People with autism spectrum conditions make more consistent decisions

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Abstract

People with autism spectrum conditions (ASC) show reduced sensitivity to contextual stimuli in many perceptual and cognitive tasks. We investigated whether this also applies to decision-making by having adult participants make a series of choices between consumer products. Participants' preferences between a given pair of options frequently switched when the third item in the set was changed, but this tendency was reduced among individuals with ASC, indicating more consistent and conventionally rational choices. A comparison of people with low- vs high-levels of autistic traits drawn from the general population revealed a weaker version of the same effect. The reduced context-sensitivity was not due to differences in noisy responding, and although the ASC group took longer over their decisions this did not account for the enhanced consistency of their choices. The results extend the characterization of autistic cognition as relatively context-insensitive to a new domain, with practical implications for socio-economic behaviour.

Introduction

People with autism spectrum conditions (ASC) often show atypical performance on tasks that require processing of local information independently of its context (Behrmann, Thomas, & Humphreys, 2006; Frith, 1989; Happé & Frith, 2006). For example, people with ASC are better than controls at finding figures embedded in complex shapes, their visual search is less affected by the number and similarity of distractors, and they often fail to take semantic context into account when pronouncing homographs (see Happé & Frith, 2006, for a review). Non-clinical samples scoring high for autistic traits display a similar pattern of performance (e.g., Stewart, Watson, Allcock, & Yaqoob, 2009). This reduced impact of context may reflect an inability to integrate information into a coherent whole (Frith, 1989), but may also be understood solely in terms of a superior ability to process local information (Plaisted, Saksida, Alcántara, & Weisblatt, 2003).

We investigated whether the reduced context-sensitivity that characterizes ASC extends to decision making. Decision-making is a fundamental cognitive operation that has received relatively little attention from autism researchers (Davis & Plaisted-Grant, 2015; Luke, Claire, Ring, Redley, & Watson, 2012). Most previous studies have focused on how people with ASC represent and evaluate probabilities and rewards, often using tasks in which the decision-maker must learn the payoffs and probabilities of different options by making a series of choices and receiving feedback (e.g., Mussey, Travers, Klinger & Klinger, 2015). We took a different approach by examining whether autistic traits correlate with altered context-sensitivity in a riskless choice task, where the participant simply selects the best alternative from explicitly-stated attribute values.

Conventional accounts of rational choice dictate that a person's preference between two items be independent of the other options on offer: if one prefers salmon to steak, this should not change just because frogs' legs are added to the menu (Luce & Raiffa, 1957). However, the choices of neurotypical adults are heavily influenced by the composition of the choice set; rather than independently assessing the subjective value of each alternative, the attractiveness of a given option depends on how it compares with the other values that are simultaneously present (Huber, Payne, & Puto, 1982; Simonson, 1989; Tversky, 1972). One of the most striking examples is the "attraction effect", which arises when people choose between two options, A and B, that "trade off" two dimensions – for example, USB drives differing in capacity and longevity (Figure 1). When the choice set includes a third, "decoy" option that is fractionally worse than A on both dimensions, people very rarely choose the decoy, but its presence boosts the tendency to choose A rather than B – and vice-versa if the decoy targets option B. This kind of context-induced preference reversal occurs in many domains (e.g., Farmer, El-Deredy, Howes, & Warren, 2015), has been extensively modelled (e.g., Trueblood, Brown, & Heathcote, 2014), and is used by marketers to influence consumer behaviour (Ariely, 2009).

If the tendency of people with ASC to prioritize local information and to be relatively insensitive to the other elements of the stimulus array extends to decision-making, then they should be less influenced by decoy options and make fewer context-induced preference reversals. Correspondingly, we hypothesized that adults with ASC would make more consistent choices -- indicative of a more rational, independent valuation of alternatives than is seen in the neurotypical population. This possibility is important because choice-consistency is regarded as normative in conventional economic theory, so reduced context-sensitivity would provide a new demonstration that autism is not in all respects a “disability” (Baron-Cohen, 2000). More importantly, context effects on choice speak to the nature and basis of autistic cognition. Many studies of altered context-sensitivity among people with ASC focus on perceptual tasks such as pitch discrimination, visual search, and motion-coherence, with corresponding theoretical frameworks that emphasize “low level” processes such as enhanced perceptual discrimination or altered magnocellular sensitivity (see Happé & Frith, 2006, for a review). Altered preferences in a choice task with verbally-described consumer products would suggest a broader characterization and a need for integrated theorizing across levels and domains of processing (Davis & Plaisted-Grant, 2014; Pellicano & Burr, 2012). Finally, the possibility of reduced contextual influence has practical implications for the economic and social functioning of people with autism spectrum conditions: attraction-effect decoys influence many “real world” decisions (e.g., Doyle, O’Connor, Reynolds, & Bottomley, 1999), and reduced decoy-sensitivity would result in different financial, consumer, political, and relationship choices among people with ASC.

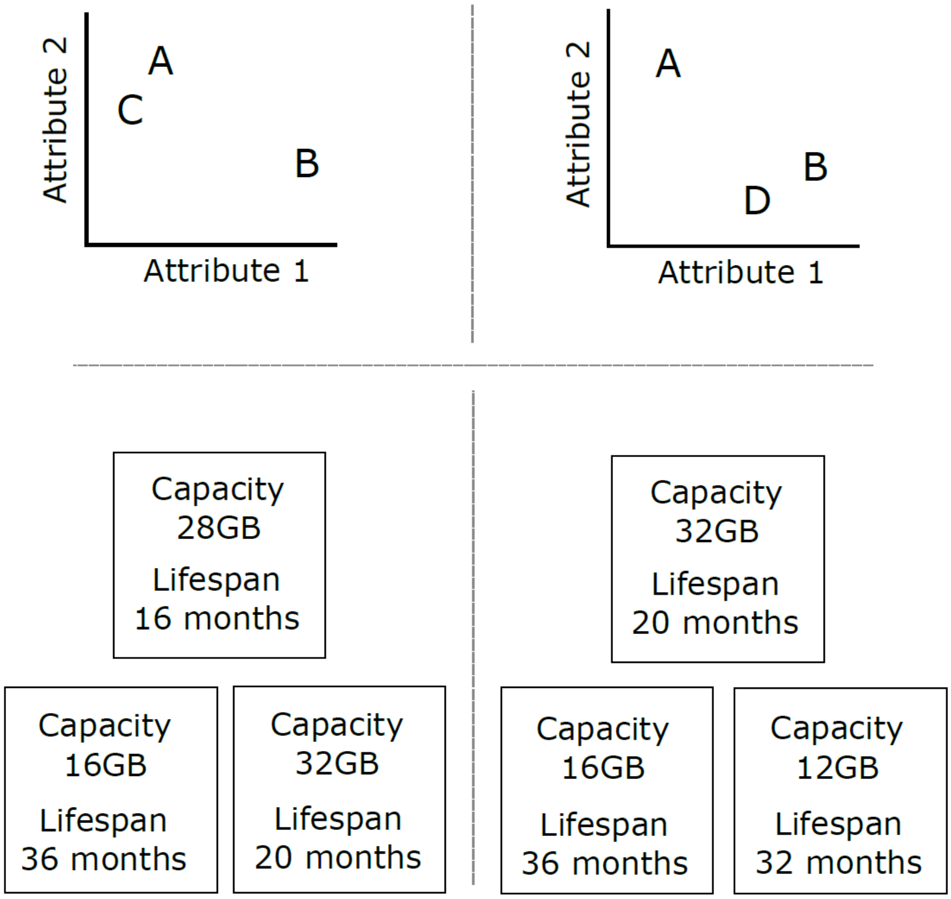

Figure 1. The top panels illustrate the configuration of choice sets that elicit the attraction effect. A and B are options that "trade-off" two positive attributes; C and D are decoys. Given the choice between A, B, and C, people typically choose A, but when the offered A, B, and D they prefer B. The bottom panels illustrate typical trials from the experiment, in this case a choice among USB drives. In the bottom left panel, the option at the right is the target, that on the left is the competitor, and the top option is the decoy. In the bottom right panel, the option at the left is the target, the option at the right is the decoy, and the top option is the competitor.

Method

We conducted two studies. Our main experiment compared adults diagnosed with ASC to controls. In an additional experiment, we compared participants from the general population who scored in the bottom (N = 176) and top (N = 194) deciles of the Autism-Spectrum Quotient (AQ) (Hoekstra et al., 2011), one of several self-report questionnaires that support the existence of a spectrum of autistic traits in the general population.

All participants completed a decision-making task adapted from previous studies of the attraction effect (Noguchi & Stewart, 2014). They also completed the International Cognitive Ability Resource (ICAR; Condon & Revelle, 2014) and the AQ-Short. The research was approved by the

University of Cambridge Psychology Research Ethics Committee and all participants provided informed consent.

Main study: Comparing ASC participants with Controls

Participants. This study was registered on the Open Science Framework (osf.io/7b9au). Ninety ASC participants were recruited via the Cambridge Autism Research Centre, a widely-used participant pool for both lab- and on-line studies (e.g., Uzefovsky, Allison, Smith, & Baron-Cohen, 2016). To register as an ASC participant in this database, participants must self-report a diagnosis of an ASC, specify its nature (e.g., Autism, Asperger's syndrome), report the kind of clinician who diagnosed them (e.g., psychiatrist) and the clinic/hospital where this took place. (In lab-based studies that we have conducted using this participant pool, the vast majority of participants are able to bring written evidence of diagnosis). In the present study, we excluded 8 participants who, despite being invited to take part via the database mailing list, indicated that they did not have an official diagnosis of an ASC. (The presence of any residual "non-genuine" participants in the ASC group would simply mean that our tests of group differences are conservative.) Our final sample comprised 37 males, 52 females and one who preferred not to say (PNTS), age range 18 to 71 (M = 43.11, SD=13.73), ICAR range 1 to 16 (M = 10.83, SD = 3.98), and AQ range 62 to 112 (M = 92.5, SD = 10.57). Country of residence was UK = 70, US = 18 and PNTS = 2. An additional 3 people were excluded for failing more than 2 catch trials (which served as an attention/comprehension check, as described below; this exclusion criterion was set in advance).

Two hundred and twelve control participants were recruited via the PureProfile platform and comprised 89 males and 123 females, age range 19 to 71 (M = 43.88, SD = 13.5), ICAR range 1 to 16 (M = 7.25, SD=3.66), and AQ range 41 to 91 (M=65.20, SD=10.04). Country of residence was UK = 169 and US = 43. An additional 41 people were excluded for failing more than 2 catch trials. Control participants were group-matched for age, gender, and residence with the ASC sample. Full demographic information including relations between variables is in the Supplementary Materials (Tables S3-S5). The sample size was based on recruiting as many ASC participants as possible and then calculating the sample of control participants necessary to give approximately 70% power based on the difference in proportion of consistent choices observed between the low- and high-AQ groups in the AQ study, which was conducted first (higher power would require unfeasibly large numbers of control participants) (Faul, Erdfelder, Buchner, & Lang, 2009). Testing took place online using custom-written software; only complete datasets from participants aged 18 or over and whose ip addresses that had not already been registered were included in the sample.

Design and Procedure. The choice task was adapted from previous studies of the attraction effect (Noguchi & Stewart, 2014). Participants saw 10 pairs of products, each differing on two dimensions (Figure 1). Each pair was presented twice, once with a decoy that targeted one product and once with a decoy that targeted the other, along with 6 catch trials where one product was clearly superior to all others. One trio of products (target, competitor, and decoy) was presented on each trial. The stimuli are provided in the Supplementary Materials (Table S1). Each trial was presented on a separate page headed by text describing the product attribute values, below which the three product-descriptions were arranged in a triangle with random allocation of items to locations. Participants clicked the item they thought was best and advanced to the next choice. Trial order was random except that a product category was not displayed for a second time until all 10 product-pairs had been displayed once. Cognitive ability was measured by the matrix reasoning, three-dimensional rotation, verbal reasoning, and letter and number sequence components of the international cognitive ability resource, a validated measure of general cognitive ability tailored for on-line testing that comprises 16 items each scored 0 for incorrect and 1 for correct (Condon & Revelle, 2014). AQ was measured with the 28 items of the Autism-Spectrum Quotient-Short, each scored from 1-4 (Hoekstra et al., 2014). Task order (choice task, ICAR, and AQ) was randomized.

Additional study: Comparing low-AQ and high-AQ groups

We also compared people with low- and high-levels of autistic traits drawn from the general population. Obtaining a similar pattern among individuals with high AQ-scores as in the clinical sample would provide converging evidence for a link between autistic traits and altered decision-making, and generalize the importance of this finding to a larger section of the population.

Participants. The additional study comprised two versions that used different stimuli and participants. (Version 1 was conducted and analysed first; Version 2 was run as a replication study. Because the results are not modulated by Version, we present the results of the combined analysis to give the best overall estimate of the effects; results for the separate versions are shown in Figures S8 and S9 of the Supplementary Materials.) In Version 1, 965 participants completed the AQ-Short, of whom 81 from the bottom decile of AQ scores and 94 from the top decile of AQ scores returned to complete the main task. In Version 2, 1008 completed the AQ-Short with 95 from the bottom decile and 100 from the top decile returning to complete the main task. Across both versions, an additional 18 participants completed the choice task but were excluded for failing more than 2 catch trials. Overall, the low-AQ group comprised 85 males, 90 females, and one PNTS, age range 19 to 75 (*M*=35.73, *SD*=11.86), ICAR range 1 to 16 (M=8.18, SD=3.48), AQ range 37 to 54 (M=49.48, SD=3.77). The high-AQ group comprised 112 males and 82 females, age range 20 to 69 (M=35.55, SD=10.48), ICAR range 1 to 16 (M=9.53, SD=3.32), and AQ range 79 to 107 (M=85.24, SD=5.38). (Full demographic information including relations between variables is in the Supplementary Materials, Tables S6-S9). Sample sizes were chosen to achieve more than 80% power to detect a "medium"-sized effect (*d* = 0.5) in simple between-group comparisons (Faul et al., 2009). Participants were recruited via Amazon's Mechanical Turk (Buhrmester, Kwang, & Gosling, 2011).

Design and procedure. Participants completed the AQ-short; those in the top and bottom deciles were invited back to complete the choice task and ICAR (task order randomized). Version 1 of the study used the same stimuli as the ASC experiment; Version 2 used different products, adapted from Noguchi & Stewart (2014). The stimuli are included in the Supplementary Materials (Tables S1 and S2).

Results

Context effects among people with ASC

Responses to each product pair were placed into one of four categories. *Consistent choices* are those in which the decision-maker chose the same item on both presentations of a particular product pair. *Attraction-effect preference-reversals* are cases where the person's selection switched when the decoy changed (the person chose option A when the decoy targeted A and chose B when it targeted B). *Non-attraction preference-reversals* were preference reversals where the person chose the non-target options on both presentations (e.g., A chosen when B is the target and B chosen when A is the target). *Decoy selections* were cases where the person chose the decoy on one or both presentations of a given product pair.

As can be seen in Figure 2, the ASC group made more consistent choices than controls, $t(203.9) = 5.15$, $p < .001$, $d = 0.60$, CI = [0.34, 0.85], and showed fewer preference reversals (attraction effect reversals: $t(206.4) = 2.27$, $p = .024$, $d = 0.26$, CI = 0.01, 0.51]; non-attraction reversals $t(194.6) = 2.12$, $p = .035$, $d = 0.25$, CI = [0.00, 0.50]). They also made fewer decoy selections, $t(294.9) = 5.46$, $p < .001$, $d = 0.53$, CI = [0.28, 0.78]. We had a surprisingly high proportion of females in our ASC sample, but the choices of male and female ASC participants differed very little (Supplementary Materials Table S10), indicating that the gender composition does not affect the representativeness of the results for the ASC population.

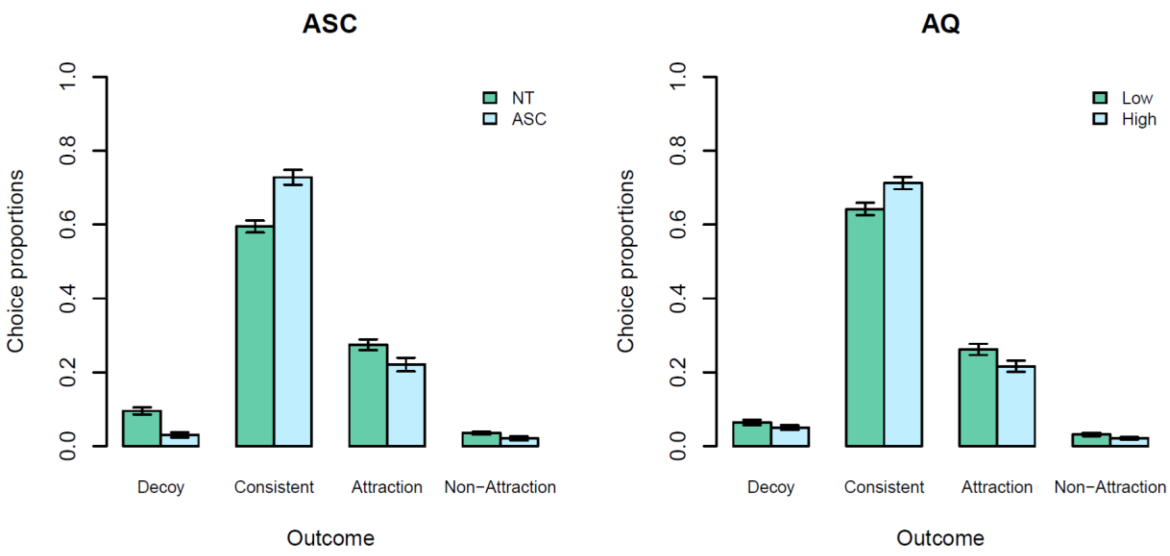

Figure 2. *Choice proportions for the four possible outcomes, with standard errors. The left panel compares the ASC group with neurotypical (NT) adults. The right panel shows the data from people scoring low or high on the Autism-Spectrum Quotient. We analysed the data with a series of mixed effects logistic regression analyses that controlled for demographic variables and tested three contrasts: consistent choices vs preference reversals; decoy selections versus non-decoy choices; and attraction-effect vs non-attraction preference reversals. The ASC group made more consistent choices than controls, demonstrating a more conventionally-rational decision style. A weaker version of the same effect is present in the AQ study.*

Our primary analysis tested these effects more rigorously with a series of mixed-effects logistic regressions that examined the effects of ASC on choice, controlling for age, gender, and cognitive ability (conducted using lme4 for R; Bates, Mächler, Bolker, & Walker, 2015). The fixed-effects predictors were participant-group (control = 0, ASC = 1), ICAR score, gender (female = 0, male = 1), and age. In all analyses, the predictors were standardized prior to each regression and we included random intercepts for participant and product-pair, and by-product random slopes for the effects of group, age, gender, and ICAR score, thereby allowing the effects of these variables to differ across product-pairs; random effects were uncorrelated (Barr, Levy, Scheepers, & Tily, 2013; dropping the random slopes did not impair model adequacy and led to virtually-identical results). All CIs are 95% Wald confidence intervals.

Our first regression contrasted consistent choices (coded 1) with preference reversals (coded 0). The ASC group made more consistent choices than controls, $B_{z.ASC}$ = 0.200 CI = [0.059, 0.341], p = .005, demonstrating reduced context-sensitivity and a more rational decision-making style. There was little effect of age, gender, or cognitive ability ($B_{z.age}$ = 0.093, [-0.046, 0.231], p = .190, $B_{z.gender}$ = 0.078, [-0.062, 0.217], p = .274, $B_{z.ICAR}$ = 0.096, [-0.062, 0.253], p = .233).

We also contrasted decoy-selections (coded 1) against all other choice types (coded 0). Decoy selections are rare and represent a form of noisy-responding/inattention (the decoy is manifestly worse than the target option). This kind of error was negatively related to general cognitive functioning, $B_{z.ICAR}$ = -0.679, CI = [-0.944, -0.414], p <.001, and was less prevalent among ASC participants than controls, $B_{z.ASC}$ = -0.371, CI = [-0.640, -0.102], p =.007, consistent with the higher attention-check failure rate in the control group. Decoy selections did not depend on age or gender ($B_{z.age}$ = 0.007, CI = [-0.234, 0.248], p = .954, $B_{z.gender}$ = 0.036, CI = [-0.214, 0.283], p = .784).

Finally, we contrasted attraction-effect and non-attraction preference reversals. Non-attraction effect choices were again very rare and, like decoy choices, likely reflect noisy responding; they were more common among people with lower cognitive ability, $B_{z.ICAR}$ = 0.689, CI = [0.357, 1.021], p <.001, but did not differ between the ASC and control groups, $B_{z.ASC}$ = -0.037, CI = [-0.381, 0.307], p = .834, and were unrelated to age and gender ($B_{z.age}$ = 0.014, CI = [-0.295, 0.324], p = .929; $B_{z.gender}$ = -0.229, CI = -0.528, 0.069, p = .132).

Autistic traits in the general population

The choice proportions for low-AQ and high-AQ participants are plotted in the right panel of Figure 2 and show an attenuated version of the pattern found in the main study: High-AQ participants made more consistent choices than did low-AQ participants, t(366.6) = 3.00, p=.003, d =0.31, CI = [0.11, 0.52], and showed fewer attraction-effect preference reversals, t(366.9) = 2.16, p = .031, d = 0.22, CI = [0.02, 0.43], although both groups exhibit a clear context effect. The high-AQ group also made slightly fewer decoy selections and non-attraction preference reversals [t(355.3) = 1.40, p = .163, d = 0.15, CI = [-0.06, 0.35], and t(328.8) = 1.80, p = .072, d = 0.19, CI = [-0.02, 0.40], respectively].

When applying the regression analyses to this study, we included Version and its interactions with all other fixed-effects variables to examine the consistency of the findings across participant samples/stimulus sets. As for other variables, Version was standardized prior to each regression, and the interaction terms were computed by multiplying the standardized predictors. (No random effects involving Version or its interactions were computed, because all participants and all product-pairs only arise for one version.) None of the effects were modulated by Version, and excluding Version and its interactions made no difference to the results. (Full regression coefficients for these terms are shown in Figure S7 of the Supplementary Materials.)

High-AQ participants were more likely to make consistent choices than low-AQ individuals, $B_{z.AQ}$ = 0.159, CI = [0.011, 0.307], p = .035. In addition, consistent choice was positively related to age, $B_{z.age}$ = 0.171, [0.037, 0.305], p = .013, and more common among males, $B_{z.gender}$ = 0.243, CI = [0.110, 0.377], p = <.001; it was also weakly related to cognitive ability ($B_{z.ICAR}$ =0.148, CI = [-0.006, 0.302], p=

.060). The tendency to choose the decoy did not differ between the low-AQ and high-AQ groups, $B_{z.AQ}$ = -0.033, CI = [-0.241, 0.176], p = .758, but, as in the main study, it was negatively related to general cognitive functioning, $B_{z.icar}$ = -0.424, 95% CI = [-0.623,-0.224], p = <.001; it was also slightly lower in males, $B_{z.gender}$ = -0.201, CI = [-0.398, -0.005], p = .044, but was independent of age ($B_{z.age}$ = -0.075, CI =[-0.287, 0.138], p = .490). Finally, non-attraction effect choices were again very rare and more prevalent among people of low cognitive ability, $B_{z.ICAR}$ = 0.538, CI = [0.205, 0.870], p = .002; there was no effect of AQ, $B_{z.AQ}$ = 0.013, [-0.271, 0.297], p = .928 or of gender or age ($B_{z.gender}$ = -0.220, CI = [-0.508, 0.068], p = .134; $B_{z.age}$ = -0.121, CI = [-0.429, 0.186], p = .439).

The demographics questions asked participants whether they had ever been diagnosed with an autism spectrum condition (response options: "yes", "no", "prefer not to say"). Seven out of 194 (3.6\%) participants in the high-AQ group answered "yes", versus 0 out of 176 in the low-AQ group. Excluding these participants made little difference to the estimated coefficients but the confidence intervals increased: for the test of consistent choices vs preference reversals, $B_{z.AQ}$ = 0.155, CI = [0.006, 0.304], p = .041. A further 13 high-AQ and 2 low-AQ participants selected "prefer not to say"; after also excluding these, $B_{z.AQ}$ = 0.123, CI = [-0.026, 0.272], p = .107.

Thus, independently of the effects of age, gender, and general cognitive performance, people scoring high on the AQ made more consistent choices than those with low AQ scores. The effect is weaker than in our main study, may reflect the presence of people with ASC in the high-AQ sample, and could be driven by different mechanisms (Gregory & Plaisted-Grant, 2016), but it provides converging evidence for an association between autistic traits and a reduction in context-sensitivity during choice.

Additional analyses

We probed three possible contributors to the enhanced rationality of the ASC group's choices: a drive for greater internal consistency; a reduction in noisy responding; and a slower, more deliberative decision style. Full results for these additional analyses, including regression coefficients for demographic control variables, are provided in the Supplementary Materials Figures S2-S6 and S10-S14.

First choices

One possible reason for a reduction in context-induced preference reversals is that people remember their own past choices and strive to be consistent. If the ASC group had better memory, or a stronger drive for consistency, then changing the position of the decoy between successive presentations of a product pair would have less effect on their choices, as we found, but this would only apply to within-subject preference reversals: the memory/consistency mechanism would reduce the ASC participants' tendency to switch preference when the context changes, but they would be just as susceptible as controls to the effects of the decoy when they first encounter a given pair of products. However, analysing the first occurrence of each product category revealed the same pattern as our main analysis: decoy selection was less common among ASC participants than among controls, $B_{z.ASC}$ = -0.410, CI = [-0.742, -0.078], *p* = .016, and, more importantly, people with ASC were less likely than controls to choose the target item rather than the competitor, $B_{z.ASC}$ = -0.131, CI = [-0.228, -0.034], *p* = .008.

The ASC group were therefore less influenced by the decoy even when they had never seen the competing options before, indicating a reduced influence of local context rather than an effect driven by memory or need-for-consistency. Notably, applying the same analysis to the data from our AQ study revealed no effect of AQ-group on the tendency to choose the decoy, $B_{z.AQ}$ = -0.056, CI = [-0.328, 0.217], *p* = .689, or on the tendency to choose the target rather than the competitor, $B_{z.AQ}$ = 0.001, CI = [-0.103, 0.105], *p* = .980. Thus, consistent with our primary analysis, the difference in context-sensitivity between people with ASC and controls was more pronounced than the difference between members of the general population with low- and high-AQ scores: we only found an effect of AQ-group on the tendency to make within-subject preference reversals, whereas ASC corresponded both to fewer preference reversals and to a reduced tendency to select the target when a given stimulus pair was encountered for the first time.

Noisy responding

Next, we tested whether the enhanced consistency of the ASC group was driven by a reduction in random responding rather than an altered sensitivity to contextual stimuli (Pettibone, 2012). This analysis and the next were not part of our pre-registered analysis strategy but seemed like useful explorations.

We computed the number of decoy selections across the 20 test trials for each participant as an index of noisy responding (Pettibone, 2012), and re-ran the regression analysis that contrasted consistent with inconsistent choices with this noisy-responding measure included as a predictor. The results were virtually identical to the original analyses: the ASC individuals made more consistent choices (fewer preference reversals) than did controls, $B_{z.ASC}$ = 0.188, CI = [0.047, 0.329], *p* = .010, and the high-AQ group made more consistent choices than did the low-AQ group, $B_{z.AQ}$ = 0.157, CI = [0.010, 0.304], *p* = .037. The index of noisy-responding only weakly predicted the tendency to make consistent choices rather than preference reversals (ASC study: $B_{z.pdecoy}$ = -0.130, CI = [-0.277, 0.017], *p* = .082; AQ study: $B_{z.pdecoy}$ = -0.124, CI = [-0.263, 0.014], *p* = .078).

The reduced attraction effect among the ASC group is therefore unlikely to be due to a change in random or inattentive choice.

Response times

Finally, we examined whether the greater consistency of the ASC group is due to slower, more deliberative decision-making. We computed each participant's mean response time (RT) across the 20 test trials and log-transformed these means to normalize the data and reduce the influence of extreme values. We examined the relationship between this measure and participant group with linear regression (including the same additional predictors as our main analyses) and then assessed the association between response times and choice behaviour by re-running our primary analysis with the response-time variable added as a predictor.

Participants with ASC had longer response latencies than controls, (Geometric means: ASC = 24.3 s, CI = [21.9, 27.1]; controls = 17.8 s, CI = [16.3, 19.5]; $B_{z.ASC}$ = 0.088, [0.014, 0.163], p = .020). However, the effects of ASC on choice behaviour were not altered by including response time as a predictor: ASC participants remained more likely to make consistent choices, $B_{z.ASC}$ = 0.189, CI = [0.048, 0.331], p = .009, and were less likely than controls to make decoy selections, $B_{z.ASC}$ = -0.249, CI = [-0.495, -0.001], p = .049. In addition, although participants with shorter response times were more likely to make decoy selections and non-attraction preference reversals ($B_{z.logmt}$ = -0.604, CI = [-0.811, -0.396], p <.001, $B_{z.logmt}$ = 0.513, CI = [0.172, 0.853], p = .003, respectively), there was no meaningful association between response latency and the tendency to make consistent choices rather than preference reversals, $B_{z.logmt}$ = 0.079, CI = -0.059, 0.216], p = .263.

Similar results emerged in the AQ study. The response latencies of the low-AQ and high-AQ groups were very similar to one another (Geometric means: low-AQ = 17.7 s, CI = [16.2, 19.3]; high-AQ = 16.8 s, CI = [15.7, 18.0]; $B_{z.AQ}$ = -0.031, CI = [-0.085, 0.024], p = .269), and although participants with shorter response times were more likely to make decoy selections, $B_{z.logmt}$ = -0.303, CI = [-0.521, -0.083], p= .007, there was no association between response latency and the tendency to make consistent choices $B_{z.logmt}$ = -0.001, CI = [-0.137, 0.135], p = .990, and controlling for response latency made very little difference to the effect of AQ-group on choice consistency, $B_{z.AQ}$ = 0.161, CI = [0.013, 0.309], p = .033.

In short, participants who rushed their decisions were more likely to make random responses, but there is no indication that the reduced context-sensitivity of people with high-AQ or ASC is a consequence of them taking longer over their choices. This increased decision time is consistent with research showing that people with ASC are reluctant to make a decision at all, rather than taking a more deliberative strategy (Luke et al., 2012).

Discussion

People with autism spectrum conditions made fewer context-induced preference reversals, leading to more conventionally rational decisions. Our results accord with evidence of reduced loss-gain framing effects when people with ASC make choices between gambles (De Martino et al., 2008) and extend the extensive demonstrations of reduced sensitivity to global context in perceptual and cognitive tasks to a new domain: ASC participants were more likely to represent the value of each attribute or option in isolation rather than being influenced by the other items in the choice set. This kind of reduced context-sensitivity has traditionally been labelled "weak central coherence", a diminished ability to integrate local information into a global "gestalt" (Frith, 1989). However, the original conception of weak central coherence does not capture enhanced choice-consistency in a "high-level" decision task such as ours, where there is no "global percept". Rather, our data support more recent suggestions that autism is characterized by a wide-ranging enhancement of, or preference for, local information processing (e.g., Happé & Frith, 1989, Plaisted et al., 2003).

Why were people with ASC and autistic traits less susceptible to context effects in our choice task? There are many putative mechanisms for context-induced preference reversals (see Howes et al., 2016, for a recent review). Two are of particular relevance to ASC. The first posits that choices are based on how readily they can be justified, "even when there is no overt need to justify to others" (Simonson, 1989, p. 159; see also Pettibone & Wedell, 2000). The target is better than the decoy on both dimensions (whereas the competitor is only superior on one), providing a reason for choosing the target option and increasing its choice share (Simonson, 1989). Consistent with this, the target is rated as more justifiable than the competitor (Pettibone & Wedell, 2000), and the attraction effect increases when people believe that they will have to justify their decisions to others (Simonson, 1989). The reduced context effect in people with ASC might therefore be a further manifestation of their reduced understanding of, or concern for, the likely beliefs and appraisals of others (Baron-Cohen, 2002). However, this framework lacks formalization, does not capture a full spectrum of context effects, and struggles to account for data from non-human species (e.g., Lea & Ryan, 2015).

A more precise and general mechanism for a wide range of context effects is offered by the *multiattribute linear ballistic accumulator* model (Trueblood et al., 2014), which posits a linear rise-to-threshold of units whose drift rates reflect the value of the corresponding option relative to the other items in the set. Difficult discriminations attract more attention, so the similarity of the target and decoy means that the target benefits from its favourable comparison with the decoy more than the competitor does, producing the attraction effect. Correspondingly, an increase in the discriminability of the target and distractor will reduce the preferential attention to the decoy-target comparison and weaken the effect. People with ASC have been found to show enhanced discrimination on a range of perceptual tasks , leading to the proposal that autism is characterized by an enhanced sensitivity to differences and a reduced processing of common features (Plaisted et al., 2003). There is debate about the generality of enhanced discrimination across tasks and domains (Happé, 2006), and about the neural mechanisms involved (Davis & Plaisted-Grant, 2015), but a greater separation of attribute values in representational space among people with ASC provides an explanation for our findings that links a wide-ranging model of context effects to a diverse body of empirical and theoretical work from studies of autism.

Recent work with neurotypical adults has also considered the functional basis for the attraction effect. While conventional accounts of rational choice dictate choice consistency, emerging Bayesian frameworks construe preference reversals as an adaptive response to uncertainty about the value of an option. One account casts the attraction effect as a rational inference about the trade-off between attribute dimensions in the marketplace (Shenoy & Yu, 2013). A more general model proposes that a decision-maker's estimate of the utilities of alternatives can be improved by using prior estimates based on the ordinal relations between the attributes (Howes et al., 2016). The mathematical specification of this model is complex, but the core principle is that decision-making is improved when noisy computations of expected-value are supplemented by considering the ordering of attribute values: options whose attributes have higher rank-positions on the relevant dimensions usually have higher expected value, and the attraction-effect decoy increases the rank position of the target (but not the competitor) on its "worst" dimension, so it is rational to infer that the target is the better option.

These ideas link to developments in theorizing about autism. In particular, Pellicano and Burr (2012) have recently proposed that autism is characterized by unusually flat priors (hypopriors), such that perception is driven by current sensory input that is little influenced by background expectations. Within the Bayesian framework for context effects on choice, such hypopriors would entail less reliance on the ordinal relations between option attributes and, correspondingly, a reduced tendency to make context-induced preference reversals –- as we observed. Thus, autistic traits may avoid the potentially biasing effect of context by sacrificing useful information about the likely state of the world, given past experience.

Our results suggest several avenues for future research. Straightforward steps include examining whether the more conventionally-rational responses of ASC participants extend to other types of context effect such as the compromise effect (Simonson, 1989) and gambler's fallacy (Kahneman & Tversky, 1972), exploring the effects of moderating variables such as time-pressure

(Pettibone, 2012), and using process-tracing techniques such as eye-tracking to uncover how autistic traits shape the processes by which options are sampled and compared (Stewart, Hermens, & Matthews, 2016). More broadly, most studies of decision-making in neuropsychiatric conditions such as ASC have focused on how people learn, represent and evaluate probabilities and rewards (e.g., Damiano, Aloi, Treadway, Bodfish, & Dichter, 2012). The present results show that choice behaviour may be atypical even when people simply select the best alternative from explicitly-stated, risk-free outcomes. Studying the context-sensitivity of such choices has the potential to reveal new insights into the decision-making strategies of individuals with a range of neuropsychological conditions.

Beyond these theoretical and empirical directions, the present findings have practical implications for the socioeconomic functioning of people with ASC. The attraction effect influences elections (Pan, O'Curry, & Pitts, 1995), legal judgments (Kelman, Rottenstreich, & Tversky, 1996), and policy decisions (Herne, 1997). The ability of decoys to shape consumer behaviour has been observed in field studies (Doyle et al.,, 1999) and real-world marketing campaigns (Ariely, 2009). Our data suggest that people with autistic traits are still influenced by such decoys, but the effect is smaller than for the general population, offering some protection against the biases that can result from context-induced preference. However, the price they pay for this resistance to contextual influence may be a reduction in the potentially adaptive updating of beliefs about optimum choice that comes from using local comparisons to inform decision-making.

Acknowledgements

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Supplementary Materials

Table S1. Product categories and attribute values used in the ASC study and in Version 1 of the AQ study. D_A is the decoy that renders option A the target; D_B is the decoy that targets option B.

Product	Attributes	A	B	D_A	D_B
Cell phone	Number of apps	16	32	12	28
	Repair rate (%)	3	5	3.5	5.5
USB drive	Capacity (GB)	16	32	12	28
	Lifespan (months)	36	20	32	16
Paper towels	Strength (0-10)	4	8	3	7
	Absorbency (millilitres)	52	28	46	22
Orange juice	Vitamin C (mg)	34	82	22	70
	Calories (Kcal)	33	69	42	78
Apartment	Size (Square feet)	759	1203	648	1092
	Crime rate (per month)	10	15	11	16
Printer	Cost (cents per page)	7.05	3.61	7.91	4.47
	Speed (pages per minute)	16.7	5.9	13.3	1.5
Headphones	Sound quality (0-100)	68	92	62	86
	Lifespan (months)	24	12	20	10
Highlighter pen	Brightness (0-1)	0.4	0.8	0.3	0.7
	Volume (millilitres)	180	100	160	80
Walking shoes	Durability (months)	8	32	2	26
	Comfort (0-100)	88	64	82	58
Part-time job	Wages ($ per hour)	6.60	8.20	6.20	7.80
	Commuting time (minutes)	20	60	30	70

Table S2. Product categories and attribute values used in Version 2 of the AQ study. A_d is the decoy that renders option A the target; B_d is the decoy that targets option B.

Product	Attributes	A	B	D_A	D_B
Car	Safety (0-5)	4	5	3.8	4.8
	Efficiency (mpg)	49.65	31.05	44.25	25.65
Six-pack beer	Price ($)	6.79	3.19	7.22	3.62
	Quality (0-5)	4.10	2.50	3.80	2.20
Cell phone battery	Price ($)	27.50	19.00	30.00	21.50
	Talk time (hours)	14	11	13	10
Restaurant	Atmosphere (0-100)	76	96	72	92
	Food (0-100)	95	74	90	69
Digital camera	Screen Size (inches)	1.2	3	1	2.8
	Zoom (magnification)	10.1x	4.1x	9x	3.0x
Light bulb	Lifetime (hours)	1000	2000	980	1980
	Price ($)	1.20	2.40	1.50	2.70
Mouthwash	Fresh Breath (hours)	6	12	5	11
	Volume (fluid ounces)	25	16	23	14
Television	Screen size (inches)	40	65	38	63
	Picture quality (0-100)	6.23	4.63	5.5	3.9
Internet provider	Average Speed (Kb per second)	386	646	290	550
	Download limit (GB)	292	150	270	128
Language course	Number of Lessons	10	18	8	16
	Price ($)	30	50	35	55

Table S3. Comparison of the Control and ASC samples

Comparison	ASC	Control	Test Statistic	*p*
N	90	212	-	-
Males / Females *	37 / 52	89 / 123	χ^2 = 0.004	.950
Residence: UK / US *	70 / 18	169 / 43	χ^2 = 0.001	.975
Mean Age (SD)	43.11 (13.73)	43.88 (13.55)	*t* = -0.445	.657
Mean ICAR (SD)	10.83 (3.98)	7.25 (3.66)	*t* = 7.328	< .001
Mean AQ (SD)	92.50 (10.57)	65.20 (10.04)	*t* = 20.840	< .001

*One person in the ASC group preferred not to state their gender. Two people in the ASC group did not indicate their country of residence. The chi-square tests exclude these participants.

Table S4. Correlations between demographic variables for the ASC group. Asterisks indicate a significant correlation, *p*<.05.

	Age	ICAR	AQ
Age			
ICAR	-.03		
AQ	.00	.01	
Gender	.39*	.04	.02

Table S5. Correlations between demographic variables for the Control group. Asterisks indicate a significant correlation, *p*<.05.

	Age	ICAR	AQ
Age			
ICAR	-.03		
AQ	.05	.22*	
Gender	.39*	.04	.11

Table S6. Means for ICAR, age, and AQ in the high and low AQ groups for the two versions of the AQ study.

		Mean (SD)		
	Males/ Females	Age	AQ	ICAR
Version 1				
Low AQ	44/37	35.42 (11.43)	48.59 (3.97)	7.98 (3.39)
High AQ	58/36	37.01 (11.79)	86.02 (5.53)	9.46 (3.33)
Version 2				
Low AQ	41/53	35.99 (12.27)	50.23 (3.43)	8.36 (3.57)
High AQ	54/46	34.17 (8.92)	84.51 (5.16)	9.59 (3.33)
Combined				
Low AQ	85/90	35.73 (11.86)	49.48 (3.77)	8.18 (3.48)
High AQ	112/82	35.55 (10.48)	85.24 (5.38)	9.53 (3.32)

Table S7. Comparison of the high and low AQ samples (collapsed across study version)

Comparison	High	Low	Test Statistic	*p*
n	194	176	-	-
Males / Females *	112/82	85 /90	$\chi^2 = 2.745$	.100
Mean Age (SD)	35.55 (10.48)	35.73 (11.86)	$t = -0.155$	.877
Mean ICAR (SD)	9.53 (3.32)	8.18 (3.48)	$t = 3.790$	< .001
Mean AQ (SD)	85.24 (5.38)	49.48 (3.77)	$t = 74.572$	< .001

*One person in the low AQ group preferred not to state their gender. The chi-square test excludes this participant.

Table S8. Correlations between demographic variables for the low-AQ group. Asterisks indicate a significant correlation, $p<.05$.

	Age	ICAR	AQ
Age			
ICAR	.06		
AQ	.06	-.08	
Gender	-.16*	.04	.02

Table S9. Correlations between demographic variables for the high-AQ group. Asterisks indicate a significant correlation, $p<.05$.

	Age	ICAR	AQ
Age			
ICAR	.08		
AQ	-.02	.15*	
Gender	-.22*	.07	-.08

Table S10. Response proportions by gender for the ASC participants. The columns show the mean proportion of choices of each type and the results of a between-subject Welch-corrected t-test that compares the two genders. The 95% CIs for all estimated effect sizes span zero.

	M_{males} (SD)	$M_{females}$ (SD)	*t*(df)	*p*	d [95% CI]
Decoy-selection	.022 (.048)	.037 (.079)	1.10 (85.06)	.273	-0.22 [-0.65, 0.21]
Consistent	.757 (.176)	.706 (.202)	1.27 (83.52)	.209	0.27 [-0.16, 0.70]
Attraction	.192 (.161)	.242 (.182)	1.38 (92.95)	.171	-0.29 [-0.72, 0.14]
Non-attraction	.030 (.062)	.015 (.041)	1.23 (58.55)	.224	0.28 [-0.15, 0.71]

Figure S1. ASC study: Primary regression analysis

The panels show the regression coefficients for the mixed-effects logistic regression analyses described in the main text. Here and for all other plots of regression coefficients, the error bars show 95% Wald confidence intervals and black data points indicate significant effects (*p* <.05, two-tailed). The panels show the coefficients for three contrasts: decoy-selection vs any other outcome, consistent choice vs preference reversal, and attraction-effect preference reversal vs non-attraction preference reversal. (BIC values: 1531.7, 3390.0, 637.9, respectively.)

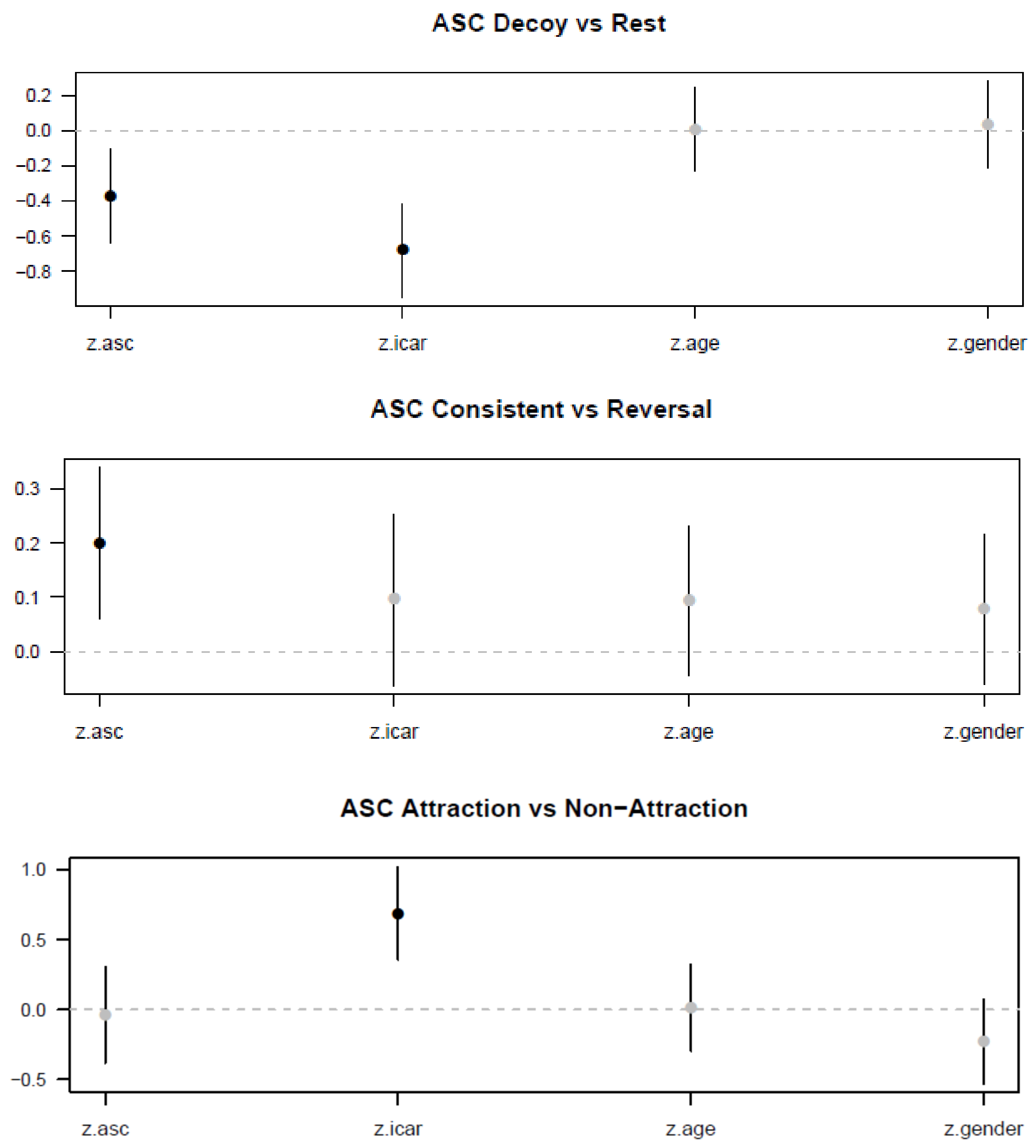

Figure S2. ASC study: First choice proportions

The plot shows the proportions of times participants in the ASC and neurotypical (NT) control group chose the target, competitor, and decoy options on the first presentation of each product pair.

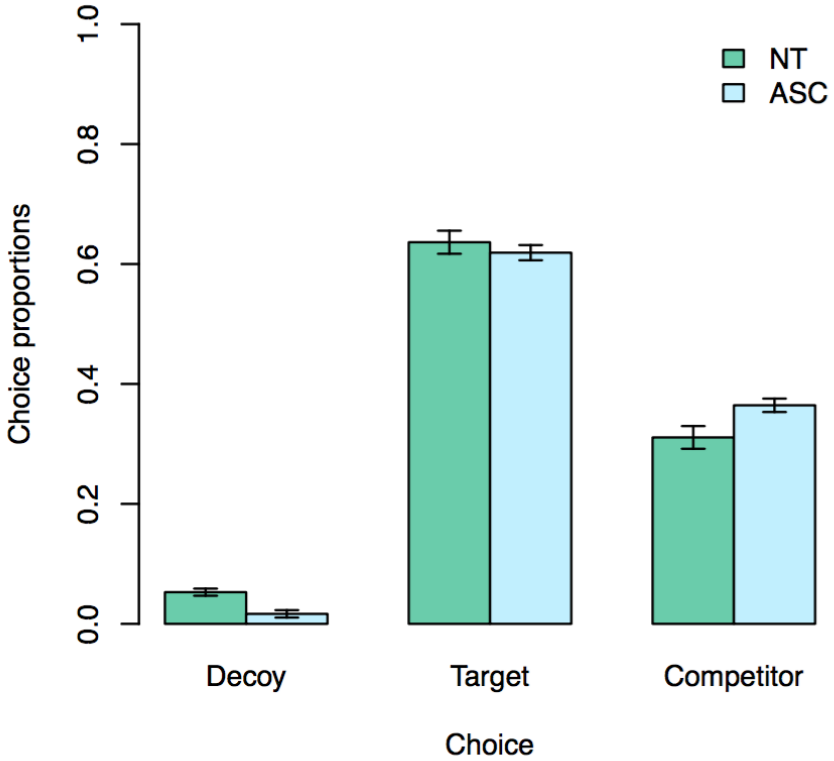

Figure S3. ASC study: Regression analysis of first choices

The panels show the results of analysing participants' responses on the first occurrence of each product pair. The top panel shows the coefficients from contrasting the tendency to choose the decoy (coded 1) with the tendency to choose one of the other options (target or competitor, both coded 1); the bottom panel plots the coefficients obtained when contrasting target choices (coded 1) against competitor choices (coded 0). (BIC values 1059.2 and 3774.6, respectively).

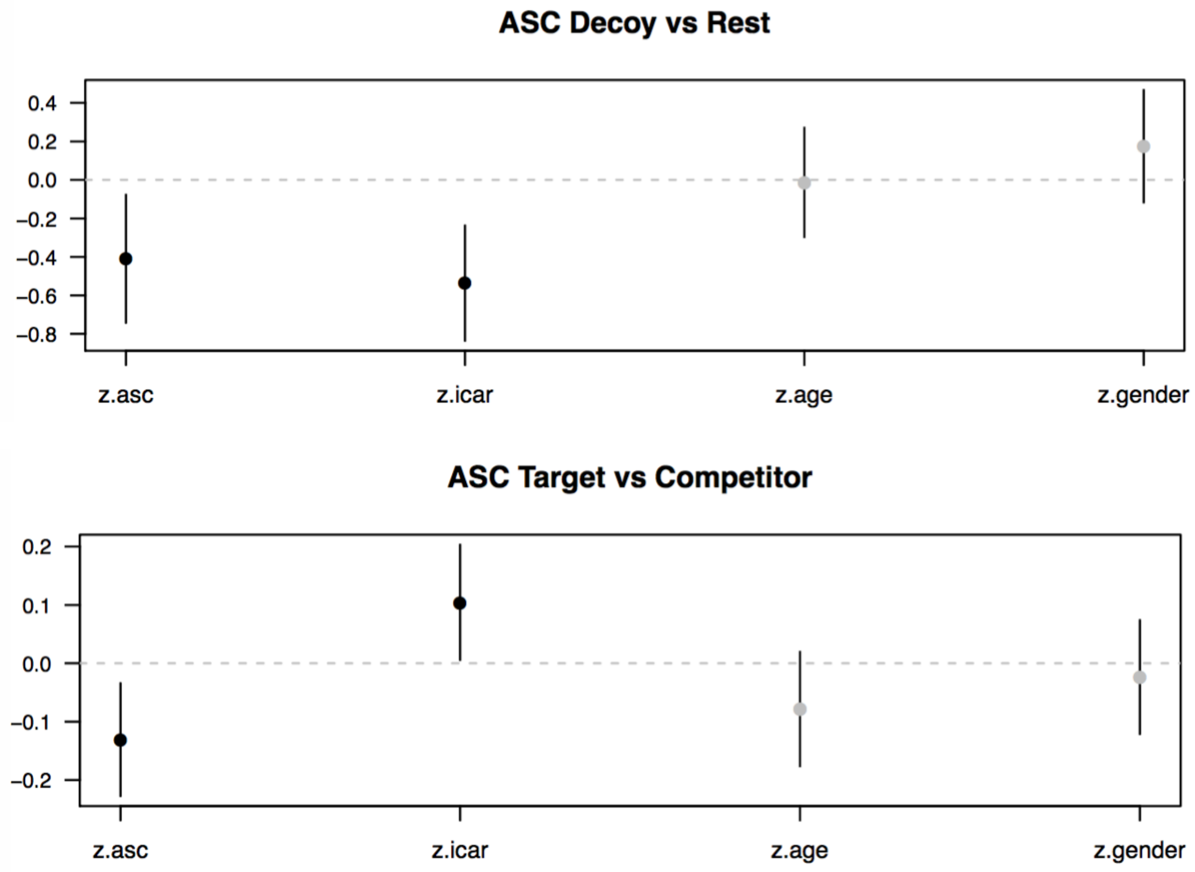

Figure S4. ASC study: Controlling for random responding

The panels show the results of re-running the primary analysis controlling for random responding, indexed by the participant's proportion of decoy selections across the 20 test trials (pdecoy). Note that it would not make sense to include pdecoy in the Decoy vs Non-decoy contrast, so only the Consistent Choice vs Preference Reversal and Attraction-Effect Preference Reversal vs Non-attraction Preference Reversal contrasts are analysed; BIC values: 3402.9 and 644.4, respectively.

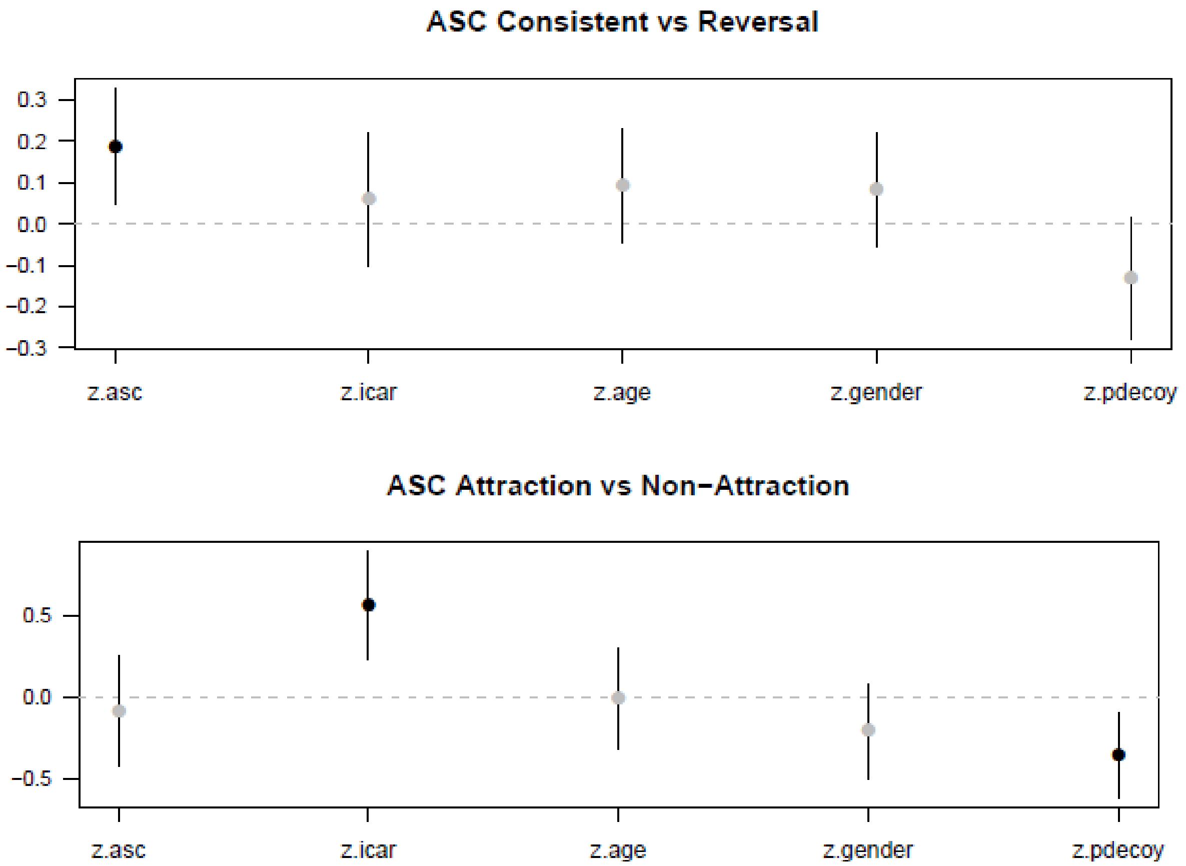

Figure S5. ASC study: Comparing decision times

As described in the main text, for our analysis of decision-times we tested whether the ASC and Control groups differed in the mean response time by running a linear regression. The plot shows the regression coefficients for this analysis (adjusted R-sq =.089).

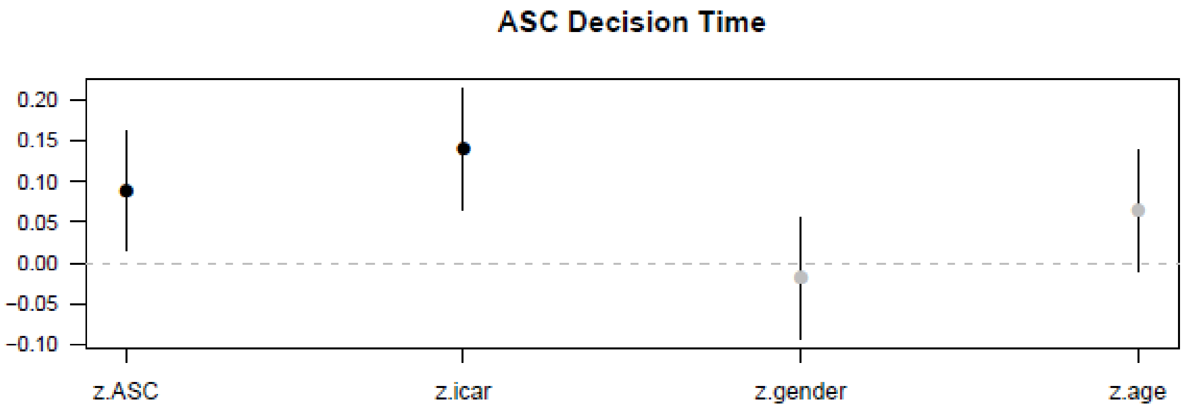

Figure S6. ASC study: Controlling for decision times

The panels show the results of re-running the primary analysis with each person's log-transformed mean response-time (logmt) as an additional predictor. (BIC values 1516.3, 3404.7, and 641.1 for top, middle, and bottom analyses, respectively.)

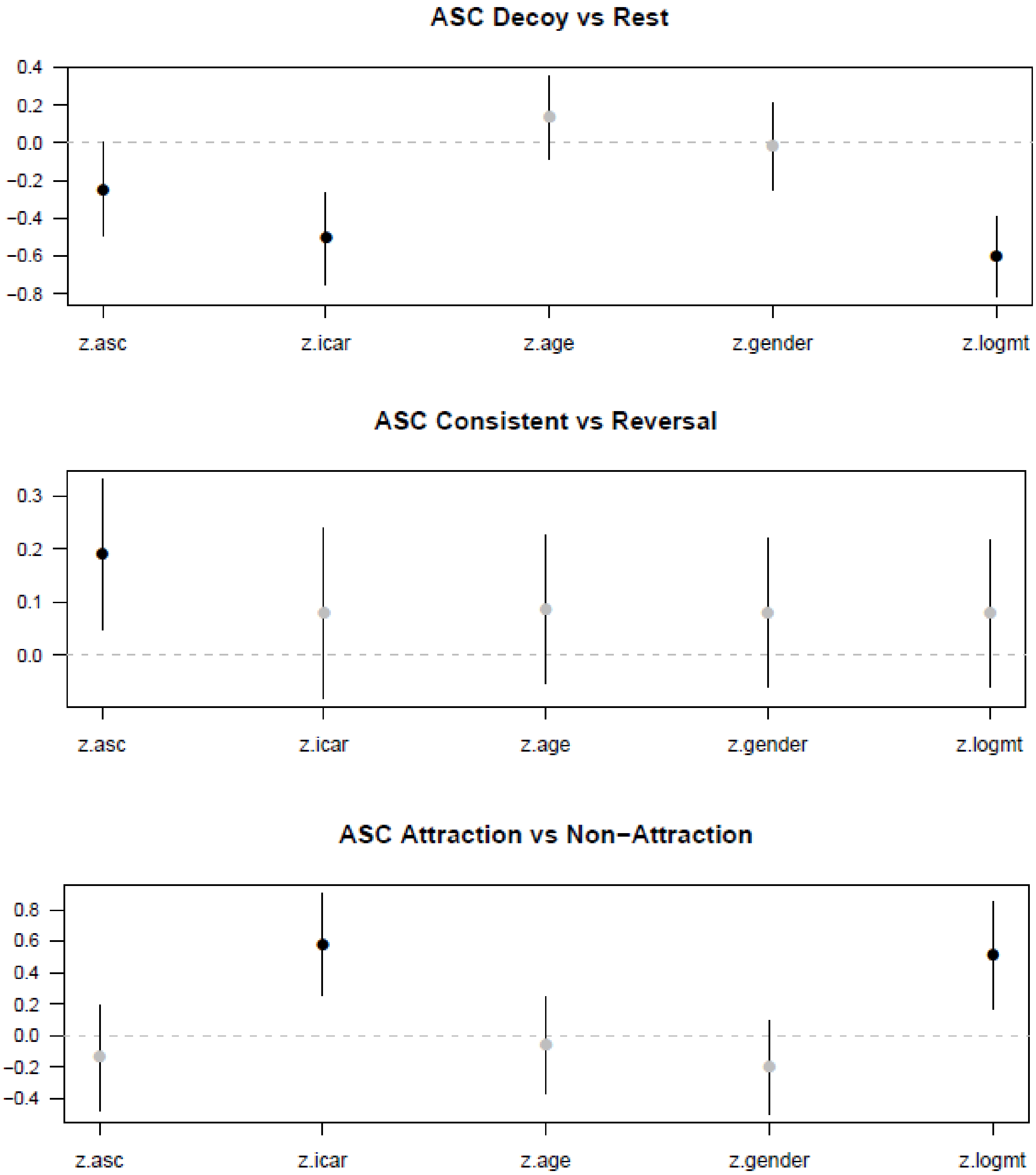

Figure S7. AQ study: Primary regression analysis

The panels show the regression coefficients for the three contrasts described in the main text. As reported in the Methods section, the analyses included the Version variable (Version 1 coded 0; Version 2 coded 1) and the interaction between Version and all other variables to examine the consistency of the findings across participant samples / stimulus sets. As for other variables, Version was standardized prior to each regression, and the interaction terms were computed by multiplying the standardized predictors (e.g., the coefficient labelled aq.int is z.aq*z.version). (BIC values for the top, middle, and bottom analyses are: 1655.2, 3959.4, and 703.7, respectively).

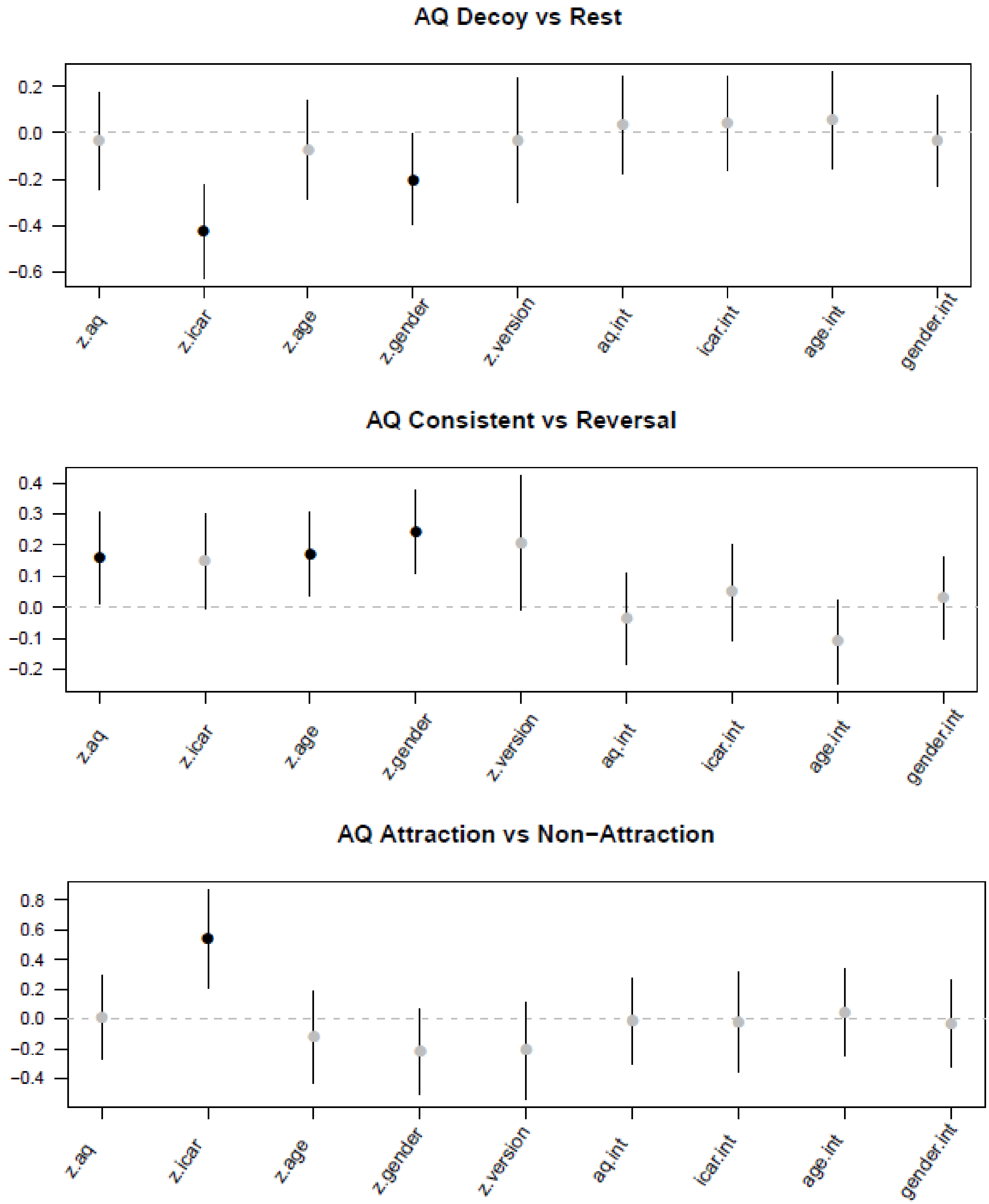

Figure S8. AQ study Version 1: Primary regression analysis

The panels show the regression coefficients for the three contrasts described in the main text, limited to the data from the first version of the study. (BIC values for the top, middle, and bottom analyses are: 815.8, 1974.5, and 349.8, respectively).

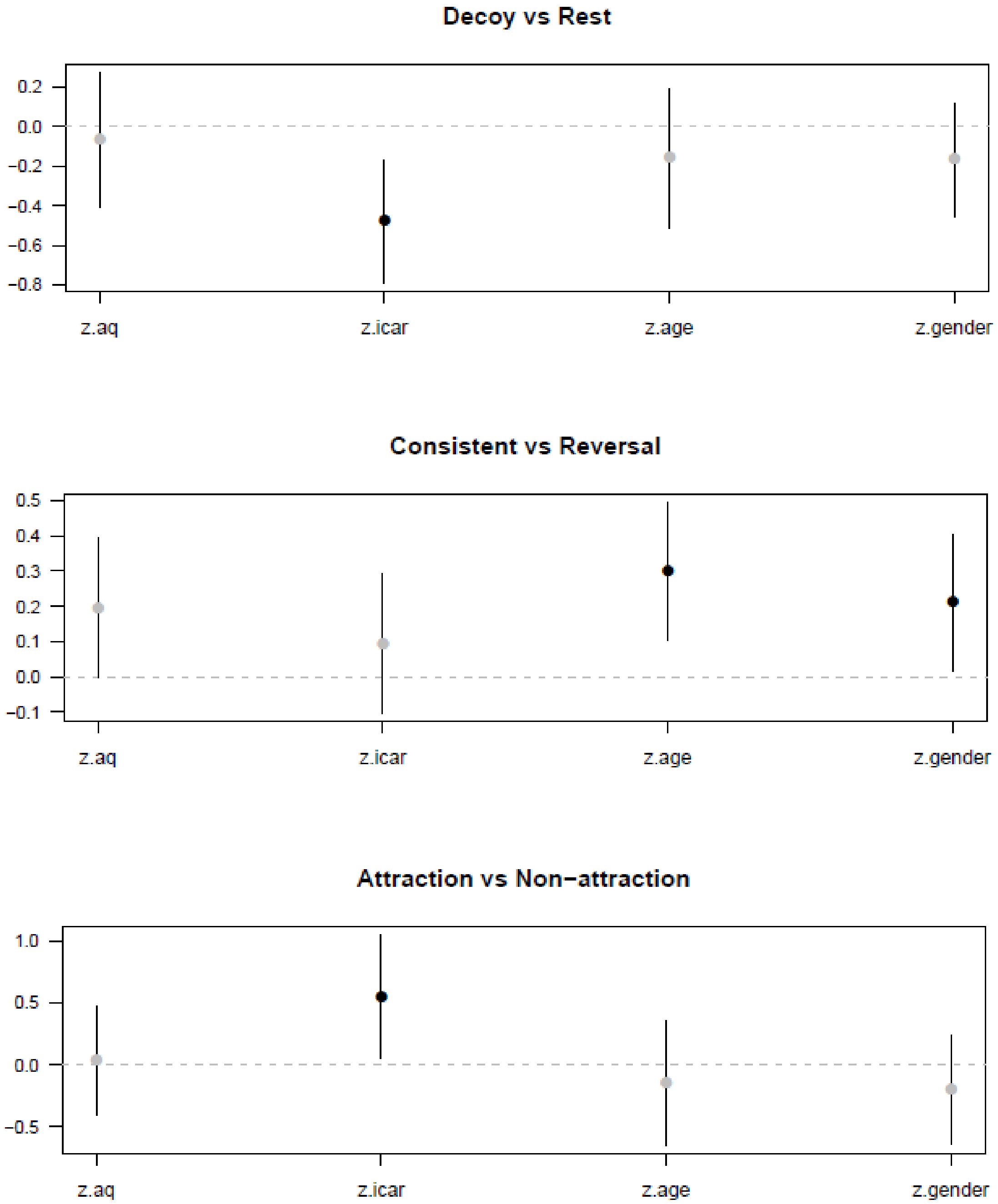

Figure S9. AQ study Version 2: Primary regression analysis

The panels show the regression coefficients for the three contrasts described in the main text, limited to the data from the second version of the study. (BIC values for the top, middle, and bottom analyses are: 871.2, 2012.3, 379.4, respectively).

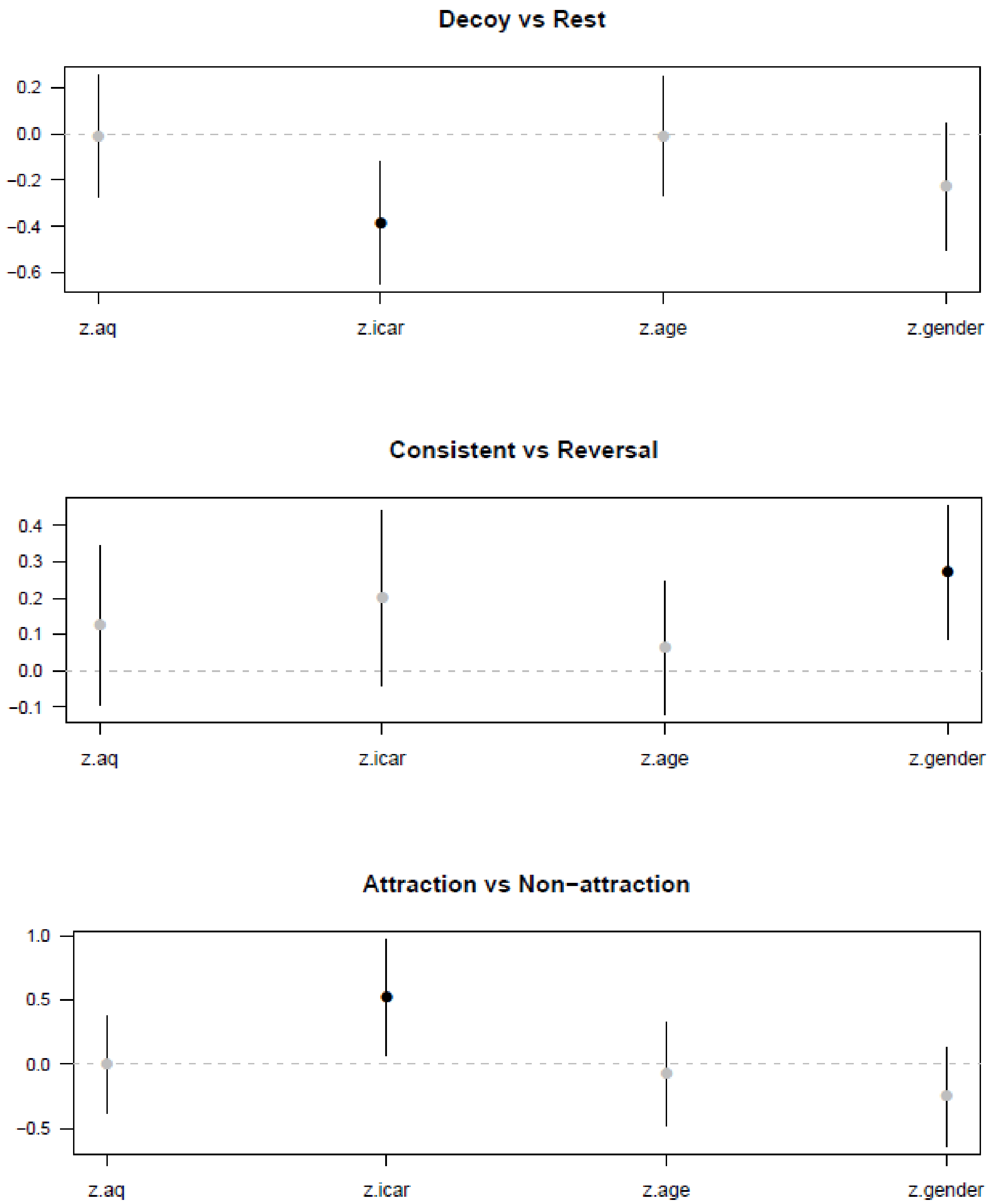

Figure S10. AQ study: First choice proportions

The plot shows the proportions of times participants in the low- and high-AQ groups chose the target, competitor, and decoy options on the first presentation of each product pair.

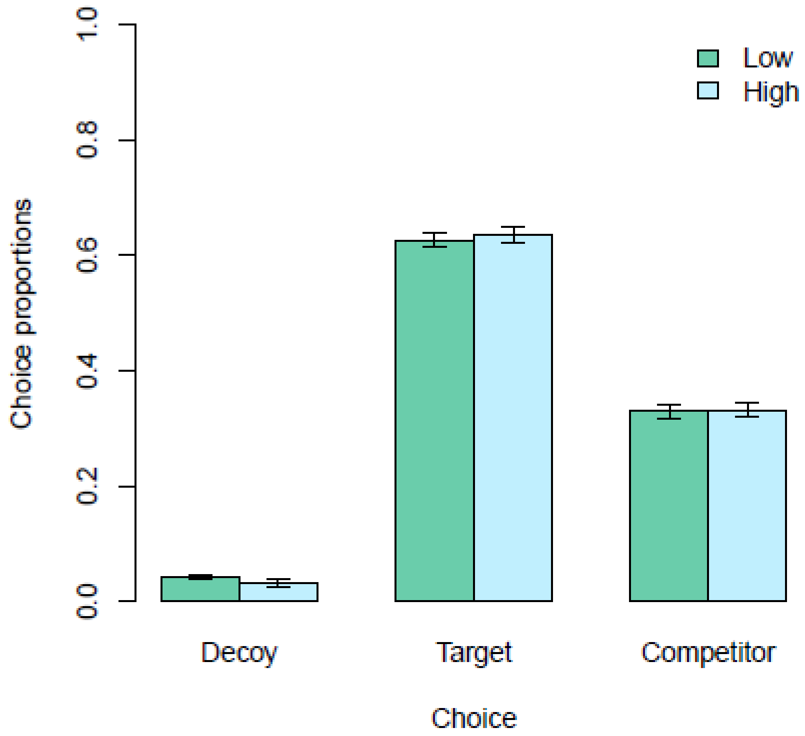

Figure S11. AQ study: Regression analysis of first choices

The panels show the results of analysing participants' responses on the first occurrence of each product pair. The top panel shows the coefficients from contrasting the tendency to choose the decoy (coded 1) with the tendency to choose one of the other options (target or competitor, both coded 1); the bottom panel plots the coefficients obtained when contrasting target choices (coded 1) against competitor choices (coded 0). (BIC values 1257.2 and 4651.2, respectively).

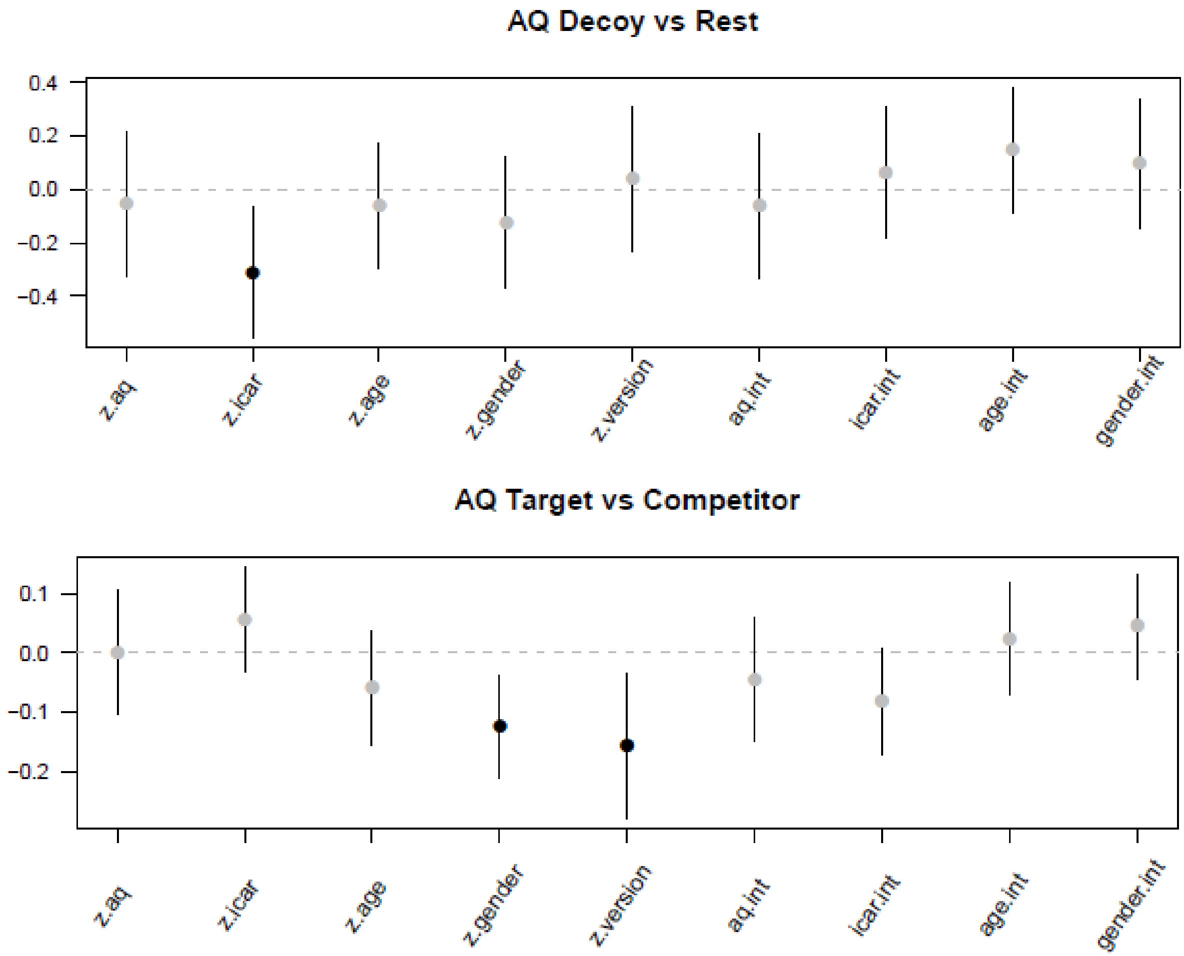

Figure S12. AQ study: Controlling for random responding

The panels show the results of re-running the primary analysis controlling for random responding, indexed by the participant's proportion of decoy selections across the 20 test trials (pdecoy). Note that it would not make sense to include pdecoy in the Decoy vs Non-decoy contrast, so only the Consistent Choice vs Preference Reversal and Attraction-Effect Preference Reversal vs Non-attraction Preference Reversal contrasts are analysed; BIC values: 3980.2 and 703.7, respectively.

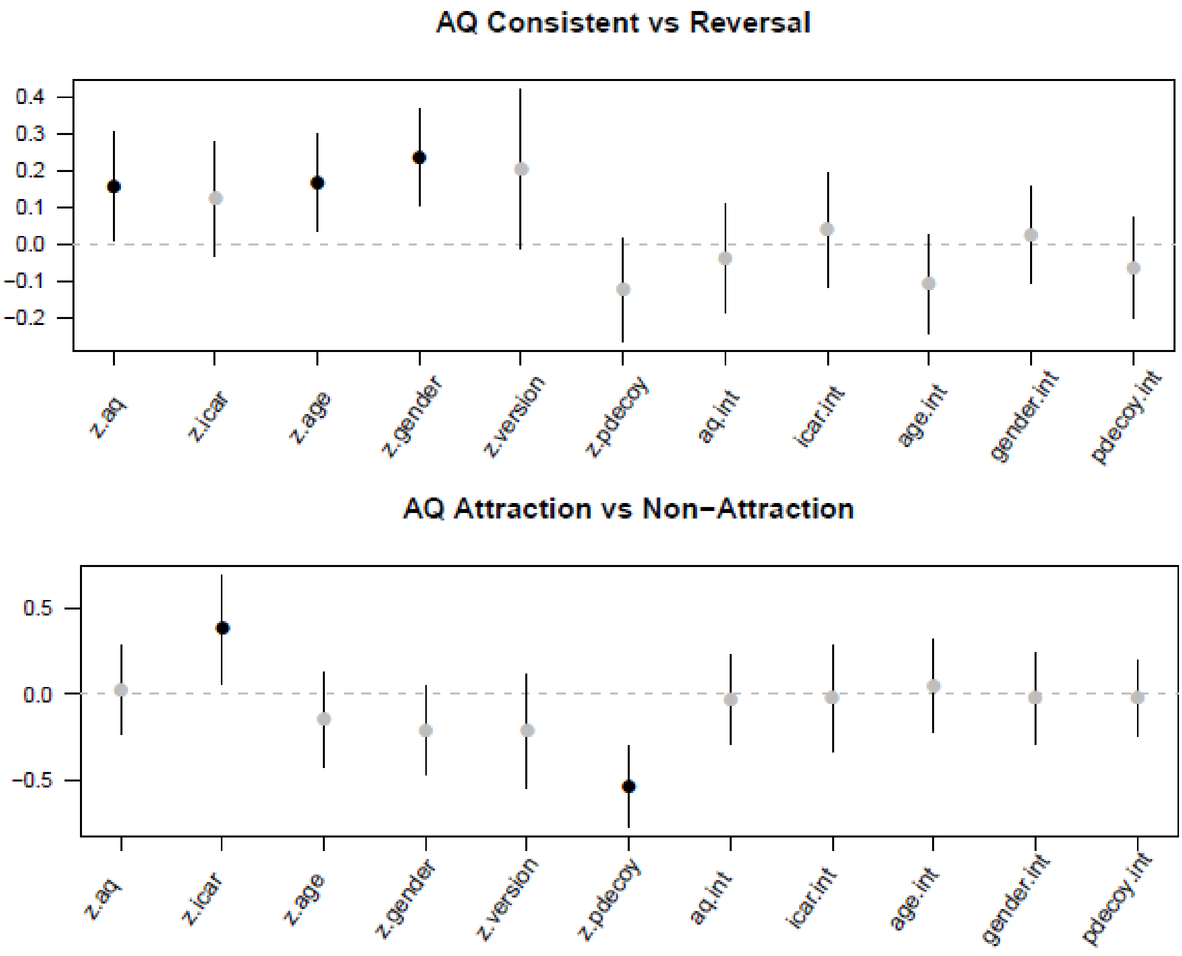

Figure S13. AQ study: Comparing decision times

As described in the main text, for our analysis of decision-times we tested whether the low-AQ and high-AQ groups differed in the mean response time by running a linear regression. The plot shows the regression coefficients for this analysis (adjusted R-sq = .088).

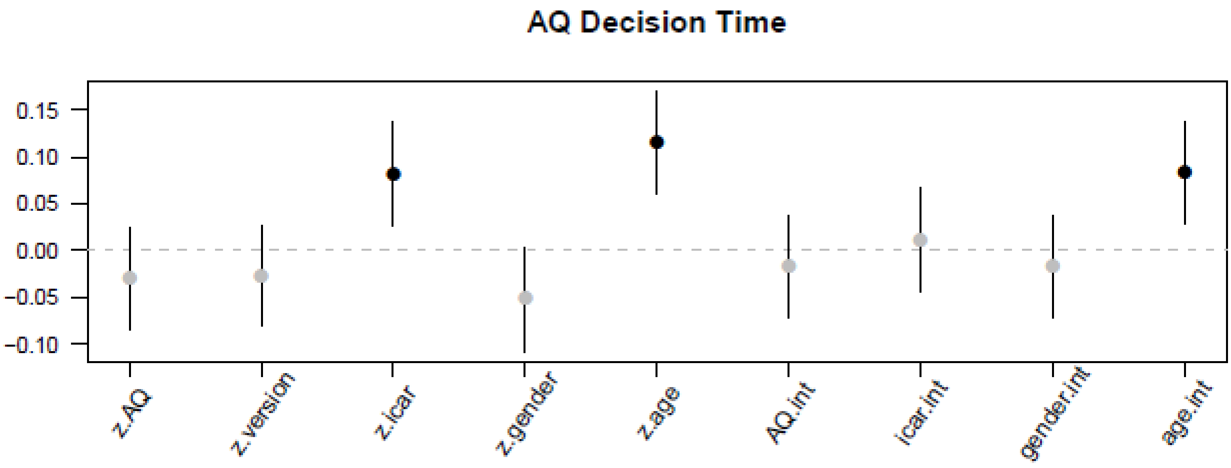

Figure S14. AQ study: Controlling for decision times

The panels show the results of re-running the primary analysis with each person's log-transformed mean response-time (logmt) as an additional predictor. (BIC values 1670.8, 3983.2, and 717.2 for top, middle, and bottom analyses, respectively.)