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Title

Social decision making in autistic adolescents: the role of theory of mind, executive functioning and emotion regulation

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Social decisions in autistic adolescents

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Abstract

Social decision making is often challenging for autistic individuals. Twenty autistic adolescents made decisions in the socially interactive context of a one-shot ultimatum game, and performance was compared to a large matched typical reference sample. Theory of mind, executive functioning and emotion regulation were measured via direct assessments, self- and parent report. Relative to the reference sample, autistic adolescents proposed fewer fair offers, and this was associated with poorer theory of mind. Autistic adolescents responded similarly to the reference sample when making decisions about offers proposed to them, however they did not appear to down regulate their negative emotion in response to unfair treatment in the same way. Atypical processes may underpin even apparently typical decisions made by autistic adolescents.

Autism spectrum disorder; ASD; social decision making; emotion regulation; executive functioning; theory of mind;

Introduction

Reciprocal social interaction and social communication difficulties are core characteristics of autism spectrum disorder (hereafter "autism") (American Psychiatric Association [APA], 2013). At least half of autistic people[2] have an IQ of 70 points or above (Loomes, Hull & Mandy, 2017). Despite their normal-range IQ, these individuals often struggle to function in the manner expected by society (Farley et al., 2009; Klin et al., 2006; VanBergeijk, Klin, & Volkmar, 2008), experiencing poor long term outcomes (Howlin, 2000; Howlin, Goode, Hutton, & Rutter, 2004), low rates of employment (Buescher, Cidav, Knapp, & Mandell, 2014; Knapp, Romeo, & Beecham, 2009) and poor quality of life (van Heijst & Guerts, 2015). More research is needed to understand the mechanisms behind the key social challenges of autism, which may in turn facilitate the development of better support strategies (Pellicano, Dinsmore, & Charman, 2014).

The decisions we make in social contexts, which affect ourselves and others – social decisions – are a critically important aspect of appropriate social functioning (Tomasello & Vaish, 2013). Social decision making is often difficult, anxiety provoking and exhausting for autistic individuals (Ahlstrom & Wentz, 2014; Hull et al., 2017).

[2] In accordance with the wishes of many members of the autism community, we use identity first (i.e., 'autsitic person') rather than person first ('i.e., person with autism') language (Kenny, Hattersley, Molins, Buckley, Povey & Pellicano, 2016)

Most systematic studies on social decision making in autistic people have reported some preserved aspects alongside subtle differences in reasoning and emotional experiences when compared to typical controls. For example, autistic individuals appear to be less able to explain the reasoning behind their decisions, rely more on the outcome of an event for their decisions, make less use of contextual factors such as a social partner's intentions, and report less sympathy and emotional reaction to situations described in vignettes (Buon et al., 2012; Channon, Fitzpatrick, Drury, Taylor, & Lagnado, 2010; Channon, Lagnado, Fitzpatrick, Drury, & Taylor, 2011; de Martino et al., 2008; Gleichgerrcht et al., 2013; Moran et al., 2011; Morsanyi et al., 2010; Shulman, Guberman, Shiling, & Bauminger, 2011; Zalla & Leboyer, 2011). Importantly, these findings do not explain the clinical challenges linked to social decision making in autistic individuals in a way that is adequate to inform the development of effective support strategies.

In developing research into social decision making by autistic individuals that has the potential to inform such support strategies, it is important to consider the role of factors that are malleable to change. In line with this objective, theory of mind, executive functioning and emotion regulation are intrinsically important in social decision making (Corradi-Dell'Acqua, Koban, Leiberg & Vuilleumier, 2016; Funahashi, 2017; Tremblay, Sharika & Platt, 2017), and appear malleable to change via psychological interventions. Indeed, there is growing interest in the development of educational/training programmes that aim to influence these factors in specific ways (e.g. Berking & Lukas, 2015; de Veld et al., 2017; Kabach & Unger, 2014; Robb, Waller & Woodcock, 2015).

Both theory of mind and executive function have been repeatedly, if not consistently, demonstrated to be impaired in autistic people (Adams, 2013; Craig, Margari, Legrottaglie, Palumbi, de Giambattista & Margari, 2016). Emotion regulation has been relatively poorly examined in autism (Mazefsky, Pelphrey & Dahl, 2012), but there is evidence of impairment (e.g. Zantinge, van Rijn, Stockmann & Swaab, 2017). Thus, it is plausible that difficulties in theory of mind, executive functioning and emotion regulation may contribute to the challenges in social decision making faced by autistic people. However, the extent and nature of such contributions is currently unclear from the extant literature.

Most studies on social decision making in autistic people have used vignettes about moral dilemmas and social trespasses. However, the ecological validity of such hypothetical scenarios is severely limited as they do not attempt to emulate the dynamic, interactive nature of real-world social decisions. Strong reliance on vignette methodology may therefore have contributed to the lack of prior research capable of informing on support strategies for social decision making.

Economic games can begin to circumvent this ecological validity problem by allowing for dynamic social interactions (Kishida, King-Casas & Montague, 2010). In this way, such games provide an important tool for increasing understanding of everyday social decision making by autistic individuals. Overall, as further elucidated below, application of economic games has illustrated a pattern of preserved aspects of social decision making in autistic individuals, along

with subtle differences. Importantly, this research has begun to highlight important roles of theory of mind, executive functioning and emotion regulation processes in social decision making, although these roles remain poorly described.

In economic games in which participants can decide to cooperate with a social partner to differing degrees, decisions about cooperation appear to be broadly similar in autistic and non-autistic individuals (Chiu et al., 2008; Downs & Smith, 2004; Edmiston et al., 2015; Yoshida, Dziobek, Kliemann, Heekeren, Friston & Dolan, 2010; Sally & Hill, 2006; Schmitz, Banerjee, Pouw, Stockmann & Rieffe, 2015). And autistic individuals are capable of making decisions that rely on high order theory of mind (Pantelis & Kennedy, 2017). However, autistic individuals evidence altered neural activity linked to their decisions in economic games, in brain networks involved in theory of mind and related social cognitive processes (Chiu et al., 2008; Edmiston, Merkle & Corbett, 2015). Thus, theory of mind is clearly relevant for autistic individuals' clinical picture of social decisions. However, atypical theory of mind may alter the way decisions are made rather than the decisions themselves.

In the general population social decisions to cooperate in an economic game appear to draw on limited capacity cognitive resources, which are taxed by tests of executive function (Halali, Bereby-Meyer & Ockenfels, 2013). Thus – although to the best of our knowledge, the role of executive functioning has not been directly examined in this context in autistic individuals – there is a clear mechanism by which impairments in executive functioning linked to autism can contribute to this type of social decision making.

Finally, an important role of emotion regulation in social decision making by autistic individuals has been is implicated. Differences in functioning in neural networks linked to social cognition shown by autistic individuals during cooperative decisions in a laboratory based economic game, have been associated with higher levels of salivary cortisol during playground interactions (Edmiston et al., 2015). This suggests that even when making the same social decisions as non-autistic people, autistic individuals may experience increased emotional arousal whilst making such decisions.

The present study

Here we aim to examine the impact of theory of mind, executive function and emotion regulation on social decision making in autistic individuals. Since our focus is driven by regulatory skills likely to affect social decision making that are malleable to change via intervention, we also focus specifically on the adolescent period. Adolescence is typically associated with rapid development of the kinds of regulatory skills under examination here (Blakemore, 2012; Casey, Jones & Hare, 2008). Furthermore, mental illness commonly onsets during this period (Merikangas et al., 2010). Thus, adolescence may be a particularly useful period in which to intervene. We expect that greater impairments in theory of mind, executive function and emotion regulation will be associated with a more atypical profile of social decisions made by autistic individuals. However limited prior research on the subject prevents us from making more specific hypotheses.

Methods

Methodological approach

Due to the stated advantages for ecological validity of examining social decision making, we employ an economic game. Most prior studies using economic games with autistic individuals have focused on the role of a single factor, usually theory of mind. The ultimatum game on the other hand, is well suited to examine the roles of multiple factors. However, to our knowledge, the game has only been used in one study with an autistic population (Sally & Hill, 2006), and one further study with a population of children with behaviour disorder, in which autism symptoms were also measured (Schoorl, van Rijn, de Wied, Goozen & Swaab, 2016). Neither of these studies systematically evaluated the effects on social decision making of the three factors of interest here.

In the ultimatum game, a *proposer* is allocated a stake (e.g. tokens or money) and must decide on a proportion to offer to their social partner (the *responder*). The responder must then decide whether to accept or reject the proposer's offer. If the offer is accepted, both players keep the proposed proportion. If the offer is rejected however, neither player receives anything. In this scenario, economic theory states that the "rational" response – which leads to the highest individual economic gain assuming both players make such rational decisions – is to propose the lowest possible offer above zero, and accept any offer above zero. However, in general people do not act rationally in this game. Players typically offer 35-50% of the stake, and the majority of respondents reject offers of less than 33% of the stake, even though this is against their immediate material interests (Güth et al., 1982; Camerer & Thaler, 1995).

Importantly, the two player roles in the ultimatum game allow different types of social decisions to be examined. Proposers must make a decision prior to receiving feedback on a social partner's behaviour. Decisions in similar contexts have been examined using other economic games in autistic individuals (see above), and the role of social cognitive processes, such as theory of mind, has been emphasised. Responder decisions on the other hand, are made after information about a social partners' behaviour is available. In responder decisions therefore, the role of other cognitive processes, such as executive functioning and emotion regulation, may be emphasised. Specifically, typical players experience negative emotion on receipt of unfair offers (Pillutla & Murnighan, 1996; Sanfey, Rilling, Aronson, Nystrom, & Cohen, 2003) and appear to actively reduce this negative emotion before accepting unfair offers (Harlé & Sanfey, 2007; van't Wout, Chang, & Sanfey, 2010). Complex versions of the ultimatum game involving repeated interactions with the same social partner are available (e.g. Sally & Hill, 2006). However, the focus of the present study was on the roles of specific cognitive /emotional processes, which have been poorly examined in previous research. Therefore, a paradigm involving a single interaction with each social partner was favoured, in order to minimise the potentially confounding influence of repeated social interaction.

Participants

We recruited twenty autistic adolescents (16 males, 4 females, M_{age} = 13.3 years, range = 11 to 17 years; M_{IQ} = 107.7, $STDEV_{IQ}$=18.1, range = 73 to 141) via a database of consenting prior research participants in the London area. All were attending the appropriate year group for

their chronological age, at a mainstream school. Inclusion criteria comprised a clinical diagnosis of pervasive developmental disorder according to DSM-IV criteria, a non-verbal IQ score of at least 70 (as measured with the Wechsler Abbreviated Intelligence scales as a part of previous research; Wechsler, 1999), English as a first language, and a chronological age between 11 and 18 years. Individuals with a substantial delay in language development were excluded. For comparison to the autistic adolescents on key measures, we tested a reference group of 194 adolescents aged between 10 and 18 years, of whom 80 matched participants (64 males, 16 females, M_{age} = 13.3 years, range = 10 to 17 years, no IQ information available) were selected for inclusion (see analyses).

The reference sample was recruited from three secondary schools in the north of Ireland (convenience sample of schools based on those responding to information letters). Most TD participants were white Caucasian and the schools fell around or below the Northern Irish average free school meal entitlement, suggesting a bias away from low socioeconomic status (McCauley, 2017), which was similar to the bias expected in the autism sample, linked to the fact that individuals volunteered to advertisements to participate in research (Rowley & Camacho, 2015).

Measures

***The ultimatum game* (UG)**

A modified version of the classic paradigm (Güth et al., 1982) ensured suitability for autistic adolescents. It was administered via computer; using visual stimuli and pre-recorded verbal

instructions constructed using PsychoPy 1.82.01 (Pierce, 2009) (*supplementary materials*). Briefly, participants were led to believe that they were playing the game with a different social partner on each trial. Participants first acted as *proposers,* making fair (50%) or unfair (20%) decisions about how to divide £1 (4 trials) and £100 (4 trials) between themselves and a future player. Participants then acted as *responders,* making decisions about whether to accept or reject fair or unfair offers made by a previous player of 10 pence, £1, £10 or £100 stakes.

The fixed proportions for fair and unfair offers were selected in line with previous work examining the role of emotion regulation in ultimatum game performance (Wang et al., 2011). Varying stake sizes were designed to alter the incentive for accepting offers across trials because higher material benefit of unfair offers has been shown to more strongly encourage participants to down-regulate the negative emotion precipitated by an unfair offer (Tabibnia, Satpute & Lieberman, 2008). It was therefore anticipated that varying stake sizes would allow the paradigm to more sensitively index the role of altered emotion regulation processes in performance. Twenty four unfair offers were presented (6 of each stake size), and 12 fair offers (3 of each stake size).

Importantly, following each decision as *responder,* participants were asked to **rate the level of negative emotion they were experiencing** on a Likert-type scale of 1 (completely calm and relaxed) to 5 (very annoyed). The emotion rating scale was adapted from the arousal rating dimension of the self-assessment manikin, which has been very widely used in emotion research (Bradley & Lang, 1994). Adaptations were designed to ensure that rating points were

easy to relate to by the autistic adolescents, and coincided with words used in previous research linking ultimatum game unfair offers to emotional experience (van't Wout et al., 2010). Since difficulties in distinguishing different emotions are commonly reported in autistic populations (Milosavljevic et al., 2016), only negative emotion (specifically anger) was considered, in line with the previous evidence linking ultimatum game unfair offers to the experience of anger, which underpins the game's purported links to emotion regulation (Pillutla et al., 1996; van't Wout et al., 2010).

Trials were presented in the same pseudorandom order to all participants but features that did not influence the trial type (e.g. name of proposer) varied randomly on a trial by trial basis. Outcome variables comprised the mean proportion of fair offers proposed (as *proposer*); the mean proportion of fair, and of unfair offers accepted (as *responder*); and the mean feeling ratings to fair and unfair offers; and to fair and unfair offers that were accepted or rejected (as *responder*). Response times for *responder* decisions were used as a criterion to identify assumed inattentive (erroneous) responses.

The Children's Anger Management Scale (CAMS) and the Children's Sadness Management Scale (CSMS)

The 11-item CAMS and the 11-item CSMS (Zeman, Shipman, & Penza-Clyve, 2001; Zeman, Shipman, & Suveg, 2002) from the Children's Emotional Management Scale (CEMS) were administered to all participants. Using a 3-point Likert scale of 1 (*hardly ever*), 2 (*sometimes*), or 3 (*often*), adolescents responded to items that assess the regulation of anger and sadness

respectively. Items were administered on a computer using pre-recorded verbal instructions and a visual aid to illustrate the response options, constructed using PsychoPy 1.82.01 (*supplementary materials*). Higher total scores on the CAMS and CSMS indicated more adaptive coping with anger and sadness. The CAMS and CSMS have demonstrated acceptable internal consistency (Chronbach's alpha coefficients of .62 to .77) and test–retest reliability (.61 to .80) for the individual scales (Zeman et al., 2001) in European samples.

Behaviour Rating Inventory of Executive Function (BRIEF)

The BRIEF was administered to the parents of autistic adolescents only. The BRIEF is a normed measure of the behavioural indicators of executive functioning in children ages 5 to 18 years. It has good internal consistency, test-retest reliability, convergent and discriminant validity (Gioia, Isquith, Guy, & Kenworthy, 2000), and has been validated in atypical samples (Gioia, Isquith, Retzlaff & Espy, 2002). Eighty-six items are rated on a three point scale. Items correspond to eight empirically derived scales tapping 7 executive functions and emotion control. A composite Behavioural Regulation Index (BRI) comprises inhibition, shifting and emotion control scales; and other scales load onto a Metacognition Index (MI). A Global Executive Composite (GEC) is derived from the sum of the BRI and MI. Raw scores are transformed into age- and gender-normed *t*-scores such that higher scores indicate poorer executive functioning. Scaled scores greater than t = 65 are considered clinically significant.

The Reading the Mind in the Eyes Test-Child Version (EYES-C)

Autistic adolescents completed the EYES-C using a tablet computer. The EYES-C was developed as a performance measure of theory of mind (Baron-Cohen et al., 2001), requiring advanced mental state attribution and facial emotion recognition. The test has face validity as a measure of theory of mind, as it involves attempting to make accurate inferences about mental states (van der Muellen et al., 2017). Evidence of construct validity has been demonstrated, as lower scores on the EYES-C are associated with conditions that are characterised by theory of mind impairments (Baribeau et al., 2015), with theory of mind -related difficulties including poorer social skills (Peterson et al., 2015) and less advanced conversational abilities (De Rosnay et al., 2014). The test consists of 28 items: each item displays a photo of a person's eye and four words that describe feelings or thoughts (e.g. 'jealous / scared / relaxed / hate'), and the participant selects the word that they think best describes the person's state of mind. The outcome variable is total score, with higher scores indicating better theory of mind ability.

Procedure

Participants provided informed consent and parents consented as appropriate, and as specified in protocols, approved by [*withheld for blind review*] (autistic group) and [*withheld for blind review*] (TD group). Since the modified ultimatum game exposed participants to events expected to precipitate the experience of negative emotion, the Children's Emotion Management Scales were administered before the ultimatum game to better correspond to prior use of this previously validated questionnaire. Both assessments were completed individually using a personal computer and headphones. To create the socially interactive context of ultimatum game, participants were informed that they were playing with social

partners who had previously participated in the research, and prizes were provided to incentivize performance. Autistic participants also completed the EYES-C using an ipad, and a parent completed the BRIEF on paper. Autistic participants completed the assessments at home during a visit by a researcher. Typically developing participants completed the assessments at school in the schools' computer laboratory, where several sessions (8-30) were conducted in parallel as required to fit in with schools' demands (see *Supplementary materials* for more details on the procedure).

Analyses

Matching strategy

Inclusion of a large typically developing reference group afforded important advantages to the present design. Although the mean IQ of autistic adolescents was around the general population mean (107.7), IQ is subject to greater measurement challenges in autistic populations relative to typically developing populations because of the autistic profile of relative strengths and weakness in the cognitive capacities that contribute to an IQ assessment (Grondhuis et al., 2018). This measurement challenge makes matching for IQ problematic. Instead, use of a large reference sample allowed the chronological age of the reference group to span the whole of the developmental and chronological age range of the autistic group (e.g. see Cornish, Scerif & Karmiloff-Smith, 2007). Furthermore, since four typical adolescents were included for each autistic adolescent, expected individual variability in the typical IQ profiles of members of the reference group offered some compensation for the potentially idiosyncratic IQ profiles of the autistic adolescents. Finally, since extreme responding (i.e. rejecting all offers), is actually predicted by economic theory, such a pattern of responding should not be

considered erroneous. Our own pilot work with the present paradigm indeed showed that a notable minority of participants adopted such a "rational" approach. The use of a large reference sample provided a better approach to considering such expected, low-frequency, relatively extreme patterns of responding than would an alternative approach of randomly selecting single typical participants to match each autistic participant.

Thus, 80 TD participants were selected from the wider sample (n=194) following exclusion of outliers and to match for chronological and developmental age in line with the above specifications. Resultant demographics were as follows: autistic mean chronological age 13.3 years (*95% CI =* [12.4, 14.2], range 11-18); autistic mean developmental age 14.2 years (*95% CI* = [13.0, 15.4], range 10.5-17.8); typically developing mean chronological age 13.3 years (*95% CI* = [13.0, 13.7], range 10-18). Furthermore, the gender ratio was matched at 80% males in both groups (see *Supplementary materials*).

Statistical analyses

Analyses were conducted using IBM SPSS Statistics. We employed a combination of regression models for ultimatum game performance with offer fairness and group as factors; unpaired t-tests; and Spearman's rank correlation coefficients; to examine differences across autism and TD groups and associations between social decisions and factors of interest. Importantly, data were reviewed to ensure appropriateness of the tests administered, with particular attention to

the uneven sample size of the autistic and reference groups (see *Supplementary materials* for more details).

Results

Group differences in ultimatum game decisions as *proposer*

On average, autistic adolescents proposed a smaller proportion of fair offers than the TD adolescents ($M_{difference}$ = -.159, *SE* = .051, *95% CI* = [-0.26, -0.06]; $t(55.9) = -3.09$, $p = 0.003$, $d = 0.66$: medium to large effect, Sawilowsky, 2009).

[*Table 1* about here]

Group differences in ultimatum game decisions as *responder*

While autistic and TD children responded similarly to fair offers ($M_{difference}$ = .019, *SE* = .021, *95% CI* = [-0.02, 0.06]; $t(98) = 0.903$, $p = 0.37$, $d = 0.25$: small effect); on average, TD participants accepted a proportion of unfair offers that was 8 percentage points higher than autistic participants. However data from autistic and TD groups also showed differently shaped distributions. Specifically, TD data showed a bimodal distribution, with adolescents often accepting almost all or almost no unfair offers. Whereas the autistic data showed a highly positively skewed distribution, with very few individuals accepting almost all unfair offers. Thus, there was insufficient evidence in the data that this difference was statistically significant ($M_{difference}$ = -.079, *SE* = .093, *95% CI* = [-0.26, 0.11]; $t(98) = -0.85$, $p = 0.40$, $d = 0.22$: small effect, further details can be found in the *supplementary materials*).

[*Table 2 about here*]

Group differences in emotional reactions to offers

The regression model examining mean feeling ratings, considering fairness (fair, unfair) and group (autism, TD) factors (*Table 3*), revealed a significant group difference ($F(1,95.0) = 5.08$, $p = .026$) and a significant effect of fairness of offer ($F(1,40) = 82.25$, $p < .001$). The effect size of the fairness of offer ($\gamma_{10} = -1.65$, 95% CI = [-2.02, -1.28]), corresponded to a difference of between one and two points on the five-point emotion rating scale (with fair offers leading to more positive emotions). The effect size of group accounted for less than one point on the scale ($\gamma_{01} = -0.37$, 95% CI = [-0.69, -0.04]; the TD children report less negative emotions towards unfair offers than their autistic peers). Further analysis can be found in the *supplementary materials*.

Effects of group were also revealed when examining feeling ratings with respect to whether an offer was accepted or rejected (see *Table 3*). Despite no significant difference between autism and TD groups in negative feeling ratings to unfair offers rejected ($M_{\text{difference}} = 0.34$, $SE = .267$, *95% CI* = [-0.2, 0.9]; $t(84) = 1.26$, $p = 0.21$, $d = 0.34$: small to medium effect), negative feeling ratings to unfair offers accepted were significantly higher in the autism versus TD groups ($M_{\text{difference}} = 0.58$, $SE = .223$, *95% CI* = [0.1, 1.0]; $t(33.1) = 2.58$, $p = 0.014$, $d = 0.64$: medium to large effect). For the lower negative feeling ratings reported with respect to fair offers, there were no significant group differences between feeling ratings to offers rejected ($M_{\text{difference}} < 0.01$, $SE = .184$, *95% CI* = [-0.4, 0.4]; $t(23) = 0.006$, $p > .99$, $d < 0.01$: very small effect) or accepted

($M_{\text{difference}}$ = -0.02, *SE* = .159, *95% CI* = [-0.3, 0.3]; $t(98) = -0.15$, $p = 0.884$, $d = 0.04$: very small effect).

[*Table 3 about here*]

Factors affecting ultimatum game decisions

Self-reported emotion regulation

Supporting the internal consistency of the CAMS and CSMS in the present samples, total scores on these measures were significantly positively correlated in both ASD (ρ = .591, p = .006) and TD groups (ρ = .471, p < .001). However, questioning concurrent validity, there were no substantial or significant relationships between CAMS/CSMS subscales and parent reported indicators of poor emotional control (autistic group only), as measured by the BRIEF emotion control subscale (-.21 < ρ < .37, p > .107). Furthermore, there were no significant correlations between CAMS/CSMS scores and ultimatum game proposer or responder decisions in either group (see *supplementary materials*). Thus, habitual anger and sadness regulation as reported by participants did not appear to be associated with ultimatum game decisions.

On the other hand, when in the context of the ultimatum game, mean feeling ratings towards unfair offers were significantly negatively correlated with the acceptance rates of unfair offers in the TD group (ρ = -.443, p < .001, 95% CI = [-0.58, -0.28]). Hence, consistent with a role for effective emotion regulation in ultimatum game responder decisions, TD participants who experienced less negative emotion overall during exposure to unfairness, were those who also accepted more of the unfair offers. However, consistent with an altered role for emotion regulation in autism decisions, there was a negligible and non-significant relationship between

mean feeling ratings towards unfair offers and acceptance rates of unfair offers in the autism group (ρ = -.06, p = .665, 95% CI = [-0.44, 0.34]).

Informant reported executive function and emotion regulation

Behavioural indicators of executive dysfunction and of emotion dysregulation were measured using the BRIEF in the autism group only (see *Table 4* for descriptive statistics).

With respect to proposer behaviour, there were no substantial or significant associations between the number of fair offers proposed and Global Executive Composite scores, Behavioural Regulation or Metacognition indices (ρ< .16, p> .49). Furthermore relationships between number of fair offers proposed and BRIEF subscale scores were weak, not in a consistent direction and not significant (-.36 < ρ < .36, p > .12).

With respect to ultimatum game responder behaviour on the other hand, there was a significant and large negative correlation between Global Executive Composite scores and acceptance rates of unfair offers (ρ= -.51, p= .021), which appeared to be driven primarily by the Behavioural Regulation Index (ρ= -.52, p= .019), and more specifically, the emotional control scale (ρ= -.54, p= .013). Poorer parent reported emotional control in autistic individuals was associated with lower acceptance rates of unfair offers (also see *Table 4*).

[*Table 4 about here*]

Theory of mind

Theory of mind was examined in individuals in the autism group only.

With respect to ultimatum game proposer decisions, higher scores on the EYES-C (M = 19.8, SD = 2.94, 95% CI = [19.0, 20.6]), which suggested better theory of mind abilities, were significantly associated with more fair offers being proposed (ρ = .55, p = .013).

With respect to responder behaviour on the other hand,

EYES-C scores were not significantly correlated with the acceptance rates of unfair offers in *responder* trials (ρ = -.10, p = .692).

Discussion

Here we examined the profile of decisions made by autistic adolescents in a standardised socially interactive context, the ultimatum game; and the roles of emotion regulation, theory of mind and executive functioning in such decisions. Autistic adolescents proposed fewer fair offers than their typically developing counterparts, reductions in such fair offers were associated with poorer theory of mind; but not with indicators of executive function or emotion regulation skill. On the other hand, responder behaviour by autistic adolescents converged to suggest an important role of relatively ineffective down regulation of negative emotion during such decision making; whereas theory of mind was less important. Thus, different types of social decisions may be affected in different ways in autistic individuals and should be examined separately.

Decisions about what to propose

Decisions about what to propose in the ultimatum game are made prior to information being available on a social partners' behaviour corresponding to that decision. This situation is similar to that assessed in other economic games (e.g. trust, Prisoner's Dilemma, Dictator) that have been used with autistic individuals. In general, such prior research has noted relative similarity in decisions made across autistic and non-autistic people (Chiu et al., 2008; Downs & Smith 2004; Edmiston et al., 2015; Li, Zhu & Gummerum, 2014; Sally & Hill, 2006; Schmitz et al., 2015; Tayama, Tateno, Park, Ukai, Hashimoto & Saito, 2012); and that autistic individuals *can* make social decisions that depend on a high level of theory of mind skill (also supported Pantelis & Kennedy, 2017). In contrast, the present findings show a clear reduction of fair offers proposed by autistic individuals, which was associated with poorer theory of mind. Importantly however, almost all prior research has involved participants repeatedly interacting with the same social partner, which differs from the presently examined scenario where each social partner was only encountered once. In an extended social interaction, there is greater opportunity to learn how to respond optimally based on prior observations; and motivations to engage socially may change (for a relevant review on social motivation, see Chevallier, Kohls, Troiani, Brodkin & Schultz, 2016). Indeed, this possibility is supported by prior research comparing initial and subsequent decisions during extended social interactions (Sally & Hill, 2006) and another single shot paradigm (Schmitz et al., 2015).

Further research systematically examining social decisions in autistic people as increased opportunity is provided for interaction with the same social partner, and the role of theory of

mind in such social decisions is therefore much needed. The present results highlight the possibility that an initially detrimental impact of impaired theory of mind on social decision making can be overcome during an ongoing social interaction. Greater understanding of such compensatory mechanisms would have important implications for therapeutic strategies.

Decisions about whether to accept

Autistic adolescents did not differ statistically from typical peers in the proportion of offers accepted. Although on average autistic adolescents accepted fewer unfair offers, there was a substantial proportion of typical adolescents who accepted similarly few. Furthermore, autistic adolescents did not differ from typical peers in their emotional experience following rejection of unfair offers. However, they experienced more negative emotion following *acceptance* of unfair offers. Furthermore, whilst typical adolescents who experienced less negative emotion after accepting unfair offers, accepted more of these, this was not the case for autistic adolescents. These findings suggest that autistic adolescents did not down regulate their negative emotional reaction to unfair offers before making their decisions to accept in the same way as typical counterparts. This is consistent with prior research evidencing less adaptive emotion regulation in autistic individuals in the absence of alterations in emotion reactivity (Patel, Day, Jones & Mazefsky, 2017; Samson, Hardan, Lee, Phillips & Gross, 2015; Zantinge et al., 2017). Thus, as a group the autistic adolescents appeared to be tolerating a higher level of negative emotion during social decision making than their typical counterparts. However, autistic individuals who evidenced more everyday behavioural deficits in emotion control

accepted fewer unfair offers – suggesting that when emotion regulation is particularly impaired, it may affect the resultant decisions, as well as the decision making process.

For those autistic individuals making typical decisions, one interesting possibility is that these individuals have learned to make socially appropriate decisions in a different way to their typical counterparts, and do not generally employ the psychologically adaptive mechanisms that would typically prevent distress or anger in the face of such decisions. Indeed, when external emotional cues are added into the social context, autistic individuals appear to make atypical decisions (Ewing, Caulfield, Read & Rhodes, 2015; Klapwijk et al., 2017), evidence consistent with an altered balance of emotion processing (Bhanji & Delgado, 2014). Furthermore, altered patterns of habitual emotion regulation have been associated with decreased mental wellbeing in autistic individuals, for example increased depression (Burns, Irvine & Woodcock, 2019; Patel et al., 2017), suggesting that alterations in emotional regulation may have psychological implications, not necessarily evidenced in social decisions made.

Importantly, there is evidence that autistic individuals *can* effectively engage in adaptive emotion regulation when instructed to do so (Samson, Hardan, Podell, Phillips & Gross, 2015), and even when the neural functional mechanisms are different (Richey et al., 2015). In addition, social learning – in which social decisions are implicit – has been highlighted as a possible root of altered emotion regulation in autism (Mazefsky et al., 2013). Thus, with increased knowledge on the interactions between the developmental profiles of social decision making and emotion regulation in autistic individuals, new possibilities for intervention can be

imagined, for example with specific emotion regulation teaching effectively tackling certain social challenges. It will be valuable in future to test this idea using a randomised controlled trial design, whereby the impact of emotion regulation interventions upon social functioning can be directly evaluated. In addition to elucidating whether emotion regulation has a causal influence on real world social behaviour, such studies would add to evidence base to inform clinical interventions to support autistic people.

Limitations

Despite the role we have suggested for emotion regulation in ultimatum game responder decisions, self-reported habitual regulation of anger or sadness was not associated with ultimatum game behaviour. Our data provided some evidence of internal consistency of the Children's Anger and Sadness Management scales in the present samples, but there was no evidence of concurrent validity with parent reports. Thus, it is possible that the present results on adolescents' self-reported habitual emotion regulation are linked to poor measurement validity.

A further limitation related to measurement arises from the application of the BRIEF to measure aspects of both executive functioning and emotion control. Although the emotion control subscale of the BRIEF has been separated from executive functioning subscales on a conceptual level, factor analyses have still linked this subscale with specific executive functions to form a broader index assumed to reflect behavioural regulation (Gioia et al., 2002). Presently, we have argued that the relationship between decisions and the behavioural

regulation index is being driven by the relationship with emotion control (specifically because, of inhibit, shift and emotion control subscales that make up the behavioural regulation index, the relationship with decisions is strongest and only significant for the emotion control subscale). However, since relationships with the executive functioning components of behavioural regulation are reasonably substantial, it is not possible to rule out a role for these processes in the decisions made. Indeed, depending on the definitions of executive function and emotion regulation one adheres to, there is substantial overlap between the two constructs, which cannot be addressed in the present design. Further research with more direct measures of emotion regulation and executive function as clearly defined separate constructs, would be needed to elucidate this issue.

An additional limitation comes from the fact that despite the previous validity data that have been associated to the EYES-C (outlined in the *Method* section), scores on this test are likely influenced by other social and emotional capacities, related to, but conceptually distinct from theory of mind, including verbal IQ and facial emotion recognition (Baribeau et al., 2015; van der Muellen et al., 2017). Therefore, in future it will be important to triangulate the EYES-C findings from this study using other techniques for measuring theory of mind, for example, the Strange Stories (White et al., 2009). In considering the limitations above, it is also important to bear in mind that BRIEF and EYES-C measures could only be administered with respect to autistic individuals. Future research should ensure that the relationships identified here can be examined across diagnostic boundaries. Finally, as discussed above, the ultimatum game used here has advantages in terms of ecological validity relative to previous research on social

decision making, for example with vignettes. However, the laboratory context and single interaction with each assumed social partner remains a long way from real-life social situations. In future research it will be important to examine the present findings in naturalistic settings.

Compliance with ethical standards

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants included in the study.

References

Adams, M. P. (2013). Explaining the theory of mind deficit in autism spectrum disorder. *Philosophical Studies, 163*(1), 233-249. doi:10.1007/s11098-011-9809-z

Ahlstrom, B. H., & Wentz, E. (2014). Difficulties in everyday life: Young persons with attention-deficit/hyperactivity disorder and autism spectrum disorders perspectives. A chat-log analysis. *International Journal of Qualitative Studies on Health and Well-Being, 9*, 10. doi:10.3402/qhw.v9.23376

Baribeau, D. A., Doyle-Thomas, K. A., Dupuis, A., Iaboni, A., Crosbie, J., McGinn, H., . . . Anagnostou, E. (2015). Examining and comparing social perception abilities across childhood-onset neurodevelopmental disorders. *Journal of the American Academy of Child and Adolescent Psychiatry, 54(6),* 479-486.e471. doi:10.1016/j.jaac.2015.03.016

Baron-Cohen, S., Wheelwright, S., Hill, J., Raste, Y., & Plumb, I. (2001). The 'Reading the Mind in the Eyes' Test revised version: a study with normal adults, and adults with Asperger syndrome or high-functioning autism. *Journal of Child Psychology and Psychiatry, and Allied Disciplines, 42(2),* 241–251

Berking, M., & Lukas, C. A. (2015). The Affect Regulation Training (ART): a transdiagnostic approach to the prevention and treatment of mental disorders. *Current Opinion in Psychology, 3,* 64 - 69. doi:http://dx.doi.org/10.1016/j.copsyc.2015.02.002

Blakemore S. J. (2012). Imaging brain development: the adolescent brain. *Neuroimage. 61(2),* 397–406. doi: 10.1016/j.neuroimage.2011.11.080

Bradley, M. M., & Lang, P. J. (1994). Measuring emotion - the self-assessment mannequin and the semantic differential. *Journal of Behavior Therapy and Experimental Psychiatry, 25*(1), 49-59. doi:10.1016/0005-7916(94)90063-9

Buescher, A. S., Cidav, Z., Knapp, M., & Mandell, D. (2014). Costs of autism spectrum disorders in the United Kingdom and the United States. *JAMA Pediatrics, 168(8)*, 721–728. http://doi.org/10.1001/jamapediatrics.2014.210

Buon, M., Dupoux, E., Jacob, P., Chaste, P., Leboyer, M., & Zalla, T. (2012). The Role of Causal and Intentional Judgments in Moral Reasoning in Individuals with High Functioning Autism. *Journal of Autism and Developmental Disorders, 43(2),* 458–470. http://doi.org/10.1007/s10803-012-1588-7

Burns, A., Irvine, M. & Woodcock, K. A. (2019) Self-focused attention and depressive symptoms in adults with autistic spectrum disorder (ASD). Journal of Autism and Developmental Disorders, 49(2), 692-703. doi: 10.1007/s10803-018-3732-5

Camerer, C., & Thaler, R. H. (1995). Anomalies: Ultimatums, Dictators and Manners. *The Journal of Economic Perspectives, 9(2),* 209–219.

Casey B. J., Jones R. M. & Hare T. A. (2008). The adolescent brain. *Annals of the New York Academy of Sciences. Mar, 1124*, 111–26.

Channon, S., Fitzpatrick, S., Drury, H., Taylor, I., & Lagnado, D. (2010). Punishment and Sympathy Judgments: Is the Quality of Mercy Strained in Asperger's Syndrome? *Journal of Autism and Developmental Disorders, 40(10)*, 1219–1226. http://doi.org/10.1007/s10803-010-0980-4

Channon, S., Lagnado, D., Fitzpatrick, S., Drury, H., & Taylor, I. (2011). Judgments of cause and blame: Sensitivity to intentionality in Asperger's Syndrome. *Journal of Autism and Developmental Disorders, 41(11)*, 1534–1542.

Chevallier, C., Kohls, G., Troiani, V., Brodkin, E. S., & Schultz, R. T. (2012). The social motivation theory of autism. *Trends in Cognitive Sciences, 16*(4), 231-239. doi:10.1016/j.tics.2012.02.007

Chiu, P. H., Kayali, M. A., Kishida, K. T., Tomlin, D., Klinger, L. G., Klinger, M. R., & Montague, P. R. (2008). Self responses along cingulate cortex reveal quantitative neural phenotype for high-functioning autism. *Neuron, 57*(3), 463-473. doi:10.1016/j.neuron.2007.12.020

Cohen, J. & Cohen, P. (1987). Applied Multiple Regression/Correlation Analysis for the Behavioural Science, New Jersey, Lawrence Erlbaum Associates.

Cornish, K., Scerif, G., & Karmiloff-Smith, A. (2007). Tracing syndrome-specific trajectories of attention across the lifespan. Cortex, 43(6), 672-685. doi:10.1016/s0010-9452(08)70497-0

Corradi-Dell'Acqua, C., Koban, L., Leiberg, S., & Vuilleumier, P. (2016). Editorial: What Determines Social Behavior? Investigating the Role of Emotions, Self-Centered Motives, and Social Norms. *Frontiers in Human Neuroscience, 10*, 5. doi:10.3389/fnhum.2016.00342

Craig, F., Margari, F., Legrottaglie, A. R., Palumbi, R., de Giambattista, C., & Margari, L. (2016). A review of executive function deficits in autism spectrum disorder and attention-deficit/hyperactivity disorder. *Neuropsychiatric Disease and Treatment, 12*, 1191-1202. doi:10.2147/ndt.s104620

de Martino, B., Harrison, N. A., Knafo, S., Bird, G., & Dolan, R. J. (2008). Explaining Enhanced Logical Consistency during Decision Making in Autism. *The Journal of Neuroscience, 28(42*), 10746–10750. http://doi.org/10.1523/JNEUROSCI.2895-08.2008

de Rosnay, M., Fink, E., Begeer, S., Slaughter, V., and Peterson, C. (2014). Talking theory of mind talk: young school-aged children's everyday conversation and understanding of mind and emotion. J. Child Lang. 41, 1179–1193. doi: 10.1017/S0305000913000433

de Veld, D. M. J., Howlin, P., Hoddenbach, E., Mulder, F., Wolf, I., Koot, H. M., . . . Begeer, S. (2017). Moderating Effects of Parental Characteristics on the Effectiveness of a Theory of Mind Training for Children with Autism: A Randomized Controlled Trial. Journal of Autism and Developmental Disorders, 47(7), 1987-1997. doi:10.1007/s10803-017-3117-1

Downs, A., & Smith, T. (2004). Emotional understanding, cooperation, and social behavior in high-functioning children with autism. *Journal of Autism and Developmental Disorders, 34*(6), 625-635. doi:10.1007/s10803-004-5284-0

Edmiston, E. K., Merkle, K., & Corbett, B. A. (2015). Neural and cortisol responses during play with human and computer partners in children with autism. *Social Cognitive and Affective Neuroscience, 10*(8), 1074-1083. doi:10.1093/scan/nsu159

Ewing, L., Caulfield, F., Read, A., & Rhodes, G. (2015). Appearance-based trust behaviour is reduced in children with autism spectrum disorder. *Autism, 19*(8), 1002-1009. doi:10.1177/1362361314559431

Farley, M. A., McMahon, W. M., Fombonne, E., Jenson, W. R., Miller, J., Gardner, M., … Coon, H. (2009). Twenty-year outcome for individuals with autism and average or near-average cognitive abilities. *Autism Research, 2(2),* 109–118. http://doi.org/10.1002/aur.69

Funahashi, S. (2017). Prefrontal Contribution to Decision-Making under Free-Choice Conditions. *Frontiers in Neuroscience, 11*, 15. doi:10.3389/fnins.2017.00431

Gleichgerrcht, E., Torralva, T., Rattazzi, A., Marenco, V., Roca, M., & Manes, F. (2013). Selective impairment of cognitive empathy for moral judgment in adults with high functioning autism. *Social Cognitive and Affective Neuroscience, 8(7)*, 780–788. http://doi.org/10.1093/scan/nss067

Grondhuis, S. N., Lecavalier, L., Arnold, L. E., Handen, B. L., Scahill, L., McDougle, C. J., & Aman, M. G. (2018). Differences in verbal and nonverbal IQ test scores in children with autism spectrum disorder. Research in Autism Spectrum Disorders, 49, 47-55. doi:10.1016/j.rasd.2018.02.001

Güth, W., Schmittberger, R., & Schwarze, B. (1982). An experimental analysis of ultimatum bargaining. *Journal of Economic Behavior & Organization, 3(4),* 367–388.

Halali, E., Bereby-Meyer, Y., & Ockenfels, A. (2013). Is it all about the self? The effect of self-control depletion on ultimatum game proposers. *Frontiers in Human Neuroscience, 7,* 1-8. doi:10.3389/fnhum.2013.00240

Howlin, P. (2000). Outcome in Adult Life for more Able Individuals with Autism or Asperger Syndrome. *Autism, 4(1),* 63–83. http://doi.org/10.1177/1362361300004001005

Howlin, P., Goode, S., Hutton, J., & Rutter, M. (2004). Adult outcome for children with autism. *Journal of Child Psychology and Psychiatry, 45(2),* 212–229. http://doi.org/10.1111/j.1469-7610.2004.00215.x

Hull, L., Petrides, K. V., Allison, C., Smith, P., Baron-Cohen, S., Lai, M.-C., & Mandy, W. (2017). "Putting on My Best Normal": Social Camouflaging in Adults with Autism Spectrum Conditions. *Journal of Autism and Developmental Disorders, 47*(8), 2519-2534. doi:10.1007/s10803-017-3166-5

Karbach, J., & Unger, K. (2014). Executive control training from middle childhood to adolescence. Frontiers in Psychology, 5, 14. doi:10.3389/fpsyg.2014.00390

Kenny, L., Hattersley, C., Molins, B., Buckley, C., Povey, C., & Pellicano, E. (2016). Which terms should be used to describe autism? Perspectives from the UK autism community. *Autism, 20*(4), 442-462. doi:10.1177/1362361315588200

Kishida, K. T., King-Casas, B., & Montague, P. R. (2010). Neuroeconomic Approaches to Mental Disorders. *Neuron, 67*(4), 543-554. doi:10.1016/j.neuron.2010.07.021

Klapwijk, E. T., Aghajani, M., Lelieveld, G. J., van Lang, N. D. J., Popma, A., van der Wee, N. J. A., . . . Vermeiren, R. (2017). Differential Fairness Decisions and Brain Responses After Expressed Emotions of Others in Boys with Autism Spectrum Disorders. *Journal of Autism and Developmental Disorders, 47*(8), 2390-2400. doi:10.1007/s10803-017-3159-4

Klin, A., Saulnier, C. A., Sparrow, S. S., Cicchetti, D. V., Volkmar, F. R., & Lord, C. (2006). Social and Communication Abilities and Disabilities in Higher Functioning Individuals with

Autism Spectrum Disorders: The Vineland and the ADOS. *Journal of Autism and Developmental Disorders, 37(4)*, 748–759. http://doi.org/10.1007/s10803-006-0229-4

Knapp, M., Romeo, R., & Beecham, J. (2009). Economic cost of autism in the UK. *Autism, 13(3),* 317–336. http://doi.org/10.1177/1362361309104246

Li, J., Zhu, L. Q., & Gummerum, M. (2014). The relationship between moral judgment and cooperation in children with high-functioning autism. *Scientific Reports, 4*, 6. doi:10.1038/srep04314

Loomes, R., Hull, L., & Mandy, W. P. L. (2017). What Is the Male-to-Female Ratio in Autism Spectrum Disorder? A Systematic Review and Meta-Analysis. *Journal of the American Academy of Child and Adolescent Psychiatry, 56*(6), 466-474. doi:10.1016/j.jaac.2017.03.013

Mazefsky, C. A., Herrington, J., Siegel, M., Scarpa, A., Maddox, B. B., Scahill, L., & White, S. W. (2013). The Role of Emotion Regulation in Autism Spectrum Disorder. *Journal of the American Academy of Child and Adolescent Psychiatry, 52*(7), 679-688. doi:10.1016/j.jaac.2013.05.006

Mazefsky, C. A., Pelphrey, K. A., & Dahl, R. E. (2012). The Need for a Broader Approach to Emotion Regulation Research in Autism. *Child Development Perspectives, 6*(1), 92-97. doi:10.1111/j.1750-8606.2011.00229.x

Merikangas K. R., He J., Burstein M., Swanson S. A., Avenevoli S., Cui L., et al. (2010) Lifetime prevalence of mental disorders in US adolescents: results from the National Comorbidity Survey Replication–Adolescent Supplement (NCS-A). *Journal of the American Academy of Child & Adolescent Psychiatry. 49(10)*, 980–989. doi: 10.1016/j.jaac.2010.05.017

Milosavljevic, B., Leno, V. C., Simonoff, E., Baird, G., Pickles, A., Jones, C. R. G., . . . Happe, F. (2016). Alexithymia in Adolescents with Autism Spectrum Disorder: Its Relationship to Internalising Difficulties, Sensory Modulation and Social Cognition. *Journal of Autism and Developmental Disorders, 46*(4), 1354-1367. doi:10.1007/s10803-015-2670-8

Moran, J. M., Young, L. L., Saxe, R., Lee, S. M., O'Young, D., Mavros, P. L., & Gabrieli, J. D. (2011). Impaired theory of mind for moral judgment in high-functioning autism. *Proceedings of the National Academy of Sciences, 108(7),* 2688–2692. http://doi.org/10.1073/pnas.1011734108

Morsanyi, K., Handley, S. J., & Evans, J. S. B. T. (2010). Decontextualised Minds: Adolescents with Autism are Less Susceptible to the Conjunction Fallacy than Typically Developing Adolescents. *Journal of Autism and Developmental Disorders, 40(11),* 1378–1388. http://doi.org/10.1007/s10803-010-0993-z

Pantelis, P. C., & Kennedy, D. P. (2017). Autism does not limit strategic thinking in the "beauty contest" game. *Cognition, 160*, 91-97. doi:10.1016/j.cognition.2016.12.015

Patel, S., Day, T. N., Jones, N., & Mazefsky, C. A. (2017). Association between anger rumination and autism symptom severity, depression symptoms, aggression, and general dysregulation in adolescents with autism spectrum disorder. *Autism, 21*(2), 181-189. doi:10.1177/1362361316633566

Pellicano, E., Dinsmore, A., & Charman, T. (2014). What should autism research focus upon? Community views and priorities from the United Kingdom. *Autism, 18(7),* 756–770. http://doi.org/10.1177/1362361314529627

Peterson, C., Slaughter, V., Moore, C., and Wellman, H. M. (2015). Peer social skills and Theory of Mind development in children with autism, deafness, or typical development. Dev. Psychol. 25, 46–57. doi: 10.1037/a0039833

Pillutla, M. M., & Murnighan, J. K. (1996). Unfairness, anger, and spite: Emotional rejections of ultimatum offers. *Organizational Behavior and Human Decision Processes, 68*(3), 208-224. doi:10.1006/obhd.1996.0100

Richey, J. A., Damiano, C. R., Sabatino, A., Rittenberg, A., Petty, C., Bizzell, J., . . . Dichter, G. S. (2015). Neural Mechanisms of Emotion Regulation in Autism Spectrum Disorder. *Journal of Autism and Developmental Disorders, 45*(11), 3409-3423. doi:10.1007/s10803-015-2359-z

Robb, N., Waller, A., & Woodcock, K. A. (2015). The Development of TASTER, a Cognitive Training Game Using Human-Centered Design, Tailored for Children with Global and Specific Cognitive Impairments. IEEE 7th International Conference on Games and Virtual Worlds for Serious Applications (Vs-Games), 208-209.

Rowley, S. J. & Camacho, T. C. (2015) Increasing Diversity in Cognitive Developmental Research: Issues and Solutions. Journal of Cognition and Development, 16(5), 683-692, doi: 10.1080/15248372.2014.976224

Sally, D., & Hill, E. (2006). The development of interpersonal strategy: Autism, theory-of-mind, cooperation and fairness. *Journal of Economic Psychology, 27*(1), 73-97. doi:10.1016/j.joep.2005.06.015

Samson, A. C., Hardan, A. Y., Podell, R. W., Phillips, J. M., & Gross, J. J. (2015). Emotion Regulation in Children and Adolescents With Autism Spectrum Disorder. *Autism Research, 8*(1), 9-18. doi:10.1002/aur.1387

Samson, A. C., Wells, W. M., Phillips, J. M., Hardan, A. Y., & Gross, J. J. (2015). Emotion regulation in autism spectrum disorder: evidence from parent interviews and children's daily diaries. *Journal of Child Psychology and Psychiatry, 56*(8), 903-913. doi:10.1111/jcpp.12370

Sanfey, A. G., Rilling, J. K., Aronson, J. A., Nystrom, L. E., & Cohen, J. D. (2003). The neural basis of economic decision-making in the ultimatum game. *Science, 300*(5626), 1755-1758. doi:10.1126/science.1082976

Sawilowsky, S. S. (2009). New effect size rules of thumb. Journal of Modern Applied Statistical Methods, 8(2), 597 – 599. Available at: http://digitalcommons.wayne.edu/coe_tbf/4

Schmitz, E. A., Banerjee, R., Pouw, L. B. C., Stockmann, L., & Rieffe, C. (2015). Better to be equal? Challenges to equality for cognitively able children with autism spectrum disorders in a social decision game. *Autism, 19*(2), 178-186. doi:10.1177/1362361313516547

Schoorl, J., van Rijn, S., de Wied, M., van Goozen, S., & Swaab, H. (2016). Emotion Regulation Difficulties in Boys with Oppositional Defiant Disorder/Conduct Disorder and the Relation with Comorbid Autism Traits and Attention Deficit Traits. *Plos One, 11*(7), 12. doi:10.1371/journal.pone.0159323

Shulman, C., Guberman, A., Shiling, N., & Bauminger, N. (2011). Moral and Social Reasoning in Autism Spectrum Disorders. *Journal of Autism and Developmental Disorders, 42(7),* 1364–1376. http://doi.org/10.1007/s10803-011-1369-8

Tabibnia, G., Satpute, A. B., & Lieberman, M. D. (2008). The sunny side of fairness - Preference for fairness activates reward circuitry (and disregarding unfairness activates self-control circuitry). Psychological Science, 19(4), 339-347. doi:10.1111/j.1467-9280.2008.02091.x

Tayama, M., Tateno, M., Park, T. W., Ukai, W., Hashimoto, E., & Saito, T. (2012). The Study of Cognitive Characteristics in Asperger's Disorder by Using a Modified Prisoner's Dilemma Game with a Variable Payoff Matrix. *Plos One, 7*(11), 7. doi:10.1371/journal.pone.0048794

Tremblay, S., Sharika, K. M., & Platt, M. L. (2017). Social Decision-Making and the Brain: A Comparative Perspective. *Trends in Cognitive Sciences, 21*(4), 265-276. doi:10.1016/j.tics.2017.01.007

van Bergeijk, E., Klin, A., & Volkmar, F. (2008). Supporting More Able Students on the Autism Spectrum: College and Beyond. *Journal of Autism and Developmental Disorders, 38(7)*, 1359–1370. http://doi.org/10.1007/s10803-007-0524-8

van der Meulen, A., Roerig, S., de Ruyter, D., van Lier, P., & Krabbendam, L. (2017). A Comparison of Children's Ability to Read Children's and Adults' Mental States in an Adaptation of the Reading the Mind in the Eyes Task. *Frontiers in Psychology*, 8(594). doi:10.3389/fpsyg.2017.00594

van Heijst, B. F., & Geurts, H. M. (2015). Quality of life in autism across the lifespan: A meta-analysis. *Autism*, *19*(2), 158-167.

van't Wout, M., Chang, L. J., & Sanfey, A. G. (2010). The Influence of Emotion Regulation on Social Interactive Decision-Making. *Emotion, 10*(6), 815-821. doi:10.1037/a0020069

Wang, C. S., Sivanathan, N., Narayanan, J., Ganegoda, D. B., Bauer, M., Bodenhausen, G. V., & Murnighan, K. (2011). Retribution and emotional regulation: The effects of time delay in angry economic interactions. Organizational Behavior and Human Decision Processes, 116(1), 46-54. doi:10.1016/j.obhdp.2011.05.007

White, S., Hill, E., Happé, F., & Frith, U. (2009). Revisiting the strange stories: Revealing mentalizing impairments in autism. *Child development*, *80*(4), 1097-1117.

Yoshida, W., Dziobek, I., Kliemann, D., Heekeren, H. R., Friston, K. J., & Dolan, R. J. (2010). Cooperation and Heterogeneity of the Autistic Mind. *Journal of Neuroscience, 30*(26), 8815-8818. doi:10.1523/jneurosci.0400-10.2010

Zalla, T., & Leboyer, M. (2011). Judgment of Intentionality and Moral Evaluation in Individuals with High Functioning Autism. *Review of Philosophy and Psychology, 2(4),* 681–698. http://doi.org/10.1007/s13164-011-0048-1

Zantinge, G., van Rijn, S., Stockmann, L., & Swaab, H. (2017). Physiological Arousal and Emotion Regulation Strategies in Young Children with Autism Spectrum Disorders. *Journal of Autism and Developmental Disorders, 47*(9), 2648-2657. doi:10.1007/s10803-017-3181-6

Table 1 Proportion of fair offers proposed described as a percentage (from 8 total offers made)

Group	**Proportion of fair offers proposed**			
	Mean	***SD***	**95% *CI***	
			Lower	**Upper**
ASD	54.4*	16.9	46.5	62.3
TD	70.3*	31.2	63.3	77.2

* *Indicates a significant difference between ASD and TD groups*

Table 2 Proportion of ultimatum game offers accepted described as a percentage and as a function of the fairness of the offer.

Group	**Fair**			**Unfair**		
	M	***SD***	**95% *CI***	***M***	***SD***	**95% *CI***
ASD	97.5	6.1	[94.7, 100.0]	39.6	35.4	[23.1, 56.2]
TD	95.6	8.8	[93.7,97.6]	47.6	37.6	[39.2, 55.9]

* *There were no significant differences between ASD and TD groups.*

Table 3 Mean feeling rating following ultimatum game *responder* decisions as separated according to offer fairness; and accept versus reject decisions. Feelings were self-rated on a Likert scale of 1-5 (1=calm and relaxed, 2= OK, 3= a little annoyed, 4=quite annoyed, 5=very annoyed).

Group	**Decision**	**Fair**			**Unfair**		
		M	***SD***	**95% *CI***	***M***	***SD***	**95% *CI***
ASD	Either	1.38	.387	[1.20, 1.56]	3.03*	.740	[2.68, 3.38]
TD	Either	1.42	.707	[1.26, 1.58]	2.67*	1.06	[2.42, 2.90]
ASD	Accept	1.35	.35	[1.18, 1.51]	2.93*	.76	[2.54, 3.32]
	Reject	.75	.29	[0.29, 1.21]	3.35	.97	[2.86, 3.83]
TD	Accept	1.37	0.69	[1.22, 1.52]	2.35*	1.05	[2.10, 2.60]
	Reject	.75	.35	[0.60, 0.91]	3.01	1.02	[2.76, 3.25]

* *Indicates significant differences between ASD and TD groups*

Table 4 Mean T scores on the Behaviour Rating Inventory of Executive Function (BRIEF) for individuals in the ASD group (BRIEF not administered to TD individuals). Higher T scores indicate poorer executive function.

	Mean T score	***SD***	***95% CI***		**Relationship to acceptance rate of unfair offers**
			Lower	**Upper**	
Inhibition	61.9	11.9	58.5	65.3	ρ= -.366, p= .112
Shift	70.2	12.6	66.6	73.7	ρ= -.426, p= .061
Emotional control	66.2	11.5	62.9	69.4	ρ= -.544, p= .013*
Behavioural Regulation Index (BRI)	67.9	12.2	64.4	71.4	ρ= -.519, p= .019*
Initiate	66.8	7.7	64.6	68.9	ρ= -.412, p= .071
Working Memory	66.5	7.7	64.3	68.6	ρ= -.317, p= .173
Plan/Organise	62.7	10.6	59.7	65.7	ρ= -.474, p= .035
Organisation of Materials	58.0	11.4	54.7	61.2	ρ= -.179, p= .450
Monitor	65.1	7.8	62.9	67.3	ρ= -.476, p= .034
Metacognition Index (MI)	64.6	7.4	62.5	66.7	ρ= -.426, p= .061
Global Executive Composite (GEC) Score	67.1	8.6	64.6	69.6	ρ= -.510, p= .021*

* p values deemed significant to p <.05 are indicated. All correlations are presented here for completeness. However, to maintain the risk of type II errors appropriate in the context of multiple statistical tests, relationships with higher order composite scores were examined first, and those with lower order composite scores were only considered where the corresponding higher order composite was also significant. Thus, because the correlation with GEC was significant, BRI and MI could be examined. Of these, only the correlation with BRI was significant, so inhibition, shift and emotional control could be examined. This procedure follows the same line of inference as a protected t-test procedure, which has been demonstrated to be robust at maintaining experiment wise error at an acceptably low level (Cohen & Cohen, 1983, page 172).

Supplementary materials

Supplementary measures and procedure

Reading the Eyes in the Mind (EYES-C)

Adolescents with ASD were provided with verbal instructions by the researcher before completing the EYES-C using an iPad.

"You are going to play a game on the computer, but before you do that, I need you to answer some questions. (Take out iPad) I am going to show you lots of pictures of people's eyes. Each picture has four words round it. I want you to look carefully at the picture and then choose the word that best describes what the person in the picture is thinking or feeling. Let's have a go with this one (practice item). Look at this person. Do you think he is feeling jealous, scared, relaxed or hate (point to words as they are read)? (Make sure child picks one of the options and give encouraging feedback without revealing whether they are right or wrong.) OK, let's have a go at the rest of them. You might find some of them quite easy and some of them quite hard, so don't worry if it's not always easy to choose the best word. I'll read all the words for you so you don't need to worry about that. If you really can't choose the best word, you can have a guess." (Proceed with test items)

Children's Anger and Sadness Management Scales (CAMS, CSMS)

Adolescents were provided with verbal instructions by a researcher before completing the CAMS and CSMS.

"You are going to play a game on the computer, but before you do that you are going to answer some questions about how you cope with difficult feelings like anger or worry or sadness. The computer will make a statement like 'When I'm sad I hide my sad feelings', and you just have to say whether you do this hardly ever, sometimes or most of the time by pressing the numbers 1, 2 or 3 on your computer keyboard."

On initiation of the computer programme to administer the CAMS and CSMS, adolescents first heard the following instructions with corresponding visual aids:
"We would like you to tell us how you cope with your feelings at different times"
"You will hear some ways that some people cope with their feelings"
"All you have to do is to decide how much you use each of the ways to cope with your feelings"
"You might use it hardly ever" (central picture of a clock with five minutes shaded in red)
"You might use it sometimes" (central picture of a clock with twenty minutes shaded in red)
"You might use it often" (central picture of a clock with forty five minutes shaded in red)
Press 1 for hardly ever 2 for sometimes and 3 for often (hardly ever (left most), sometimes (middle) and often (right most) clocks presented

Following these initial instructions, each item of the scales was administered in the order it appears in the previously validated paper measure. Although not a focus of the present research, the anxiety scale (11-items) was administered following the anger and sadness scale. Items were administered as illustrated in *Figure S1*.

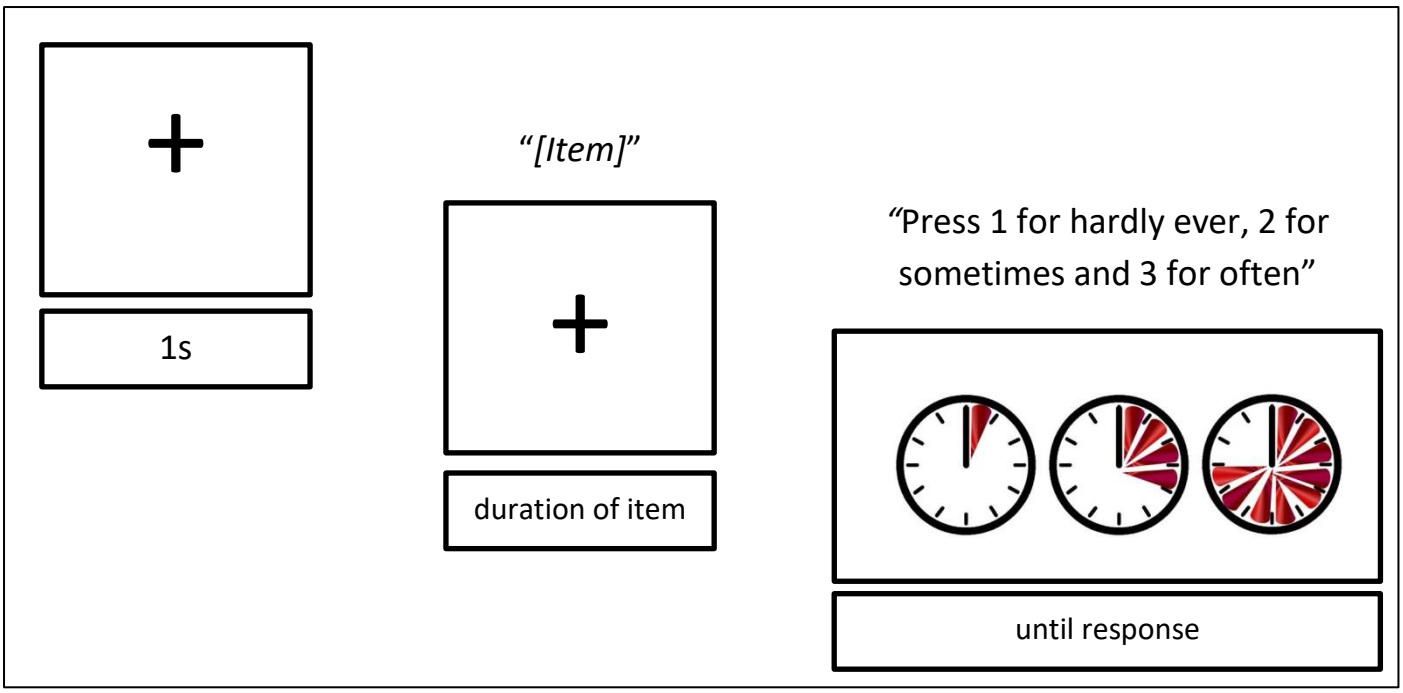

Figure S1: Trial structure for presenting items of the CAMS and CSMS.

Introduction to the ultimatum game

Before initiating the ultimatum game a verbal instructions were provided to adolescents by a researcher, using props for assistance. The instructions were as follows. At the end of the instructions below, participants completed the ultimatum game *proposer* procedure (*Figure S2*).

"Now you are going to a game on the computer. You will be playing the game against lots of other children/people just like you who have taken part in our research. You will play lots of rounds of the game and in each round you will play against one of these children/people. So, each round has 2 players – you and another child/person. The game goes like this – player 1 is given some pretend money and they have to decide how to share it with player 2. They can either decide to give player 2 the same as them, or they can decide to give themselves more and player 2 less. Player 2 then gets to decide if they want to say yes to player 1's offer, or if they want to say no. If they say yes, they get the money player 1 has offered them. If they say no to an offer, nobody gets any money – the pretend money just goes away."

"So, imagine I am the player who has the money to share out. Here I have £100 in £10 notes [show real notes]. *I might decide to share the money out like this, giving myself £50 and the other player £50, or I might decide to share it out by giving myself £80 and the other player £20. So which offer would you prefer: sharing the money out so I get £50 and you get £50; or sharing the money out so I get £80 and you get £20? If the other player says yes to my offer, the pretend money will be shared out between us in the way I have decided – so they will get the pretend money shown here in red and I will get the rest. If the other player says no my offer, neither of us gets any money – the pretend money just goes away."*

[Repeat with coins].

Any questions?

[For ASD participants only]: *"You will win a prize for playing the game. You might win a small prize like a packet of sweets/crisps or a big prize like a book or a DVD worth about £5 for taking part in our research. The better you do in the game, the more chance there is that you will win the big prize."*

[For TD participants only]: *"You may win a prize for playing the game. The better you do the more chance you have of winning a prize."*

"In the first round of the game, you are going to be the player who shares out the pretend money. The computer will show you the pretend money you have to share out, and you press 1 if you want to give the other player the same as you, and press 2 if you want to give the other player less than you. You will have to make lots of offers to lots of different children/people."

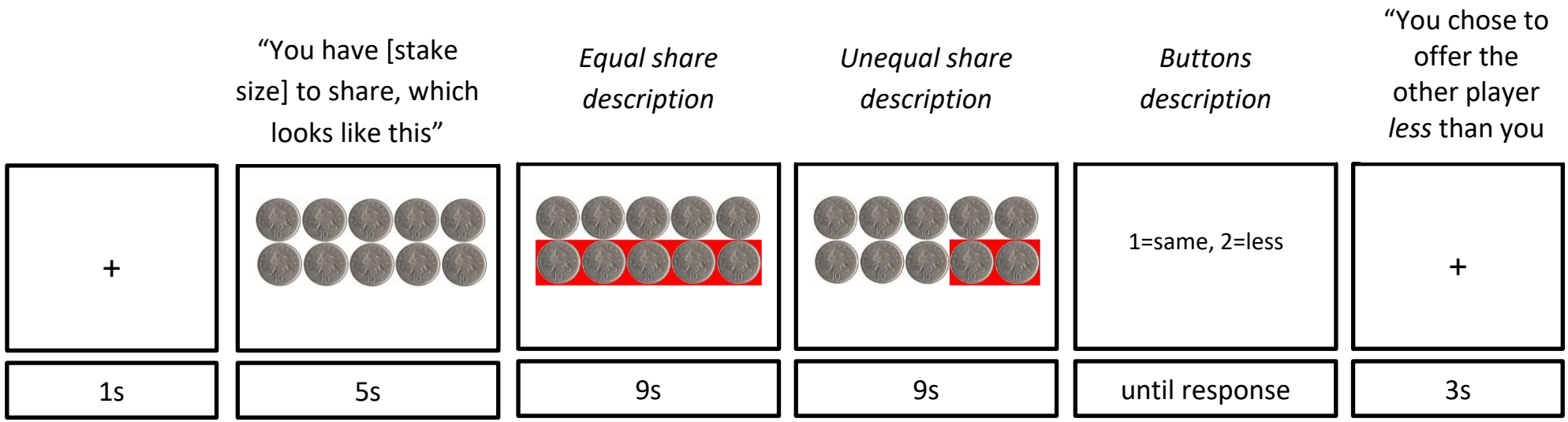

Figure S2: Ultimatum game *proposer* trial procedure
[Stake size] was either £1 (as above) or £100, as illustrated with ten £10 notes (see *Figure S3*). The *equal share description* was: "You can decide to share it so that the other player gets the same as you. So they would get the money shown in red, and you would get the rest". The *unequal share description* was: "Or you can decide to share it so that the other player gets less than you. So they would get the money shown in red, and you would get the rest." The *buttons description* was: "If you want to share it so that the other player gets the same, press one. If you want to share it so that the other player gets less, press two." Verbal feedback was presented alongside a fixation cross, which depended in content on whether the participant selected the unfair offer (as above), or the fair offer ("You chose to offer the other player *the same* as you"). Stakes were presented in the same pseudorandom order for all participants across the eight proposer trials (trials 1, 2, 5 & 8 presented £1 stakes).

Introduction to the ultimatum game responder practice session

The following instructions were provided to participants after their completion of the ultimatum game *proposer* trial procedure, and before initiation of the ultimatum game *responder* practice session.
"Now you are going to play the same game, but this time the other players will decide how they are going to share out the pretend money. So, they will decide how much of the pretend money they are going to give to you and how much they are going to keep for themselves. You will see a picture of the pretend money and the share they want to give to you will be shown in red. You can decide to say yes or no to the share they offer you. If you say yes, you get the money shown in red. If you say no, nobody gets any money – you don't get any money and the other player doesn't get any money – the pretend money just goes away. Any questions? After each offer, you will see this picture [show the picture of the emotion rating scale that appears in the *responder* trial procedure] *and you will be asked to say how you feel about the other player's offer. If you feel very relaxed and calm about their offer, press 1, if you feel ok about their offer press 2, if you feel a little bit annoyed press 3, if you feel quite annoyed press 4 and if you feel very annoyed press 5. Are you ready to start the game? This first time is just for practise. You are going to get lots of different offers from lots of different children/people just like you who have taken part."*

Ultimatum game responder practice session

Five ultimatum game *responder* practice trials were presented prior to the ultimatum game *responder* trial procedure.
Practice trials were similar in structure to the ultimatum game *responder* trials (*Figure S3*), but additional verbal explanation was provided to explain the task. Specifically:

1. Instead of being introduced to a previous player by their first name and cartoon picture, participants were presented with a placeholder image and told:
   "*First you will see the picture that the other player has chosen*" [4 seconds].
2. After being presented with a picture of the stake (always 10 pence), and told:
   "They have ten pence to share" [4 seconds]
3. Participants were told about the options the proposer has available to them. Specifically:
   "*They can decide to share it out so that you both get the same"* (whilst being shown 50% of the stake highlighted in red). [4.5 seconds]
   "Or they can decide to share it out so that you get less than them" (whilst being shown 20% of the stake highlighted in red). [5.5 seconds]
4. After being informed about the offer, but before being asked to make a decision (see *Figure S3*), participants were reminded what each of their decisions would mean. Specifically:
   "*If you say yes, you will get the money shown in red, and they will get the rest"* (whilst being shown the picture of the stake with the proposed offer highlighted in red). [6 seconds]
   "If you say no, you won't get any money, and they won't get any money either" (whilst being shown a blank screen). [6 seconds]

Introduction to the ultimatum game responder procedure

Following completion of the ultimatum game *responder* practice session, the ultimatum game *responder* procedure (*Figure S3*) was introduced to participants verbally by a researcher.

"Now you are going to play the same game for real. It's the same as the practise game you just played. The other players will decide how they are going to share out the pretend money. So, they will decide how much of the pretend money they are going to give to you and how much they are going to keep for themselves. And you have to decide if you want to say yes or no to their offer. If you say yes, you will get the money shown in red; if you say no, nobody gets any money. You will be asked to say how you feel after every offer. You will get lots of different offers from lots of different children/people. Remember, the better you do in the game, the more chance there is that you will win the big prize. Any questions? Are you ready to start the game?"

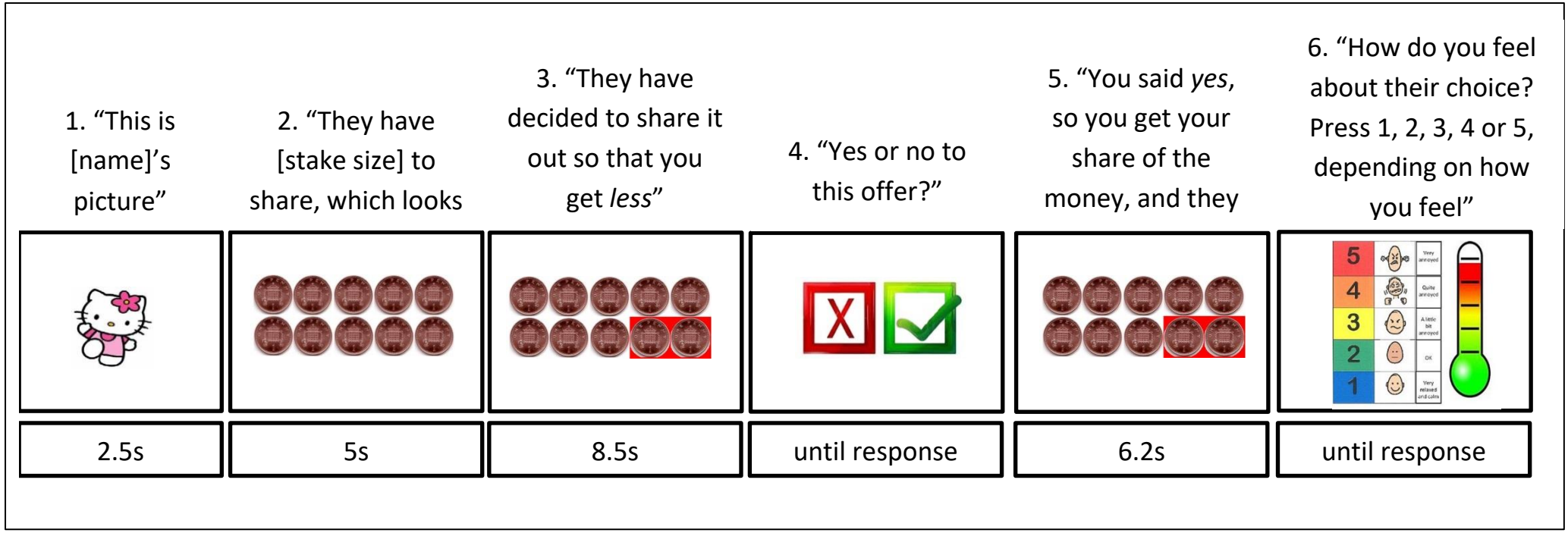

Figure S3: Ultimatum game *responder* trial procedure. The stimuli in each trial illustrated were preceded by a fixation cross (as in *Figure S2*), presented for 1 second.

1. [Name] was one of 55, single syllable names (27 most typically female; 28 most typically male), randomly selected (without replacement) on each trial. The cartoon is also an example of one of 36 widely known cartoon characters – without a particular emotional association e.g. an image of the young Simba from the Lion king was included, but an image of Scar was not included as that image is likely to have a negative association – selected randomly, also without replacement. There were 36 trials (see *Table S1*), so this procedure ensured that participants were presented with a different cartoon *and* a different name on each trial; that different participants were presented with different name-cartoon pairings; and that not all participants received offers from proposers with the same 36 names. These features were important because TD data were collected in groups, so it was essential that if participants happened to see another participants’ computer screen during play, it did not appear that they were being presented with the same offers. Furthermore, this procedure helped to prevent contamination of information across participants from the same school.
2. [Stake size] was either “ten pence” (as above), “one pound”, “ten pounds” or “one hundred pounds”, except for one school based in the Republic of Ireland, when Euros were used instead of pounds and images were altered accordingly (see *Figure S4*) for alternative stake photographs.

3. Two possible proposals were presented. Unfair proposals (as above) comprised 20% of the stake. Fair proposals comprised 50% of the stake, and were described as "…*so that you both get the same*", and were illustrated with half of the stake being highlighted in red (see *Figure S4*). Offers (defined by fairness and stake size) were presented in the same pseudorandom order for all participants.
4. Response options were counterbalanced such that half of participants responded with the letter Q to indicate a reject response and a letter P to indicate an accept response (as above), and the other half of participants responded with the opposite response mapping. In the TD sample, counterbalancing was conducted within each school year group. In the ASD sample, counterbalancing was conducted within the sample, balanced across ages and gender as far as possible.
5. Verbal-visual feedback was presented following the participant's decision. If the participant accepted the offer, the photograph of the proposed split was presented again (as above). If the participant rejected the offer, a photograph of an empty money wallet (see *Figure S4*) was presented, alongside the verbal phrase "You said *no*, so you don't get any money and they don't get any money either."
6. Participants were asked to rate their emotion on a scale of 1 to 5 where 1 = very relaxed and calm; 2= OK; 3 = A little bit annoyed; 4 = Quite annoyed and 5 = very annoyed.

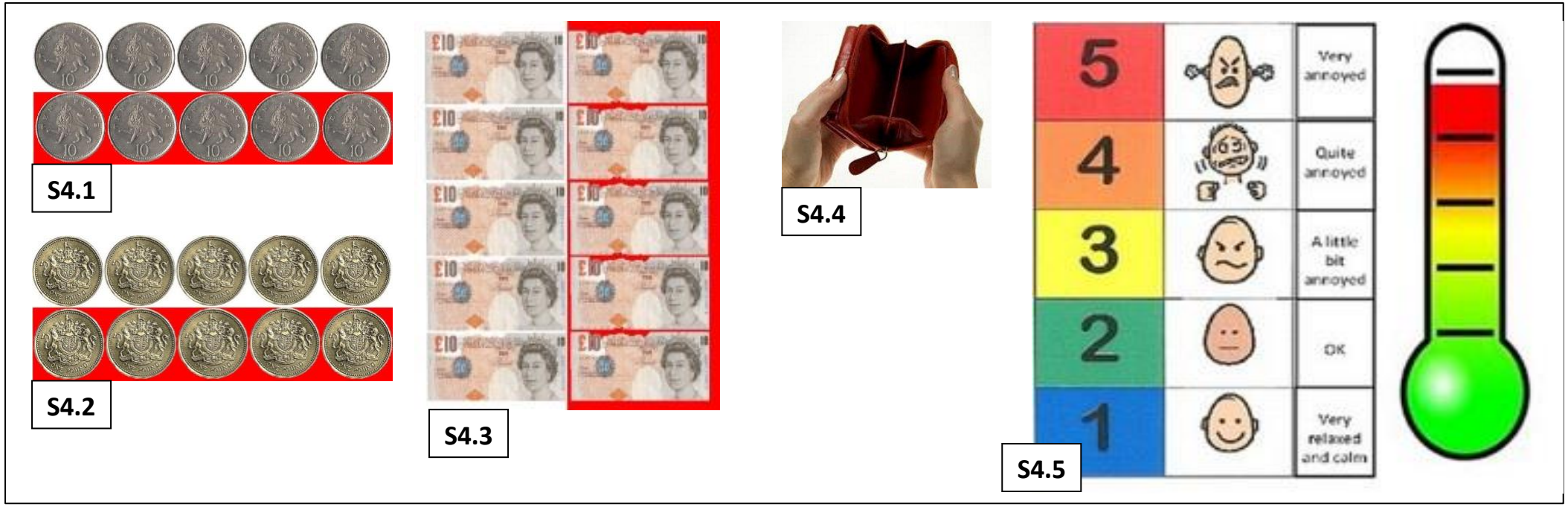

Figure S4: £1 (S4.1), £10 (S4.2) and £100 (S4.3) stakes are shown, each with the fair (50%) offer highlighted. The picture of the empty money walled, which was presented to illustrate feedback following a participant's reject decision is also shown (S4.4). Finally, an enlarged version of the image used to illustrate the self-report feeling ratings is shown (S4.5).

Table S1: Pseudorandom trial order in Ultimatum game *responder* trials. Trials were presented in two sessions. Trials comprised 6 unfair of each stake size (24 unfair trials in total), and 3 fair of each stake size (12 fair trials in total).

	Session 1																	
Trial #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Stake size	0.1	1	10	100	0.1	100	100	1	10	0.1	100	10	0.1	10	0.1	100	1	10
Fairness	fair	fair	unfair	unfair	unfair	unfair	fair	unfair	unfair	unfair	unfair	unfair	unfair	fair	fair	fair	unfair	unfair
	Session 2																	
Trial #	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
Stake size	0.1	1	10	1	0.1	100	10	0.1	100	10	1	0.1	1	1	100	10	1	100
Fairness	unfair	unfair	fair	unfair	unfair	unfair	fair	fair	unfair	unfair	unfair	unfair	fair	unfair	unfair	unfair	fair	fair

Following administration of the ultimatum game

Following completion of the ultimatum game procedure, participants were asked the following questions: *"What did you think of the game?", "Why did you respond in the way you did?", "What did you think of the other players?"* (e.g. their age/ gender). Responses indicated that all participants believed that they had been playing against real social partners, as had been specified by researchers.

Incentives for good performance in the ultimatum game

Practical necessity meant that the incentive to perform well in the ultimatum game different slightly across the two groups. Whilst individuals with ASD were informed that they would certainly receive a prize but that the size of that prize would vary depending on their performance (in fact it was always a £10 Amazon voucher), TD participants were informed that some individuals from their school would receive a prize and that they would be more likely to receive one if they did better in the game (in fact winners of £5 Amazon vouchers were selected randomly). This is consistent with previous ultimatum game research, that has adapted the incentive to the population (Koenigs, Kruepke, & Newman,2010; Radke, Brazil, et al., 2013; Sally & Hill, 2006).

Supplementary analyses

Matching procedure

From the wider sample of TD participants (n=194), six participants with missing data on gender or CAMS/CSMS were removed. Furthermore seven participants were removed because their ultimatum game performance suggested responding based on random selection, lack of understanding of the rules, or inattention (n=5 where <67% of fair offers and <67% of high stake offers were accepted; n=2 where mean response time > 3rd quartile plus 2 inter-quartile ranges). Ultimatum game data from the ASD group were similarly examined for outlying participants. However, none met the criteria for exclusion, most likely because the individual testing procedure helped to ensure participants' understanding and sustained attention. Following this, both the wider TD sample (n=181), and the ASD sample were classified into 4 age/gender strata based on estimated developmental ages for ASD participants, and chronological ages for TD participants. Developmental ages of participants with ASD were estimated based on IQ scores as derived from the Wechsler Abbreviated Scales of Intelligence (Wechsler, 1999). Within each stratum, for every individual with ASD, four TD individuals were selected at random. In doing so, the maximum amount of data was used while maintaining the proportions of the strata. Since in the TD sample, data on chronological age were recorded in full years of age only (e.g. for an individual aged 15 years 3 months, an age of 15 years was recorded), the number of months was trimmed from the ASD developmental age estimate for strata formation (e.g. 15 years, 3 months, would be trimmed to 15 years). The four strata therefore comprised females aged 11 – 13, females aged 14 – 17, males aged 11 – 13 and males aged 14 – 17 years. This procedure led to groups matched for chronological age (ASD mean 13.3 years, range 11-17; TD mean 13.3 years, range 10-17 years); developmental age (ASD mean 14.2 years, range 10.5-17.8, mean IQ 107.7, range 73-141; no IQ data were collected from TD participants but the mean IQ in the ASD sample is consistent with IQ expectations for the middle/high socioeconomic status TD sample, at the time of testing, Pietschnig & Voracek, 2015; von Stum & Plomin, 2015); and gender ratio (80% males in both groups). There was no significant difference between the estimated mental age of the ASD group and the chronological age of the TD group, $t(23.3) = .676$, $p = .506$.

Normality screening

It was tested whether variables had a skewness between -1 and 1 and a kurtosis smaller than 3 (Kline, 2013). Kolmogorov-Smirnov and Shapiro-Wilk tests were performed and histograms of the data created. However, ultimate judgements on normality were based on the inspection of Q-Q plots, using the previous tests as indicators of the plausibility of the judgement.

Statistical analyses

In examining acceptance rates and feeling ratings in the ultimatum game, multivariable (single level) regression models were used, based on multilevel models (MLMs) as described in (Hoffman & Rovine, 2007; Snijders & Bosker, 1999; Weaver & Black, 2015). When the sample sizes of the compared groups are uneven, it is likely that their responses --- the dependent variable --- can show inhomogeneous variances. While this would break the assumptions for an ANOVA, an important feature of MLMs is that inhomogeneous variances can be included in the model. The models used here can be written as:

$$y_i = \beta_0 + \beta_1(\text{fairness of offer}) + e_i(\text{ASD}) + e_i(\text{TD})$$

$$\beta_0 = \gamma_{00} + \gamma_{01}(\text{group})$$

$$\beta_1 = \gamma_{10} + \gamma_{11}(\text{group})$$

In this notation, y_i is the dependent variable for participant i (the mean proportion of accepted offers and the reported feeling of the participant, respectively). The effects of the predictors ($\beta_i s$) consist of main (fixed) effects of the intercept, γ_{00} (the mean value of the dependent variable when the participant is of the ASD group and the offer is unfair); of group, γ_{01}(the difference in the mean of the dependent variable when the participant is of the TD group); of fairness of offer, γ_{10}(the difference when the offer is fair); and of the group by fairness of offer interaction, γ_{11}(when both the group is TD and the offer fair). The residual variances e_i are modeled as normally distributed with mean zero and were computed separately for each group.

Further analyses were performed for feeling ratings, as the interaction between group, fairness and whether an offer was accepted or rejected, was also of interest. However, since acceptance was not controlled in the experiment, this interaction was examined using a series of t-tests.
Degrees of freedom for the MLMs (as well as t-tests when homogeneity of variance could not be assumed) were adjusted using Satterthwaite's method. This can be identified in the text in that the reported degrees of freedom include a fractional part. Effect sizes were computed using $d = \frac{|M_{ASD} - M_{TD}|}{0.5 \cdot (\sigma_{ASD} + \sigma_{TD})}$ and rules of thumb for their interpretation were taken from Sawilowsky, 2009. Notably, this estimate for effect sizes is independent of the sample size of the groups. Spearman's correlations were conducted to examine the relationship between theory of mind, executive functioning and emotion regulation variables and social decisions made in the ultimatum game.

Supplementary results

Relationships between social decisions and chronological age

ASD and TD groups were matched for chronological age. However, individual variability within groups may potentially be associated with chronological age, with important implications. However, the number of fair offers proposed was not significantly correlated with chronological age, (ρ = -.183, p = .07). Furthermore,

acceptance rates of unfair offers were not significantly correlated with chronological age, (ρ = .033, p = .746). Similarly, given the range of IQ in the autistic sample, relationships between non-verbal IQ and ultimatum game decisions and feeling ratings were examined. However, the number of fair offers proposed was not significantly correlated with non-verbal IQ (ρ = -.28, p = .27), and neither were acceptance rates of unfair offers (ρ = .30, p = .20).

Group differences in emotional reactions to offers

Supporting the ability of autistic and TD participants to rate their negative feelings appropriately, as expected, feelings were rated most negatively when unfair offers were rejected (ASD: mean 3.35, stdev .97; TD: mean 3.05, stdev 1.02). Feelings were rated less negatively when unfair offers were accepted (ASD: mean 2.93, stdev .76; TD: mean 2.35, stdev 1.02). Feelings were rated least negatively when fair offers were presented (and accepted) (ASD: mean 1.34, stdev .35; TD: mean 1.29, stdev .55).

Autistic children on average reported more negative feelings towards unfair offers than TD children. This effect of group accounted for just less than half a point on the emotion rating scale, which is unlikely to have arisen due to chance ($\gamma_{01} = -0.37$, p = .03). The effect size of the group by fairness of offer interaction was of similar magnitude and opposite sign, driven by the fact that autistic and TD children on average reported more similar feelings towards fair offers. However, the interaction was not significant ($\gamma_{11} = 0.41$, p = .08). The standard deviation of negative feeling ratings in the group of autistic children was 0.56, in the TD group 0.90; so in both groups there were non-negligible effects related to the individuals. That the standard deviations differ suggests that there were individual variability factors that were stronger in the TD group relative to the autistic group. Further research could try to find out what these effects are.

Table S2 Estimated parameters from the regression models for the mean proportion of accepted offers and the reported feeling of the participants, as a function of the fairness of the offers. The data for the acceptance of unfair offers were not normally distributed, so the veracity of the results for the acceptance model cannot be assured.

Parameter	**Mean proportion of accepted offers**		
	Est	***SE***	**95% *CI***
Fixed Effects			
Intercept (γ_{00})	0.396***	0.055	[0.285, 0.508]
Group (γ_{01})	0.079	0.063	[-0.047, 0.205]
Fairness of offer (γ_{10})	0.579***	0.078	[0.421, 0.737]
Group × fairness of offer (γ_{11})	-0.098	0.089	[-0.276, -0.080]
Variance Components†			
Residual variance (e_i)	0.061***	0.014	[0.039, 0.095]
	0.074***	0.008	[0.059, 0.092]

Parameter	Feeling		
	Est	***SE***	**95% *CI***
Fixed Effects			
Intercept (γ_{00})	3.029***	0.129	[2.769, 3.289]
Group (γ_{01})	-0.368*	0.163	[-0.693, -0.044]
Fairness of offer (γ_{10})	-1.650***	0.182	[-2.018, -1.282]
Group × fairness of offer (γ_{11})	0.410	0.232	[-0.050, 0.870]
Variance Components†			
Residual variance (e_i)	0.331***	0.074	[0.214, 0.513]
	0.802***	0.091	[0.642, 1.001]

*p < .05. ***p < 0.001
†First value: ASD group; second value: TD group

Self-reported emotion regulation

With respect to ultimatum game proposer behaviour, there was no substantial or significant relationship between number of fair offers proposed and habitual anger or sadness regulation as indexed by the CAMS or CSMS in either ASD (CAMS ρ = -.063; CSMS ρ = -.066) or TD groups (CAMS ρ = .079; CSMS ρ = -.025).

With respect to ultimatum game responder behaviour, 80% of adolescents with ASD, and 74% of TD adolescents accepted all fair offers, so relational analyses focused on acceptance rates of unfair offers. Neither CAMS anger regulation or CSMS sadness regulation, were significantly correlated with acceptance rates of unfair offers in ASD (CAMS ρ = .144; CSMS ρ = -.198) or TD groups (CAMS ρ = .122; CSMS ρ = .073).

Supplementary references

Hoffman, L., & Rovine, M. J. (2007). Multilevel models for the experimental psychologist: Foundations and illustrative examples. *Behavior Research Methods*, *39*(1), 101-117.

Koenigs, M., & Tranel, D. (2007). Irrational economic decision-making after ventromedial prefrontal damage: Evidence from the Ultimatum Game. *Journal of Neuroscience, 27(4),* 951–956.

Radke, S., Schafer, I., Muller, B., & de Bruijn, E. R. (2013). Do different fairness contexts and facial emotions motivate 'irrational' social decision-making in major depression? An exploratory patient study. *Psychiatry Research, 210(2),* 438–443.

Snijders, T., & Bosker, R. (1999). Multilevel analysis: An introduction to basic and applied multilevel analysis.

Weaver, B., & Black, R. A. (2015). Comment on Hoffman and Rovine (2007): SPSS MIXED can estimate models with heterogeneous variances. *Behavior research methods*, *47*(2), 355-360.