Natt* Nopt |
|---|---|---|---|---|---|---|---|---|
| Decision Time | $F$ | 1.61 | 431.18 | 453.96 | 9.61 | 2.44 | 1.10 | 0.54 |
| | df | 1, 68 | 1.8, 120.4 | 1.8, 122.6 | 1.8, 120.4 | 1.8, 122.6 | 7.6, 519.6 | 7.6, 519.6 |
| | $p$ | .209 | <.001 | <.001 | <.001 | .097 | .359 | .816 |
| | $\eta_p^2$ | .02 | .86 | .87 | .12 | .03 | .02 | .01 |
| | CI | 0, .11 | .83, .89 | .83, .89 | .04, .21 | 0, .09 | 0, .02 | 0, .01 |
| Number of Dwells | $F$ | 3.11 | 503.53 | 644.47 | 7.01 | 1.63 | 2.29 | 0.81 |
| | df | 1, 68 | 1.7, 114.6 | 2, 138.7 | 1.7, 114.6 | 2, 138.7 | 7.7, 523.2 | 7.7, 523.2 |
| | $p$ | .082 | <.001 | <.001 | .002 | .199 | .022 | .587 |
| | $\eta_p^2$ | .04 | .88 | .90 | .09 | .02 | .03 | .01 |
| | CI | 0, .14 | .85, .9 | .88, .92 | .02, .18 | 0, .07 | 0, .05 | 0, .02 |
| Search Depth | $F$ | 7.12 | 253.23 | 311.73 | 5.91 | 1.30 | 30.68 | 0.61 |
| | df | 1, 68 | 1.8, 123.3 | 1.8, 121 | 1.8, 123.3 | 1.8, 121 | 6.7, 455.8 | 6.7, 455.8 |
| | $p$ | .010 | <.001 | <.001 | .005 | .273 | <.001 | .738 |
| | $\eta_p^2$ | .09 | .79 | .82 | .08 | .02 | .31 | .01 |
| | CI | .01, .21 | .73, .82 | .77, .85 | .02, .16 | 0, .07 | .25, .35 | 0, .01 |
| Dwell Duration | $F$ | 0.29 | 18.69 | 24.07 | 1.44 | 2.00 | 1.32 | 1.77 |
| | df | 1, 68 | 2.4, 164.6 | 2.1, 146.1 | 2.4, 164.6 | 2.1, 146.1 | 7.4, 500.9 | 7.4, 500.9 |
| | $p$ | .590 | <.001 | <.001 | .238 | .135 | .234 | .087 |
| | $\eta_p^2$ | .00 | .22 | .26 | .02 | .03 | .02 | .03 |
| | CI | 0, .06 | .12, .29 | .16, .35 | 0, .06 | 0, .08 | 0, .03 | 0, .04 |
| Search Index | $F$ | 0.18 | 99.27 | 36.65 | 2.14 | 2.32 | 4.66 | 0.95 |
| | df | 1, 68 | 2.2, 150.4 | 2, 137.9 | 2.2, 150.4 | 2, 137.9 | 7.5, 506.8 | 7.5, 506.8 |
| | $p$ | .672 | <.001 | <.001 | .116 | .101 | <.001 | .468 |
| | $\eta_p^2$ | .00 | .59 | .35 | .03 | .03 | .06 | .01 |
| | CI | 0, .05 | .51, .65 | .24, .43 | 0, .08 | 0, .09 | .02, .09 | 0, .02 |
| Time on Chosen Option | $F$ | 0.52 | 51.18 | 895.89 | 4.83 | 1.03 | 2.39 | 0.73 |
| | df | 1, 68 | 2.7, 183.8 | 2.7, 184 | 2.7, 183.8 | 2.7, 184 | 7.2, 492.1 | 7.2, 492.1 |
| | $p$ | .474 | <.001 | <.001 | .004 | .375 | .019 | .654 |
| | $\eta_p^2$ | .01 | .43 | .93 | .07 | .01 | .03 | .01 |
| | CI | 0, .07 | .34, .5 | .91, .94 | .01, .12 | 0, .04 | 0, .05 | 0, .01 |
| Dwells on Chosen Option | $F$ | 0.30 | 73.11 | 1203.64 | 4.78 | 0.46 | 2.96 | 0.47 |
| | df | 1, 68 | 2.7, 184.5 | 2.7, 183 | 2.7, 184.5 | 2.7, 183 | 7.4, 505.9 | 7.4, 505.9 |
| | $p$ | .583 | <.001 | <.001 | .004 | .688 | .004 | .864 |
| | $\eta_p^2$ | .00 | .52 | .95 | .07 | .01 | .04 | .01 |
| | CI | 0, .06 | .43, .58 | .93, .95 | .01, .12 | 0, .02 | .01, .06 | 0, .01 |

Note: See main text for explanation of dependent variables. Group = ASC vs NT; Natt = Number of attributes defining each option; Nopt = Number of options.
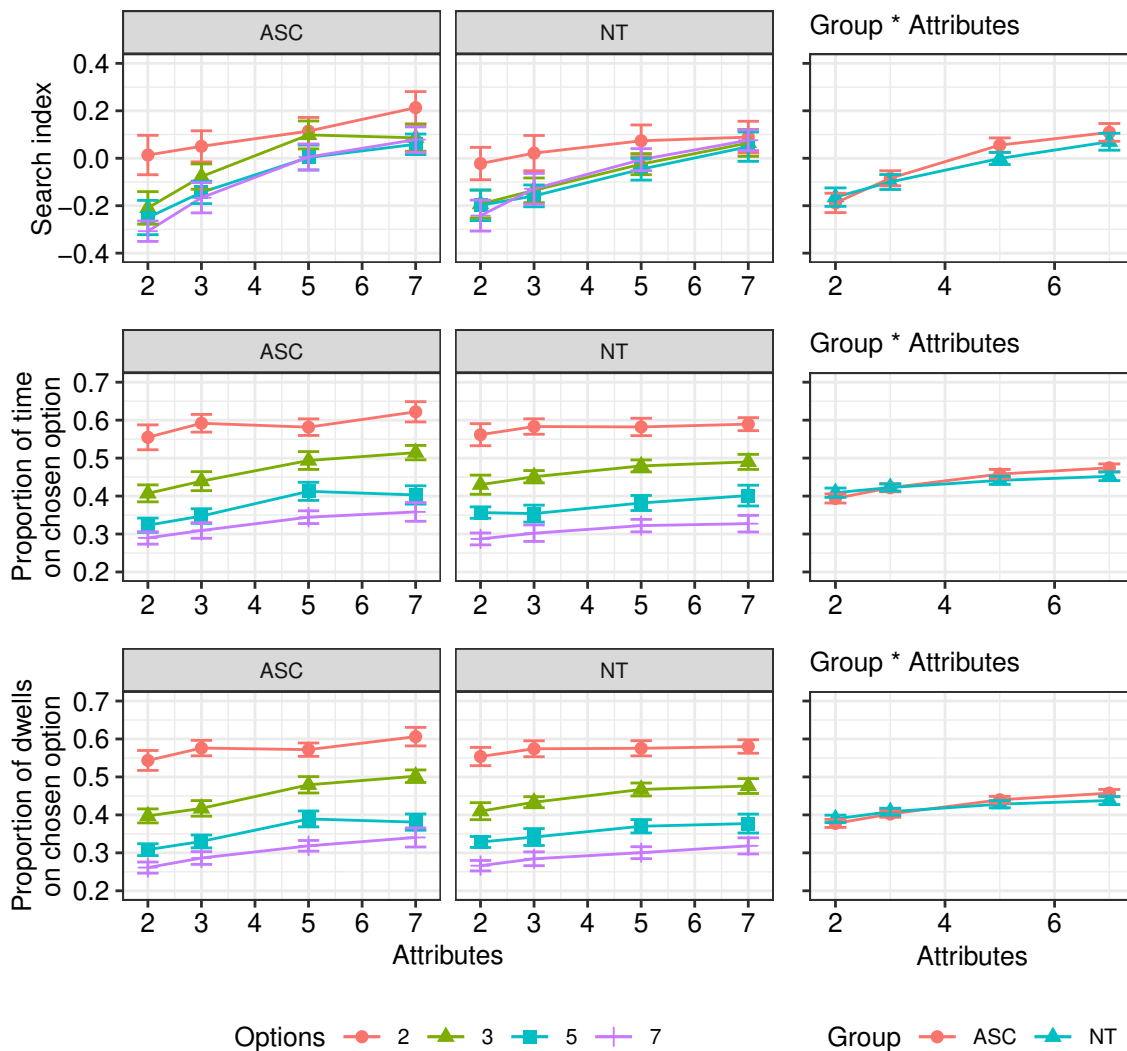
FIGURE 3: The first two columns show the effect of number of attributes and options on the dependent variables for the autism and neurotypical groups respectively. The third column shows the same data collapsed over the number of options with separate lines for the autism and NT groups. The rows are search index (the ratio of within option transitions to between option transitions), proportion of time on chosen option, and proportion of dwells on chosen option. Error bars are 95% C.I.'s with a within-subjects correction (Morey, 2008).

(Smith & Krajbich, 2019). For each trial, we computed both the proportion of inspection time and the proportion of dwells that were spent on the option that was ultimately chosen. The results are similar for both measures (Figure 3; Table 4): increasing the number of options or the number of attributes leads people to allocate proportionally more attention to the chosen option. More importantly, the only effect involving autism was that autistic participants were more sensitive than neurotypical participants to changes in the number of attributes: when the number of attributes increased, autistic people directed a particularly large share of their visual attention to the ultimately-chosen option.

## 3.8    Did the participant groups judge different attributes to be important?

A 2 (participant group) x 7 (attributes) mixed ANOVA revealed a significant interaction between group and attributes ($F(5.1, 348.9) = 4.00$, $p = .001$, $\eta_p^2 = .06$). The discrepancies in attribute rank judgement between the groups are shown in Figure 4. The largest difference in attribute ranking was for space, which was much more important to the neurotypical group than the autistic group. Both groups ranked notice period as similarly unimportant, while noise was the most important attribute for autistic participants. Noise was even more important then rent (which ranked second) for the autistic group, and perhaps reflects the impact that differences in sensory sensitivity can have on people with autism (e.g., Stiegler & Davis, 2010).
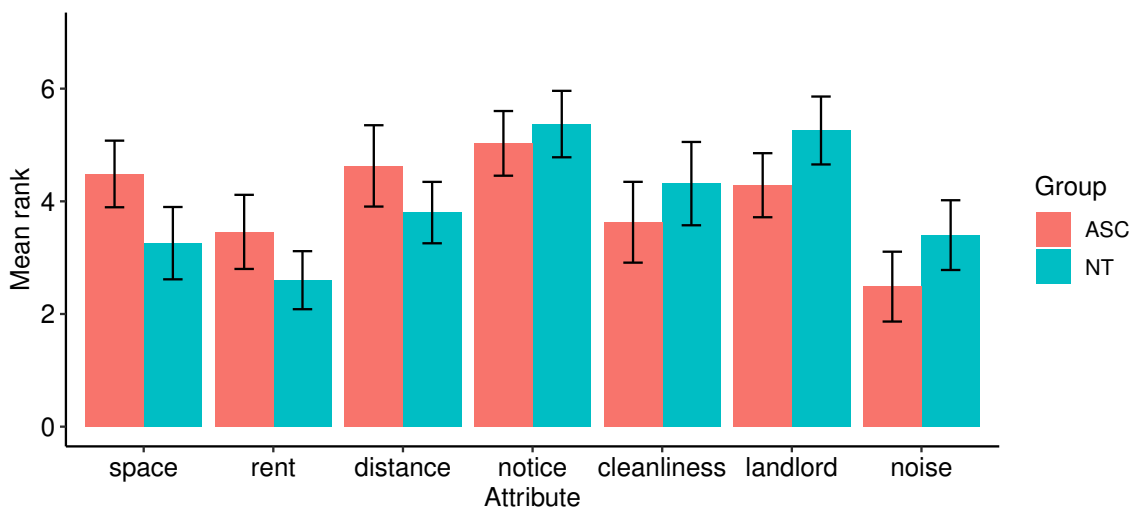


FIGURE 4: Mean attribute rank for each group. Attributes are sorted by size of difference between the groups. Note that lower ranks indicate greater subjective importance. Error bars are 95% C.I.'s.

## 3.9    Did the participant groups differ in the amount of attention they devoted to each attribute?

Finally, we examined how the allocation of attention was affected by the stated importance of the attributes, the number of attributes, the number of options, and the participant group. Because many trials did not involve all 7 attributes, there were missing data which meant that we could not run a full factorial analysis. We therefore conducted two separate analyses.

First, for each participant we computed the mean proportion of dwells devoted to each attribute separately for each of the 2, 3, 5, and 7-option conditions,[1] and submitted these to a

[1]The calculation was as follows: for each participant, take all trials where the top-ranked attribute was present and compute the proportion of dwells to that attribute on that trial; then take the mean of these

2 (participant group) x 4 (number of options) x 7 (attribute importance) mixed ANOVA. The means are shown in Figure 5 and the ANOVA output is in Table 5. The ANOVA indicates a three-way interaction: when participants chose between 2 options, they devoted more attention to more important attributes but the effect was relatively mild for both autistic and neurotypical adults. As the number of options increased, both groups directed more attention to the most subjectively-important attribute dimensions; this effect was relatively modest for the neurotypical group but quite pronounced for the autistic group. For example, when choosing between 7 options, the autistic group dedicated on average 34% of their dwells to the most important attribute and 26% to the second most important attribute, whereas the figures for the neurotypical group are 28% and 27%, respectively.

For our second analysis we computed the mean proportion of dwells to each attribute separately for each of the 3, 5, and 7-attribute conditions (the 2-attribute condition was excluded because for some participants not all 7 attributes were presented in this condition). The means are shown in Figure 5 and the results of the 2 (participant group) x 3 (number of attributes) x 7 (attribute importance) ANOVA are shown in Table 5. As one would expect, there is a main effect of attribute rank (participants paid more attention to more important attributes) and of number of attributes (the greater the number of attributes defining each option, the less attention paid to any one attribute). More interestingly, the effect of rank was more pronounced for the autistic group, such that they paid relatively greater attention to the most subjectively important attribute when making their decisions. The results for both analyses were very similar when the proportion of inspection time, rather than the proportion of dwells, was used as the measure of attention (Supplemental Materials).

# 4   Discussion

Contrary to our expectations, we found no evidence that the autistic participants engaged in more thorough, analytical information sampling. Rather, they were less affected than neurotypical participants by increases in the amount of information provided about each option: when the task required the decision-maker to take account of a large number of attributes, autistic participants were faster, drew fewer samples, inspected a smaller proportion of the available information, and spent less time viewing options that they did not ultimately choose than did neurotypical participants.[2] This did not reflect a general tendency to respond more quickly or to simplify information search: there was no main effect of participant group, and autistic and neurotypical participants responded similarly to

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proportions separately for the 2, 3, 5, and 7-options conditions (or, when analysing the effect of the number of attributes, compute the mean of these proportions separately for the 3, 5, or 7 attribute conditions); repeat for each of the other attributes.

[2]It's worth clarifying that we do not present these results as completely separate findings; for example, the finding that autistic participants had faster response times is related to the fact that they drew fewer samples. Still, these various measures did not have to be correlated – for example, one group might draw more samples but spend less time on each sample, such that the overall response times are the same.
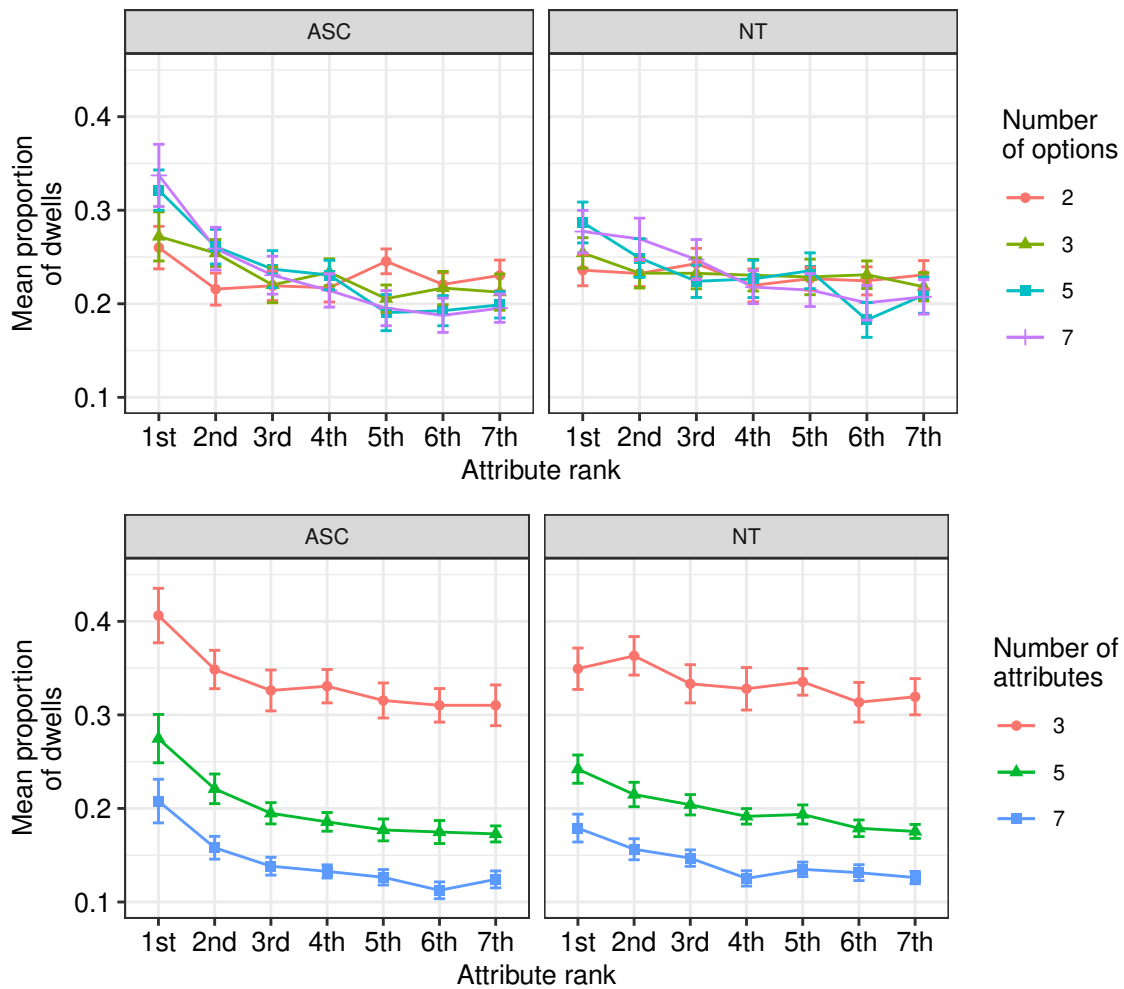
FIGURE 5: The top row shows the mean proportion of dwells by subjective attribute rank and the number of options available. The bottom row shows the mean proportion of dwells that each attribute received, broken down by the subjective rank of the attribute and the number of attributes available. The data in the second row are collapsed over the number of options. Some participants will not have seen a particular rank of attribute when only 2 attributes were present, so only 3, 5 and 7 attributes are shown. Error bars are 95% C.I.'s with a within-subjects correction (Morey, 2008).

changes in the number of options. Instead, the data suggest that the autistic group attached relatively high weight to a small number of attributes, allowing them to simplify the decision process when each apartment was defined by many different attribute values by focusing on just a few values. Consistent with this, autistic participants directed a larger proportion of their gaze at the attributes that they judged to be most important.[3]

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[3]Our participants' tendency to focus more of their attention on subjectively high-ranking attributes suggests an efficient sampling of information based on its utility. There is an interesting contrast here with schizophrenia: Glöckner & Moritz (2009) found that schizophrenic participants were less likely than controls to use the validity of cues as the basis for sampling information.

TABLE 5: Effects of attribute importance on dwells on that attribute.

Proportion of Dwells by Attribute Importance and Number of Options

|  | Group | Nopt | Rank | Group* Nopt | Group* Rank | Nopt* Rank | Group* Nopt* Rank |
|---|---|---|---|---|---|---|---|
| $F$ | 0.15 | 0.91 | 35.70 | 1.17 | 3.81 | 9.15 | 2.04 |
| df | 1, 68 | 2.8, 192.1 | 4.4, 297.6 | 2.8, 192.1 | 4.4, 297.6 | 13.6, 925.2 | 13.6, 925.2 |
| $p$ | .697 | .435 | <.001 | .322 | .004 | <.001 | .014 |
| $\eta_p^2$ | 0 | .01 | .34 | .02 | .05 | .12 | .03 |
| CI | 0, .05 | 0, .04 | .27, .4 | 0, .05 | .01, .09 | .08, .14 | 0, .03 |

Proportion of Dwells by Attribute Importance and Number of Attributes

|  | Group | Natt | Rank | Group* Natt | Group* Rank | Natt* Rank | Group* Natt* Rank |
|---|---|---|---|---|---|---|---|
| $F$ | 0.20 | 28730.82 | 37.61 | 0.14 | 4.50 | 0.96 | 1.02 |
| df | 1, 68 | 1.3, 86.6 | 3.6, 244.8 | 1.3, 86.6 | 3.6, 244.8 | 7.9, 535.1 | 7.9, 535.1 |
| $p$ | .657 | <.001 | <.001 | .766 | .002 | .467 | .416 |
| $\eta_p^2$ | 0 | 1 | .36 | 0 | .06 | .01 | .01 |
| CI | 0, .06 | 1, 1 | .27, .42 | 0, .04 | .01, .11 | 0, .02 | 0, .02 |

Note: The top portion of the table shows the effect of changing the number of options (collapsing over the number of attributes); the bottom portion shows the effect of changing the number of attributes (collapsing over the number of options). Natt = Number of attributes; Nopt = Number of options.

Although unexpected, the less comprehensive decision-style found here accords with broader features of autism and offers a new perspective on previous research. In particular, repetitive behaviour and restricted interests are a defining characteristic of autism, and Wu et al. (2018) have recently noted that this may be important in decision-making. The current work suggests that, in the context of multi-attribute choice, a propensity to have restricted interests entails a relatively narrow focus on a small set of attributes and thereby simplifies the decision-process when the task becomes increasingly complex. This suggestion qualifies rather than negates the proposal that autism entails a more deliberative or "systemizing" mind-set (Baron-Cohen et al., 2003): a person may be highly motivated to engage in complex cognitive operations, or to deal with systems characterized by rules and lawful behaviour, but nonetheless prioritize particular dimensions when deciding which of several options they prefer. Which tendency predominates in a particular decision context will depend on multiple features of the task and individual.

This perspective provides a new explanation for the finding that autistic people show more rational behaviour seen in some decision tasks – behaviour previously attributed to a more analytic decision style. For example, autistic adults have been found to be less susceptible than neurotypical adults to the attraction effect, wherein preference between two items is affected by the properties of a third, "decoy" option (Farmer et al., 2017). A decision-maker who simply chooses the option that is best on one particular dimension, ignoring the other attribute, will be immune to the decoy because it is never the best on any dimension. Similarly, the sunk-cost task used by Fujino et al. (2019) requires people to choose between 2 travel destinations prior to informing them that they had inadvertently bought tickets for both. A decision-maker with a strong focus on a particular aspect of the destinations (e.g., distance from home) will be less affected by the news that they have expended money on a less-preferred option – as observed for the autism group.

These interpretations are speculative, but eye-tracking provides a way to test them in future by directly assessing the allocation of visual attention across different aspects of the decision problem. Such process-tracing might also reconcile other, somewhat contradictory results regarding the extent to which people with autism exhibit enhanced rationality. In particular, De Martino et al. (2008) and Shah et al. (2016) found that autistic adults were less affected than neurotypical adults by the loss-gain framing of risky choices; Gosling & Moutier (2018) found no such difference and suggested that the difference arose because they, unlike the previous studies, did not impose a response deadline. By examining how the imposition of a time limit affects information sampling, researchers may be able to explain the different pattern of choices in these two versions of the task. More generally, the eye-tracking approach described in the present paper could serve as a blueprint for more sophisticated manipulations of the choice parameters in future – for example, the steepness of the trade-offs between different attributes, and the extent to which attribute values are similar or different from one another.

Finally, like Luke et al. (2012) we found that autistic adults reported a more "avoidant" decision style than did neurotypical adults (although the p-value of .043 would not survive a correction for multiple comparisons), but scored the same as them on measures of rational and intuitive thinking. The latter result differs from those found in studies using the REI (e.g., Gaeth et al., 2016), suggesting that it would be productive to include both measures in a single study. More importantly, the fact that our autistic participants were often faster than neurotypical adults suggests that their self-reported procrastination does not equate to slower decision-making once information sampling has begun, and that they may be relatively efficient decision-makers despite finding the task difficult. Indeed, a tendency to prioritize a subset of the available attributes might alleviate the distress that might come from prolonged engagement with the decision task; that is, it might be regarded as a way of coping that is distinct from, but related to, compensation mechanisms (Livingston et al., 2020). We suggest that all of the self-report results should be treated with some caution given the relatively small sample size

It is important to note the limitations of our work. Although we ended up with a reasonably well-powered study (some studies in this area use samples of approximately half our final sample size — e.g., De Martino et al., 2008; Johnson et al., 2006; Minassian et al., 2007; Mussey et al., 2015; Robic et al., 2015; Yechiam et al., 2010), the difficulty of recruiting autistic participants meant that we were not able to conduct a replication study. Replication is clearly very desirable, especially given that our findings were unexpected, and we hope that other researchers might be better placed than us to pursue this. We therefore do not make strong claims about the magnitude or robustness of the effects that we have reported, but we do think that the available evidence suggests that they are potentially important and merit further study.

A second class of limitations concerns the experimental methodology. Our groups were well-matched in terms of verbal IQ, but there are well-established differences in language processing in autism (e.g., Eigsti et al., 2011). Therefore, the use of descriptive labels in our task may have led our autistic participants to process the information differently. Although we used a well-established scenario (Lohse & Johnson, 1996), the use of hypothetical choices might have been problematic for some autistic participants, and the task of choosing an apartment might have been less familiar to the autistic group; a task featuring a decision-problem of more interest or relevance to people with autism might result in a different information processing style. In addition, our task does not permit us to test whether participants made "correct" (i.e., utility-maximizing) choices. Such an analysis requires strong assumptions about the subjective utility of each attribute value, which would not be justified for the kinds of non-linear, sometimes non-numeric attribute labels used here: our work might have been improved by using a more standard set of attribute values — for example, ratings from 1 to 5 for each dimension — and by replacing the ranking of attribute importance with a rating procedure that provides a more detailed picture of their significance to the decision-maker. An alternative approach is to use the participant's choices to infer the subjective utility of each attribute value and the weight that the decision-maker assigns to each attribute dimension; this requires more choices per participant than we obtained, but offers a potential tool in future comparisons of autistic and neurotypical decision-makers.

A third class of limitation concerns our participant sample. Our autistic participants were high functioning and the sample did not have the strong male-bias that might be expected for the autistic population. We therefore cannot be sure how well our results will generalize to the broader community. In addition, although we screened for comorbidity with OCD and ADHD, we did not screen for other potentially moderating conditions such as anxiety or alexithymia (Shah et al., 2016), or for medication. Finally, like most work this area we focused on the binary comparison of groups with and without a diagnosis of autism (and our power analyses were based on such a between-group comparison) rather than considering possible sub-populations or analysis using a continuum of traits: We obtained autism-quotient scores for each participant simply to permit overall comparison of the groups with each other and with other published samples, but in principle it would be

possible to consider using AQ as a continuous predictor of the eye-tracking variables, and to consider different dimensions of the AQ as differential predictors (e.g., task switching tendency vs social skills). These were not part of our planned analyses so we have not pursued them here, but the data are available publicly should others wish to explore these directions.

# 5   Conclusion

Our results suggest that adults with autism differ from neurotypical adults in the way that they search for information about options during a consumer choice task. Autistic participants directed more attention towards the most subjectively important attributes, and were correspondingly less affected than neurotypical adults by increases in the number of attributes — resulting in quicker, shallower information search when the decisions involved trading-off many attribute dimension. Whether these patterns of sampling led to "better" or "worse" decision-making is an open question, but they run contrary to the idea that autism is associated with a more "analytical" or "deliberative" decision style (Brosnan et al., 2016; De Martino et al., 2008; Vella et al., 2018). More broadly, eye-tracking has helped to illuminate how neurotypical adults sample information in a range of decision paradigms, including risky choice (e.g., Fiedler & Glöckner, 2009; Glöckner & Herbold, 2011; Stewart, Hermens, et al., 2016), intertemporal choice (e.g., Reeck et al., 2017), on-line shopping (e.g., Ashby et al., 2015), and economic games (Stewart, Gächter, et al., 2016). Such methodologies, coupled with increasingly sophisticated mathematical models of eye movement data (e.g., Shi et al., 2013) could be used to compare autistic and neurotypical decision-makers, and may uncover important differences in their information-processing style – differences which might not be apparent in their overt choices (Gharib et al., 2015).

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