Rethinking Fast and Slow Processing in Autism

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Abstract

Following the popularity of dual process models in social and cognitive psychology, there is major interest in the possibility that autism is associated with impaired 'fast' intuitive thinking but enhanced 'slow' or 'rational' deliberative thinking. If correct, this has great potential to help understand various strengths and difficulties characteristic of autism. Previous empirical investigations of this phenomenon, however, are marred by concerns about the measurement of intuitive and deliberative processing, as well as broader problems in clinical psychological science (e.g., small underpowered studies, lack of replication). Making a step change, we conducted 4 large-scale studies to examine dual processing in autism, including a pre-registered comparison of 200 autistic and non-autistic adults. Participants completed contemporary cognitive and self-report measures of intuitive and deliberative processing, as well as a psychometrically robust measure of general cognitive ability. Except for lower self-reported intuitive thinking, we found no unique contributions of autism to intuitive or deliberative thinking across all 4 studies, as evidenced by frequentist and Bayesian analyses. Overall, these studies indicate that intuitive and deliberative thinking is neither enhanced nor particularly impaired in relation to autism. We deliberate on the implications of these findings for theories of autism and future investigation of strengths and difficulties in autistic people.

Keywords: autism, dual process theory, deliberation, intuition, decision making

General Scientific Summary

When solving problems or making decisions, autistic people engage in intuitive and deliberative mental processing similarly to non-autistic people. These mental processes are therefore unlikely to underlie clinical difficulties or strengths in autism.

Dual process theories have become dominant explanatory accounts of cognition and behavior, such as decision making, reasoning, learning, and social cognition (Evans & Stanovich, 2013). Fundamental to these theories is the overarching idea that there are two types of information processing: ‘fast’ intuitive and ‘slow’ deliberative processes. Although the precise attributes associated with these types of processing are debated (Evans, 2011; Osman, 2004), intuitive processes are broadly considered to be rapid, autonomous, non-conscious and less dependent on working memory and cognitive ability. Intuitive processes therefore underlie quick, instinctive judgements and ‘snap’ decisions, such as spontaneous trait inferences and behaviors. Conversely, deliberative processes are slower, effortful, and conscious, and more dependent on higher-order cognition. Therefore, these processes are engaged in more analytical thinking, such as solving a problem, deciding on purchases, or planning events. Default-interventionist models posit that intuitive processing occurs first, yielding a primary default response, which may be followed by deliberative processing that results in the overriding of the primary response (Evans & Stanovich, 2013).

Dual process theories have been applied to investigate and treat psychopathology, including schizophrenia, anxiety, and depression (Bronstein et al., 2019; Haeffel et al., 2007; Remmers & Zander, 2018). Such theories have also been applied to understanding Autism Spectrum Disorder (ASD; henceforth autism). Autistic people, in comparison to non-autistic people, are thought to show more engagement in ‘slow’ deliberative thinking and less engagement in ‘fast’ intuitive thinking (e.g., Brosnan et al., 2016; De Martino et al., 2008; Rozenkrantz et al., 2021). This follows growing evidence that autistic people show a *reduced* susceptibility to cognitive biases, making more consistent and rational decision choices (Farmer et al., 2017; Fujino et al., 2019). Autistic adults, for example, are less susceptible to the framing effect, a bias that results in people changing their decision choice between two equivalent options depending on the framing of options (De Martino et al., 2008; Shah et al., 2016). Under dual process theory, it has previously been proposed that this more normative responding occurs due to greater deliberation.

Dual process theories have potential to explain autism-related difficulties and strengths. Autistic social communication difficulties, for example, may be underpinned by difficulties in making rapid, intuitive judgements of social, emotional, and contextual information, which are thought to depend on intuitive processes in non-autistic populations (e.g., Rand, 2016). Equally, enhanced deliberation may confer an autistic strength enabling, for example, more rational thinking, optimal real-life decision outcomes, and enhanced moral reasoning. Consequently, dual process theory may have important practical implications, with potential to inform interventions for managing social communication difficulties in autism, whilst also speaking to recent advocacy for harnessing autistic strengths in applied settings (e.g., Huntley et al., 2019; Rozenkrantz et al., 2021). More generally, better evidence and understanding of enhanced deliberative thinking as an autism-related strength may improve societal attitudes towards autistic people, by working against the historical focus on autism-related difficulties.

However, rigorous empirical testing of the dual process theory of autism is required before pursuing its broader application. If not supported, clinical or educational interventions grounded in dual process theory would fail to target the cognitive mechanisms underpinning atypical behaviors and would be unlikely to yield improved outcomes. For instance, assuming that autistic people will benefit from additional time to accommodate their more deliberative processing style (e.g., during interviews and exams; Morsanyi & Byrne, 2020) may not be effective across contexts and could have negative consequences (e.g., creating inaccurate perceptions about their time management). Likewise, if grounded in rhetoric rather than empirical evidence, strength-based approaches to autism may potentially be more harmful than beneficial, particularly if they fail to consider the cognitive heterogeneity within the autistic population. They may perpetuate stereotypes to which many autistic people may not conform, creating unrealistic expectations of autistic people; from themselves, employers, and society. These issues reflect a broader concern that putative autistic strengths, often cited within the context of strengths-based interventions (e.g., Huntley et al., 2019), are yet to be rigorously investigated.

Few studies have directly examined dual processing in autism, with most reporting that autism was associated with lower levels of intuitive thinking and comparable or enhanced levels of deliberative thinking (Brosnan et al., 2016; 2017; Levin et al, 2015). These seminal studies had a notable strength, employing the classical Cognitive Reflection Test (CRT; Frederick, 2005) and Rational Experiential Inventory (REI; Pacini & Epstein, 1999), which are widely used measures of intuitive and deliberative thinking. The CRT is a performance-based objective measure, whereas the REI is a self-report measure of an individual's perceived engagement and ability to think intuitively and deliberatively. The CRT is the only well-validated objective measure to capture intuitive and deliberative processing on equivalent scales, rather than deliberation alone. Both intuitive and deliberative thinking scores derived from the CRT have good construct validity, predicting phenomena consistent with dual process accounts. For example, CRT scores predict performance on other cognitive bias tasks, everyday decision outcomes, job performance, and even receptivity to 'fake news' (Hoppe & Kusterer, 2011; Oechssler et al., 2009; Otero et al., 2021; Pennycook et al., 2015; Phillips et al., 2016; Toplak et al., 2011). CRT performance has also been linked with brain regions associated with inhibitory control and suppression of intuitive thinking to engage in analytical processing (e.g., Oldrati et al., 2016). The classical CRT additionally demonstrates good test-retest reliability despite being a brief measure, showing high levels of stability even after 2 years (Meyer et al., 2018; Stagnaro et al., 2018).

Whilst progress has been made in studying dual processing in autism, often using classical CRT measures, there are also methodological limitations of these initial studies that leave unanswered questions about judgement and decision-making processes in autistic people. First, there was inconsistent measurement and group matching on general cognitive ability. As deliberative thinking is highly predicted by general cognitive ability (e.g., Toplak et al., 2014), accurately measuring and accounting for the confounding influence of general cognitive ability is essential. When accounting for general cognitive ability, there may be no unique association between autism and deliberative thinking (e.g., Brosnan et al., 2017). Second, the studies utilized small samples, limiting statistical power and the generalizability of the findings. This reflects a wider problem in autism and decision-making research (e.g., De Martino et al., 2008; Shah et al., 2016). Partly addressing these issues, a recent study involved a comparatively more rigorous examination of autism-related intuitive and deliberative thinking based on autistic trait measurement in a larger sample of mainly university staff and students (Lewton et al., 2019). Having more autistic traits was predictive of lower levels of intuitive thinking and higher levels of deliberative thinking on the CRT, in line with dual process explanations of autism. Although more statistically powerful, this finding is yet to be replicated in a more representative sample of the general population and clinically diagnosed autistic samples.

Evidence in support of enhanced deliberation and lower intuition in autism is limited and has not been replicated. In total, studies have comprised fewer than 400 participants, of which fewer than 15% had clinically diagnosed autism. Further, the samples were homogeneous, consisting largely of current or prospective university students and staff, which are unrepresentative of autistic or non-autistic populations (see also, Hanel & Vione, 2016). Recently, concerns have been raised regarding the lack of replicability of clinical psychological science (Tackett et al., 2017), which can often be due to ostensibly trivial but critical limitations in sample characteristics. Unsurprisingly, therefore, many longstanding ideas in autism research have failed to hold when re-examined in larger, better-powered empirical studies and meta-analyses (e.g., atypical local-global processing; Van der Hallen et al., 2015). Given the potentially substantial theoretical and practical implications of research on dual processing in autism, conducting further studies in larger, more diverse samples is required to test the validity and replicability of the findings.

We therefore conducted four large-scale studies to replicate and extend previous work on intuition and deliberation in autism. Study 1 involved a conceptual replication of the recent and largest study on autism-related dual processing (Lewton et al., 2019). Study 2 extended Study 1 and previous research using contemporary, more psychometrically robust performance-based and self-report measures. It was conducted in a larger, well-powered non-clinical student sample. Study 3 was a pre-registered internal replication of Study 2 in a non-clinical sample of the general population to ensure replicability and generalizability of our findings. Finally, and most critically, Study 4 examined performance-based and self-reported deliberative and intuitive thinking in a pre-registered comparison of 200 clinically diagnosed autistic and 200 non-autistic adults (Study 4a). This was the most rigorous examination of dual processing in autism to date, including 5 well-powered analyses pooling data from all four datasets (Study 4b). Across all studies, we complemented the use of frequentist statistics with Bayesian analyses to quantify the strength of evidence for the null and the alternative hypothesis, therefore testing for the existence or absence of atypical intuitive and/or deliberative thinking in autism. This approach has recently led to major advances in understanding autism and other clinical phenomena (e.g., Lind et al., 2020; Nicholson et al., 2018; Taylor, Livingston, Callan, Hanel, et al., 2021).

Study 1: Conceptual Replication

We conceptually replicated Lewton et al. (2019) by examining the relationship between autistic traits and intuitive and deliberative thinking, while accounting for general cognitive ability in our analyses.

Methods

A sample of 199 English-speaking adults (130 female), aged 18-71 years, were recruited via Prolific.co (see Table 1 for characteristics), an online platform that involves several participant verification processes (Prolific Team, 2019). This sample size was chosen to be comparable to the most recent investigation of dual processing in autism (i.e., N = 189; Lewton et al., 2019) and gave us 80% power to detect at least 'small-to-medium' effects (f^2 =.040) in our regression analyses (α = .05, 2-tailed). One participant was excluded for failing one of three attention check questions (specifically, "Please select 'slightly agree' to indicate that you are reading these questions"). For all studies, research was conducted in line with APA ethical standards, as approved by Psychology Ethics Committees (projects: 2020-8378-12905 & 19-025). Participants completed the following measures in a randomized order and reported their age and sex.

Autistic Traits

Using the 50-item Autism-Spectrum Quotient (AQ; Baron-Cohen et al., 2001), participants reported their agreement with statements, such as "I find social situations easy", on a 4-point scale (*definitely agree* to *definitely disagree*). Responses were dichotomously scored, such that agreement (definitely or slightly) is scored 1 and disagreement 0, with approximately half the items reverse scored. AQ scores can range from 0-50.

General Cognitive Ability

General cognitive ability was assessed using the International Cognitive Ability Resource (ICAR; Condon & Revelle, 2014). This well-validated measure is designed for online use and comprises of matrix reasoning, three-dimensional rotation, verbal reasoning, and letter and number series. The ICAR strongly correlates with in-person intelligence tests, including the Wechsler Adult Intelligence Scale (Condon & Revelle, 2014; Dworak et al., 2020). It has previously been used in autism research (e.g., Clutterbuck et al., 2021; Farmer et al., 2017) and dual process studies in non-clinical populations (e.g., Blacksmith et al., 2019; Erceg et al., 2020). ICAR scores can range from 0-16.

Deliberative and Intuitive Thinking

The classical Cognitive Reflection Test (CRT; Frederick, 2005) was used as the performance-based cognitive measure of deliberative and intuitive thinking. Each of the three trials has an intuitive (but incorrect) answer and a deliberative (correct) answer (e.g., "A bat and a ball cost $1.10 in total. The bat costs $1.00 more than the ball. How much does the ball cost?" [intuitive response: 10 cents; deliberative response: 5 cents]). Each trial was individually presented on-screen and participants were instructed to respond as quickly and accurately as possible using a free-text response field. Following previous research using the task, there was no time constraint on each trial, such that participants had an equal opportunity to provide an intuitive or deliberative response. After responding, participants manually advanced to the next trial, and they were unable to view or modify previous responses.

Responses formed two separate measures of intuitive and deliberative thinking, where 1 point was assigned to each intuitive or deliberative response (i.e., scores can range from 0-3 on each measure). The CRT can be scored using one overall scale, however this cannot differentiate incorrect from intuitive responses. Therefore, we followed previous autism and non-autism related research (e.g., Lewton et al., 2019; Piazza & Sousa, 2014) to operationalize intuitive and deliberative thinking as two separate measures throughout our studies.

Table 1.

Participant Characteristics – Studies 1 to 3

Measure	Study 1 (n = 199)			Study 2 (n = 396)			Study 3 (n = 397)		
	M	*SD*	Range	*M*	*SD*	Range	*M*	*SD*	Range
Age (Years)	32.83	12.25	18-71	18.70	1.26	17-28	36.38	11.49	18-73
General Cognitive Ability (ICAR)	7.76	3.51	1-16	9.61	3.04	1-16	8.16	3.49	0-16
Autistic Traits (AQ)	20.34	6.78	5-40	17.43	7.18	2-43	21.09	7.91	3-49

Note: The ICAR and AQ have maximum scores of 16 and 50, respectively.

Results and Discussion

In line with previous research (e.g., Lewton et al., 2019; Ruzich et al., 2015; Taylor et al., 2020), there was a wide range of AQ scores (Table 1), suggesting adequate variance to test for autism-related associations. There were no significant correlations between autistic traits and deliberative, $r(197) = 0.03$, $p = .68$, or intuitive, $r(197) = -0.06$, $p = .42$, thinking (Table S1). Regression analyses examined the unique contribution of autistic traits to intuitive and deliberative thinking, while accounting for age, sex, and general cognitive ability (variables were modelled simultaneously). As expected, general cognitive ability was predictive of CRT performance and, supporting the non-significant correlations, autistic traits were not significantly predictive of deliberative or intuitive thinking (Table 2). Bayesian equivalents of each regression were also conducted by comparing models with and without autistic traits included as a predictor (following Taylor, Livingston, Callan, Hanel, et al., 2021; see Supplementary Materials for details). Bayes Factors (BF_{10}) quantified the support for the two-tailed hypothesis (H_1 = autistic traits are uniquely predictive of the outcome) compared to the null hypothesis (H_0 = autistic traits are not uniquely predictive of the outcome). This revealed evidence, albeit ‘anecdotal’, supporting the null over the alternative hypotheses (Table 2; i.e., BF_{10} between $0.3\dot{3}$ – 1). That is, autistic traits were neither predictive of deliberative nor intuitive thinking (see Table S2 for Bayes Factor interpretation from Wagenmakers et al., 2011).

Table 2.

Regression Analyses Predicting Intuitive and Deliberative Thinking – Study 1

Criterion Predictors	R^2	*B* [95% CI]	SE_B	*β*	sr^2	*p*	BF_{10}
Deliberative Thinking	.46						
Autistic Traits (AQ)		0.01 [-0.00, 0.03]	0.01	0.08	.007	.13	0.391
General Cognitive Ability (ICAR)		0.22 [0.19, 0.26]	0.02	0.67	.397	<.001	
Sex (Males = 1, Females = 0)		0.21 [-0.06, 0.48]	0.14	0.09	.007	.13	
Age (Years)		-0.00 [-0.02, 0.01]	0.01	-0.05	.002	.36	
Intuitive Thinking	.32						
Autistic Traits (AQ)		-0.02 [-0.04, 0.00]	0.01	-0.11	.011	.08	0.701
General Cognitive Ability (ICAR)		-0.17 [-0.21, -0.13]	0.02	-0.57	.285	<.001	
Sex (Males = 1, Females = 0)		-0.09 [-0.37, 0.18]	0.14	-0.04	.002	.51	
Age (Years)		0.01 [-0.01, 0.02]	0.01	0.06	.003	.33	

Study 1 provided initial evidence against differential contributions of autism to intuitive and deliberative thinking, in contrast with most previously published findings (e.g., Lewton et al., 2019). However, several limitations preclude drawing strong conclusions. First, the classical CRT has previously been susceptible to floor and ceiling effects (Stieger & Reips, 2016). Although we did not find this in Study 1, it has a limited range, as well as a focus on numerical cognition, tapping less into intuitive and deliberative thinking without numerical computation (Sirota & Juanchich, 2011). This is particularly important within the context of the present research, as autism has classically been associated with preferences for, and enhanced abilities in, mathematics (Baron-Cohen et al., 2001). Therefore, enhanced CRT performance in autism – though not found in Study 1 but reported in previous research – may be indicative of numerical preferences and abilities rather than deliberative processing *per se*. More generally, Study 1 relied on performance-based measures of intuitive and deliberative thinking, however their use could be augmented by subjective, self-report measures, for a more complete characterization of these processes in everyday life.

Second, the classical CRT is now widely used, even within non-scientific situations, hence it was possible that our participants had previously been exposed to its items. Indeed, in a previous sample recruited via Prolific, 51% of the participants were familiar with the CRT items (Haigh, 2016). Given that the validity of the CRT may be dependent on the naivety of participants (i.e., that the items initially elicit an incorrect intuitive answer), increased familiarity may result in more 'deliberative' responding without genuine deliberation (e.g., Stieger & Reips, 2016). Exposure to CRTs has not been explored in autism, and whether it was consequential for task performance in previous research and Study 1 is unclear.

Third, although Study 1 was well-powered, it remained possible that we were unable to detect a very small association between autistic traits and intuition and deliberation. Accordingly, the Bayes factors only provided ‘anecdotal’ evidence for the null hypotheses, which may be more conclusive in follow-up studies with larger samples.

Finally, our recruitment of a sample from the general population was a major deviation from previous research largely focusing on students. This was a strength rather than a limitation, yet it left open the possibility that previous findings of autism-related links to dual processing were a feature of students or young adults.

Study 2: Student Sample

Addressing limitations in Study 1, we conducted a follow-up study using comprehensive measures of performance-based and self-reported intuitive and deliberative thinking. We administered newer, longer CRTs (Sirota et al., 2020; Toplak et al., 2014), including numerical and non-numerical intuition and deliberation. The validity, reliability, and utility of improved CRTs have been rigorously tested across multiple studies and samples (e.g., Sirota et al., 2020; Šrol, 2018; Toplak et al., 2014), to the extent that some are even being used in important studies on COVID-19 misinformation interventions (e.g., Juanchich et al., 2021; Pennycook et al., 2020). More comprehensive CRT measures also have a demonstrable relationship with emerging self-report measures of intuitive and deliberative thinking (Newton et al., 2021). Like the classical CRT, they have good predictive validity, with established associations with intuitive and deliberative thinking that underlies performance on various cognitive tasks (e.g., belief bias, denominator neglect, Bayesian reasoning), moral reasoning, and risk/time preferences (Jackson et al., 2016; Sirota & Juanchich, 2018; Sirota et al., 2020; Toplak et al., 2014). Moreover, these measures have good test-retest reliability (e.g., Sirota et al., 2020) and, compared to the classical CRT, produce a greater range of scores for a more sensitive measure of individual differences in intuitive and deliberative thinking. In addition to administering these measures, we also explored whether prior exposure to their items influences the potential link between autism and task performance. Finally, we conducted this study in a large student sample. Whilst limiting the generalizability of the arising findings, this would permit closer comparisons with previous student-focused research.

Methods

A sample of 396 English-speaking students on various degree programs (341 female, 54 male, 1 other), aged 17-28 years, were recruited from two UK universities to form a convenience sample (see Table 1 for participant characteristics). A minimum sample size of 395 was pre-determined to provide 80% power to detect at least “small” effect sizes ($f^2 = 0.02$, $\alpha = 0.05$, two-tailed). Following recommendations from Camerer et al. (2018), this also provided >90% power to detect 50% of the smallest effect size of a published link between autistic traits and intuitive and deliberative thinking (Lewton et al., 2019). Nine additional participants were excluded for failing either of two simple attention checks. Participants completed the measures of autistic traits (AQ; Baron-Cohen et al., 2001) and general cognitive ability (ICAR; Condon & Revelle, 2014) used in Study 1 and the following measures in a randomized order.

Numerical Deliberative and Intuitive Thinking

The Numerical Cognitive Reflection Test (Numerical CRT) was administered as an improved measure of deliberative and intuitive thinking. Its 7 trials include the classical CRT, as used in Study 1, and 4 more recently developed trials (Toplak et al., 2014). With additional trials, this CRT has increased sensitivity to individual differences and guards against concerns of participant exposure to the classical CRT items. Like the classical CRT, participant responses are scored on two scales, where 1 point is scored for each intuitive or deliberative response. Scale scores range from 0-7. The CRT necessitates manual scoring, typically performed by the experimenter in previous research, as in Study 1. Moving forward, a research assistant, blind to the study aims, additionally scored participant responses to obviate any concerns about bias on CRT scoring. There was excellent inter-rater agreement (99.9% across Studies 2-4).

Verbal Deliberative and Intuitive Thinking

The Verbal Cognitive Reflection Test (Verbal CRT; Sirota et al., 2020), the most recently developed CRT, measures deliberative and intuitive thinking without numerical computation. Its 10 trials can elicit an intuitive (but incorrect) response and a deliberative (correct) response (e.g., “Mary’s father has 5 daughters but no sons – Nana, Nene, Nini, Nono. What is the fifth daughter’s name probably?” [intuitive answer: Nunu, deliberative answer: Mary]). Responses are scored on two scales, where 1 point is scored for each intuitive or deliberative response. Scale scores range from 0-10. Double coding of responses had excellent inter-rater agreement (99.4% across Studies 2-4).

Cognitive Reflection Test Exposure

To measure exposure to the CRT items, participants were asked “Have you ever encountered any of the previous items before completing them in this study” after completing the CRTs (as in Stieger & Reips, 2016). Participants provided a “Yes” or “No” response that was coded as 1 or 0, respectively. Exposure to Numerical and Verbal CRT items was measured separately.

Self-reported Deliberative and Intuitive Thinking

The 40-item Rational-Experiential Inventory (REI; Pacini & Epstein, 1999) measured self-reported deliberative and intuitive thinking. The questionnaire has two scales: The ‘Rational’ scale measured perceived ability and preference for deliberative thinking (e.g., “I have a logical mind”), whereas the ‘Experiential’ scale measured perceived ability and preference for intuitive thinking (e.g., “I believe in trusting my hunches”). Participants reported their agreement with statements on a 5-point scale (*definitely not true* to *definitely true*). Scores can range from 20-100 on each scale.

Results and Discussion

Despite being a student sample, predictably limited in age range, there was a wide range of AQ scores (Table 1). This was comparable to Study 1 and previous research. Also following Study 1, autistic traits were not significantly correlated with deliberative or intuitive thinking (all *p*s ≥.25), aside from one association with lower self-reported intuitive thinking, $r(394) = -0.22$, $p < .001$ (Table S3). Consistent with these correlations and Study 1, autistic traits remained non-significant predictors of performance-based deliberative or intuitive thinking, whilst accounting for participants’ age, sex, and general cognitive ability (Table 3). Bayesian modelling indicated ‘substantial’ evidence that autistic traits were not predictive of deliberative and intuitive thinking (i.e., all BF_{10} between 0.10 – 0.33). This pattern of results was also found whilst accounting for exposure to the CRT items (see Supplementary Materials). Similarly, autistic traits were not a significant predictor of self-reported deliberative thinking and the Bayesian analysis did not provide conclusive evidence for or against this association. Following the only significant autism-related correlation, autistic traits were uniquely predictive of lower self-reported levels of intuitive thinking, with ‘extreme’ evidence for this link ($BF_{10} > 100$; Table 3).

This study extended the findings from Study 1, providing stronger evidence *against* differential contributions of autism to deliberative and intuitive thinking. By including the Verbal CRT measure, this was the first evidence that the pattern of results generalizes to contexts without requiring numerical calculations. While Study 2 represented an advance on previous research, there were two critical limitations and outstanding issues to pursue in a follow-up study. First, the sample consisted of university students to permit comparisons with previous research. Specifically, Study 2 did not replicate previously reported links between autistic traits and intuitive and deliberative thinking (e.g., Lewton et al., 2019), which cannot be attributed to a change in sample composition (i.e., students versus non-students). Moving forward, however, the findings required replication in a more representative sample of the population. This would necessitate sampling from a broader age range and a balanced number of males and females. Second, while we adhered to many good practices in Studies 1 and 2 (e.g., conducting *a priori* power calculations to determine sufficient power), we had not pre-registered our hypotheses or analysis plan.

Table 3

Regression Analyses Predicting Deliberative and Intuitive Thinking – Study 2

Processing Type	**Criterion Predictors**	R^2	***B* [95% CI]**	SE_B	β	sr^2	p	BF_{10}
Deliberative	**Numerical**	.31						
	Autistic Traits (AQ)		-0.01 [-0.03, 0.02]	0.01	-0.03	.001	.50	0.143
	General Cognitive Ability (ICAR)		0.36 [0.30, 0.42]	0.03	0.51	.251	<.001	
	Sex		0.88 [0.35, 1.40]	0.27	0.14	.019	.001	
	Age (Years)		-0.07 [-0.21, 0.07]	0.07	-0.04	.002	.34	
	Verbal	.13						
	Autistic Traits (AQ)		0.00 [-0.03, 0.03]	0.02	0.00	.000	.99	0.150
	General Cognitive Ability (ICAR)		0.27 [0.19, 0.35]	0.04	0.32	.096	<.001	
	Sex		0.20 [-0.51, 0.92]	0.36	0.03	.001	.58	
	Age (Years)		-0.33 [-0.52, -0.14]	0.10	-0.17	.027	<.001	
	Self-reported	.08						
	Autistic Traits (AQ)		-0.14 [-0.27, 0.00]	0.07	-0.10	.009	.052	1.083
	General Cognitive Ability (ICAR)		0.83 [0.50, 1.16]	0.17	0.25	.058	<.001	
	Sex		2.23 [-0.73, 5.18]	1.50	0.07	.005	.14	
	Age (Years)		0.34 [-0.45, 1.13]	0.40	0.04	.002	.40	
Intuitive	**Numerical**	.21						
	Autistic Traits (AQ)		0.02 [-0.01, 0.04]	0.01	0.06	.004	.17	0.328
	General Cognitive Ability (ICAR)		-0.25 [-0.30, -0.19]	0.03	-0.42	.166	<.001	
	Sex		-0.71 [-1.19, -0.23]	0.24	-0.14	.017	.004	
	Age (Years)		0.06 [-0.07, 0.19]	0.06	0.04	.002	.36	
	Verbal	.12						
	Autistic Traits (AQ)		-0.01 [-0.03, 0.02]	0.01	-0.03	.001	.52	0.183
	General Cognitive Ability (ICAR)		-0.18 [-0.24, -0.12]	0.03	-0.28	.077	<.001	
	Sex		-0.08 [-0.62, 0.45]	0.27	-0.02	.000	.76	
	Age (Years)		0.31 [0.17, 0.45]	0.07	0.21	.042	<.001	
	Self-reported	.06						
	Autistic Traits (AQ)		-0.31 [-0.46, -0.17]	0.08	-0.21	.042	<.001	700.204
	General Cognitive Ability (ICAR)		-0.07 [-0.42, 0.29]	0.18	-0.02	.000	.71	
	Sex		-2.73 [-5.91, 0.44]	1.61	-0.09	.007	.092	
	Age (Years)		-0.03 [-0.87, 0.82]	0.43	-0.00	.000	.95	

*Note***.** Males = 1 and Females = 0 when coding sex. Further details about REI subscales and exploratory regressions are reported in the Supplementary Materials.

Study 3: Pre-registered Study in a Non-Clinical Sample

Study 3 involved an internal replication, whereby a more representative sample from the general population than previous research and Studies 1 and 2 completed the procedure used in Study 2. In addition to improving upon the generalizability of the findings from Studies 1 and 2, internal replication studies help to improve reproducibility by reducing the likelihood that an originally identified (null) effect is due to unmeasured contextual moderator variables (e.g., time of data collection; Lewandowsky & Oberauer, 2020). This study was pre-registered on *aspredicted.org* prior to data collection (https://aspredicted.org/wi2ib.pdf).

Methods

Replicating Study 2, a minimum sample size of 395 was pre-determined to provide 80% power to detect at least "small" effect sizes ($f^2 = 0.02$, $\alpha = 0.05$, two-tailed). A sample of 397 English-speaking adults from the UK were recruited via Prolific.co. The sampling approach ensured a much wider age range (18-73 years) and balance of male ($n = 190$) and female ($n = 207$) participants compared to Studies 1 and 2 (Table 1). Six additional participants were excluded for failing either of two attention checks. Participants completed the same procedure from Study 2.

Results and Discussion

A wide range of AQ scores were found in the sample, even more so than Studies 1 and 2 (Table 1). Autistic traits were correlated with performance-based numerical deliberative, $r(395) = 0.14$, $p = .006$, numerical intuitive, $r(395) = -0.11$, $p = .034$, and self-reported intuitive, $r(395) = -0.31$, $p < .001$, thinking (Table S4). Critically, after accounting for age, sex, and general cognitive ability, regression analyses revealed a pattern of results consistent with Studies 1 and 2 (Table 4). Autistic traits were not a significant predictor of performance-based deliberative or intuitive thinking, with 'substantial' evidence for this pattern of results (BF_{10} between 0.10 – 0.33). Replicating Study 2, this pattern did not change after accounting for exposure to CRT items (see Supplementary Materials). Autistic traits were not a significant predictor of self-reported deliberative thinking and the Bayesian analysis indicated 'anecdotal' support (BF_{10} between 0.33 – 1) for the null hypothesis. Autistic traits were predictive of lower self-reported levels of intuitive thinking, with 'extreme' evidence for this association (BF_{10} >100), also replicating Study 2.

Table 4

Regression Analyses Predicting Deliberative and Intuitive Thinking – Study 3

Processing Type	**Criterion** / **Predictors**	R^2	***B* [95% CI]**	SE_B	β	sr^2	p	BF_{10}
Deliberative	**Numerical**	.42						
	Autistic Traits (AQ)		0.01 [-0.01, 0.03]	0.01	0.04	.002	.31	0.157
	General Cognitive Ability (ICAR)		0.38 [0.33, 0.43]	0.03	0.59	.335	<.001	
	Sex		0.80 [0.45, 1.14]	0.18	0.18	.030	<.001	
	Age (Years)		0.01 [-0.00, 0.03]	0.01	0.06	.003	.12	
	Verbal	.26						
	Autistic Traits (AQ)		-0.00 [-0.04, 0.03]	0.02	-0.01	.000	.79	0.126
	General Cognitive Ability (ICAR)		0.40 [0.33, 0.48]	0.04	0.50	.235	<.001	
	Sex		0.32 [-0.17, 0.82]	0.25	0.06	.003	.20	
	Age (Years)		0.02 [-0.00, 0.04]	0.01	0.07	.005	.10	
	Self-reported	.14						
	Autistic Traits (AQ)		-0.13 [-0.27, 0.00]	0.07	-0.09	.008	.058	0.862
	General Cognitive Ability (ICAR)		1.21 [0.90, 1.53]	0.16	0.36	.123	<.001	
	Sex		1.38 [-0.84, 3.60]	1.13	0.06	.003	.22	
	Age (Years)		0.09 [-0.01, 0.18]	0.05	0.08	.007	.077	
Intuitive	**Numerical**	.27						
	Autistic Traits (AQ)		-0.01 [-0.03, 0.01]	0.01	-0.03	.001	.52	0.152
	General Cognitive Ability (ICAR)		-0.24 [-0.29, -0.20]	0.02	-0.47	.208	<.001	
	Sex		-0.56 [-0.87, -0.24]	0.16	-0.15	.023	<.001	
	Age (Years)		-0.01 [-0.03, 0.00]	0.01	-0.08	.007	.053	
	Verbal	.20						
	Autistic Traits (AQ)		-0.00 [-0.03, 0.03]	0.01	-0.00	.000	.94	0.135
	General Cognitive Ability (ICAR)		-0.28 [-0.34, -0.22]	0.03	-0.42	.170	<.001	
	Sex		-0.38 [-0.80, 0.04]	0.21	-0.08	.006	.079	
	Age (Years)		-0.01 [-0.03, 0.01]	0.01	-0.05	.002	.30	
	Self-reported	.19						
	Autistic Traits (AQ)		-0.39 [-0.52, -0.26]	0.07	-0.27	.069	<.001	8.84×10^5
	General Cognitive Ability (ICAR)		-0.69 [-1.00, -0.39]	0.15	-0.21	.042	<.001	
	Sex		-4.40 [-6.51, -2.28]	1.08	-0.19	.035	<.001	
	Age (Years)		-0.00 [-0.10, 0.09]	0.05	-0.00	.000	.91	

*Note***.** Males = 1 and Females = 0 when coding sex. Further details about REI subscales and exploratory regressions are reported in the Supplementary Materials.

Study 3 suggested the findings from our earlier studies are robust, generalizable, and independent of contextual factors and sampling technique. However, while examining autistic traits in non-clinical samples (as in Studies 1-3) is widely used to inform understanding of clinically diagnosed populations (see Happé & Frith, 2020 for recent discussion), it was important to establish if the results from Studies 1 to 3 would be found in samples with clinically diagnosed autism.

Study 4a: Pre-registered Case-Control Study

To guard against the possibility that the foregoing results were due to the use of our dimensional, trait-wise measurement of autism, we conceptually replicated Studies 1-3 by comparing intuitive and deliberative thinking in clinically diagnosed autistic adults with a non-autistic group. Study 4a involved the largest clinically diagnosed sample to date, with a sample >7× larger than previous research (e.g., Brosnan et al., 2017; Levin et al., 2015).

Methods

Two hundred autistic adults (105 female, 94 male, 1 other), aged 18-59 years were recruited via Prolific.co, after undergoing multiple participant verification processes (Prolific Team, 2019). All participants were UK residents and had a clinical diagnosis of an ASD according to DSM or ICD criteria (American Psychiatric Association, 2013; World Health Organization, 2019). Participants received their diagnoses, either as a child or adult, from an independent UK or US-based healthcare professional in a well-recognized clinical setting. Diagnoses were confirmed at multiple time points during a screening process and at the start of the study. Following recent approaches to recruiting large samples of clinically diagnosed autistic people (e.g., Farmer et al., 2017; Grove et al., 2013; Milne et al., 2019), participants provided detailed information about their diagnosis (e.g., Asperger Syndrome, Autism Spectrum Disorder), including specific details about the diagnosing clinician(s) (e.g., Psychiatrist, Psychologist), and the location of diagnosis. Importantly, individuals who self-identified as autistic or those seeking a diagnosis were *not* eligible to participate. Many participants had also recently participated in our autism research (e.g., Clutterbuck et al., 2021; Livingston et al., 2019; Livingston et al., 2021), including in-person studies (e.g., Taylor, Livingston, Callan, Ashwin, et al., 2021), providing further confidence that they had a formal diagnosis of ASD. Overall, recruitment of our ASD sample was carefully conducted to mitigate against potential concerns with online autism research. One additional participant was excluded as they did not provide sufficient diagnostic information and 11 other participants were excluded for failing either of two attention checks.

The non-autistic group of 200 participants was formed by randomly selecting participants from the Study 2 and 3 datasets who had specifically indicated, at multiple time-points during a screening process, that they did not i) have a clinically diagnosed ASD, ii) self-identify as autistic, or iii) suspect they had a diagnosable ASD. This selection process was fully automated, with the constraints being that the autistic and non-autistic groups were as closely matched as possible on age, sex, and general cognitive ability (Table 5). This permitted far more closely matched groups than would have been possible by recruiting a new sample. The final sample size of 400 gave us 80% power to detect at least "small-to-medium" sized group differences ($d = 0.28$, $\alpha = 0.05$, two-tailed). This study was pre-registered prior to data collection in the autistic group and any group comparisons (https://aspredicted.org/vg4dc.pdf). Apart from questions about their diagnosis, autistic participants completed the same procedure as non-autistic participants in Studies 2 and 3.

The autistic group reported having significantly more autistic traits than the non-autistic group, $t(398) = 19.93$, $p < .001$, $d = 1.99$ [1.75, 2.23], $BF_{10} = 1.13\times10^{58}$ (Table 5). Most of the autistic group scored ≥32 (65%) on the AQ, i.e., meeting the 'clinical' threshold, and 82% scored ≥26, i.e., the 'screening' threshold for clinically significant levels of autistic traits (Baron-Cohen et al., 2001). In contrast, almost all non-autistic participants scored <26 and <32 on the AQ (85% and 96%, respectively). These percentages align with the sensitivity and specificity of the AQ to clinically diagnosed autism (Ashwood et al., 2016; Woodbury-Smith et al., 2005). Accordingly, average AQ scores in our autistic ($M = 34.05$) and non-autistic ($M = 18.55$) groups were comparable to existing clinical and lab-based research (e.g., Shah et al., 2016; Taylor, Livingston, Callan, Ashwin, et al., 2021) and were within the range of AQ scores reported in a large meta-analysis of clinically diagnosed autistic ($M = 35.19$, Range = 27.6 – 41.1) and non-autistic samples ($M = 16.94$, Range = 11.6 – 20.0; see Ruzich et al., 2015).

Table 5.

Matching Autistic and Non-Autistic Groups

Measure	**Autistic**			**Non-Autistic**			**Group Comparisons**			
	M	*SD*	Range	*M*	*SD*	Range	*t*	*p*	*d* [95% CI]	BF_{10}
Sex (*n* female, male, other)	105, 94, 1			105, 94, 1			-	>.99	-	-
Age (Years)	28.15	8.91	18-59	28.45	8.86	18-59	-0.33	.74	-0.03 [-0.23, 0.16]	0.117
General Cognitive Ability (ICAR)	8.37	3.74	0-16	8.59	3.32	0-16	-0.61	.54	-0.06 [-0.26, 0.14]	0.132
Autistic Traits (AQ)	34.05	8.49	14-49	18.55	7.00	5-37	19.93	<.001	1.99 [1.75, 2.23]	1.13×10^{58}

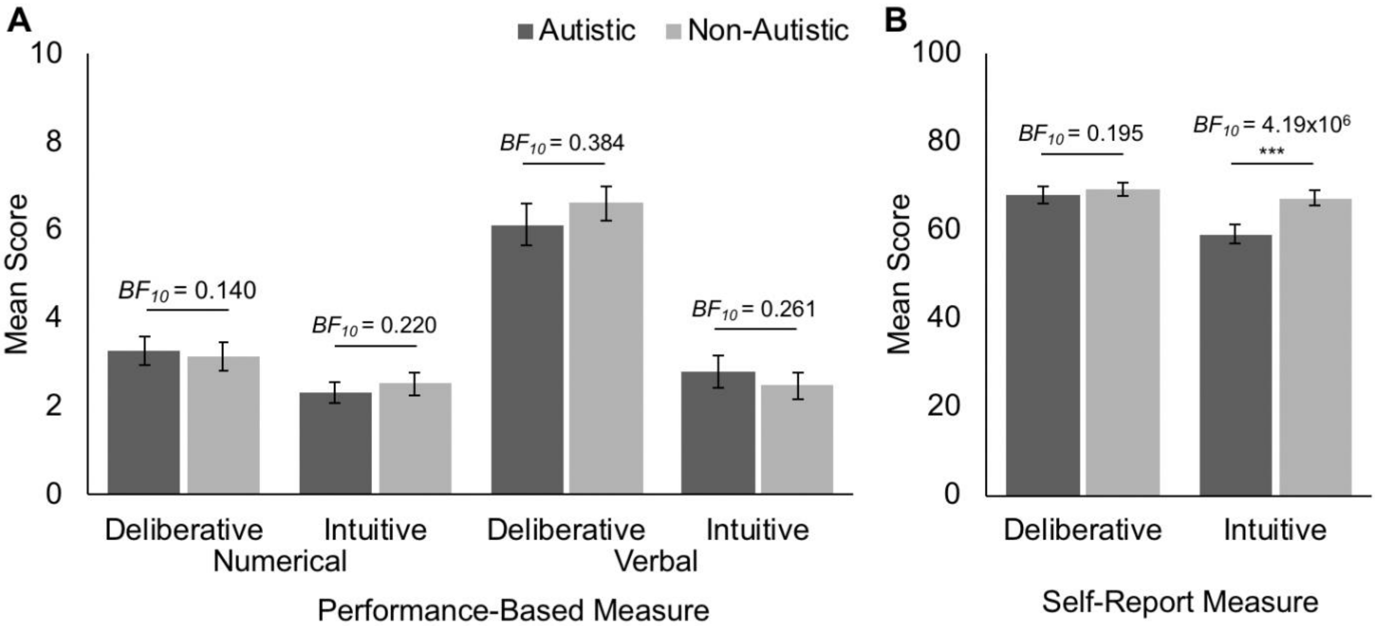
Note. Independent samples t-tests are reported. Robust t-tests and Mann-Whitney U tests produced the same pattern of results. The ICAR and AQ have maximum scores of 16 and 50, respectively.

Results and Discussion

Following Studies 1-3, the autistic group *did not* significantly differ from the non-autistic group on performance-based deliberative or intuitive thinking. The Bayesian analyses confirmed evidence for no group differences (Figure 1A). There were no significant group differences in self-reported deliberative thinking, with 'substantial' evidence (all BF_{10} between 0.10 – 0.33) in support of this null relationship (Figure 1B). Consistent with Studies 2 and 3, the autistic group self-reported significantly lower intuitive thinking than the non-autistic group, with 'extreme' evidence for this group difference (BF_{10} >100; Figure 1B). This pattern of results held when accounting for participant age, sex, and general cognitive ability (Table S5) and exposure to CRT items (see Supplementary Materials). Overall, Study 4 was consistent with the foregoing studies.

Figure 1

Comparing Intuitive and Deliberative Thinking between Autistic and Non-Autistic Groups using (A) Performance-Based and (B) Self-Report Measures.



Note. Results from frequentist and Bayesian t-tests are shown. Robust t-tests and Mann-Whitney U tests produced the same pattern of results. Error bars represent 95% confidence intervals. Group means and correlations across groups are reported in Table S6 and S7, respectively. BF_{10}: Bayes Factor, ***p <.001

Study 4b: Pooled Analyses using AQ Thresholds and Scores

In Study 4a, we did not conduct research-derived assessments to confirm autism diagnoses (e.g., Autism Diagnostic Observation Schedule [ADOS]; Lord et al., 2000). Not conducting such assessments is common in large-scale studies (e.g., Farmer et al., 2017; Grove et al., 2013; Milne et al., 2019; Taylor et al., 2020) and, even when these assessments are conducted, researchers often retain autistic participants falling below ASD thresholds to aim for a representative sample (e.g., De Martino et al., 2008; Lind et al., 2020; Nicholson et al., 2018; Ring et al., 2017). Nonetheless, in the absence of research-derived autism assessments, it could be argued that Study 4a results were due to poorly defined groups.

To determine the robustness of Study 4a, in Study 4b we re-analyzed our data using the well-established ≥32 ‘clinical’ and ≥26 ‘screening’ thresholds on the AQ as additional inclusion/exclusion criteria to define autistic and non-autistic groups. Because there is debate regarding AQ thresholds (e.g., Ashwood et al., 2016), we applied both the ≥26 and ≥32 values across separate analyses. Using these criteria across different analyses provided a robustness check – by further ensuring the correct classification of participants to the autistic and non-autistic groups – before we re-tested the associations between autism and dual processing.

Method

We pooled and re-analyzed data from Studies 2-4a to conduct 5 analyses based on AQ scores (see Table S8 for sample characteristics). We first compared groups of non-autistic participants scoring <26 with autistic participants who scored ≥26 (n = 164; Analysis 1) and ≥32 (n = 130; Analysis 2) on the AQ. An automated matching procedure, as used in Study 4a, ensured groups were matched on age, sex, and general cognitive ability (Table S9). As this reduced sample sizes, Analyses 3 and 4 compared the two autistic groups, defined based on the ≥26 and ≥32 AQ thresholds, to *all non-autistic participants* scoring <26 (n = 603). These groups were not matched (Table S9), hence age, sex, and general cognitive ability were covariates in these analyses. Finally, to overcome any residual concerns about diagnostic status, AQ thresholds, and statistical power, all 991 participants from Studies 2-4a were pooled into Analysis 5. Continuous AQ score, between 0-50, was the predictor of each dependent variable, whilst accounting for age, sex, and general cognitive ability.

Results and Discussion

Regression models demonstrated a pattern of results that was consistent with Studies 1-4a, confirming that autism was not meaningfully associated with intuitive or deliberative scores on the CRTs. All effects were approximately zero, with 100% of Bayes Factors and 90% of *p*-values supporting the null results (Table 6). Following Studies 2-4a, autism was associated with lower self-reported intuitive thinking, which was the only consistent association across Study 4b (all $p<.001$, $BF_{10}>100$). Autism also predicted *lower* self-reported deliberative thinking in Analyses 3 and 5, however these associations were not stable across Study 4b, and we had not consistently found them in Studies 2-4a. Irrespective of their robustness, the associations were in the *opposite* direction to the positive association between autism and deliberative thinking that would be expected under dual process explanations of autism. Overall, the results of Study 4b were highly consistent with our previous findings. They provide additional support for our group classifications in Study 4a, conceptually replicate Studies 1-3, and provide further evidence against the dual process account of autism.

Table 6.

Pooled Analyses using Autism-Spectrum Quotient (AQ) Thresholds and Continuous Scores – Study 4b

Analysis	**AQ Threshold**	***n* (ASD, NA)**	**Deliberative**						**Intuitive**					
			Numerical		Verbal		Self-report		Numerical		Verbal		Self-report	
			B [95% CIs]	BF_{10}	*B* [95% CIs]	BF_{10}	*B* [95% CIs]	BF_{10}	*B* [95% CIs]	BF_{10}	*B* [95% CIs]	BF_{10}	*B* [95% CIs]	BF_{10}
Study 4a	None	200, 200	0.16 [-0.29, 0.61]	0.14	-0.49 [-1.08, 0.11]	0.38	-1.39 [-3.89, 1.12]	0.20	-0.21 [-0.56, 0.14]	0.22	0.32 [-0.15, 0.79]	0.26	-8.21*** [-10.84, -5.58]	4.2×10^{6}
1	ASD ≥26 NA <26	164, 164	0.35 [-0.15, 0.84]	0.31	-0.18 [-0.83, 0.46]	0.14	-2.20 [-5.04, 0.63]	0.37	-0.38* [-0.76, -0.01]	0.84	0.07 [-0.44, 0.59]	0.13	-13.20*** [-15.99, -10.41]	2.2×10^{15}
2	ASD ≥32 NA <26	130, 130	0.45 [-0.09, 0.98]	0.48	0.02 [-0.66, 0.71]	0.14	-2.29 [-5.27, 0.68]	0.40	-0.39 [-0.81, 0.03]	0.68	0.01 [-0.54, 0.55]	0.14	-14.91*** [-18.00, -11.81]	2.4×10^{15}
3	ASD ≥26 NA <26	163, 603	0.08 [-0.23, 0.38]	0.11	-0.38 [-0.82, 0.05]	0.42	-2.62** [-4.54, -0.69]	3.05	-0.20 [-0.47, 0.07]	0.30	0.34 [-0.01, 0.69]	0.54	-12.61*** [-14.62, -10.60]	2.8×10^{28}
4	ASD ≥32 NA <26	129, 603	0.18 [-0.15, 0.52]	0.20	-0.08 [-0.55, 0.39]	0.12	-1.69 [-3.75, 0.38]	0.35	-0.31* [-0.61, -0.02]	0.88	0.14 [-0.24, 0.52]	0.14	-14.73*** [-16.88, -12.57]	2.7×10^{33}
5	None, Continuous AQ score	991	0.01 [-0.01, 0.02]	0.09	-0.01 [-0.02, 0.01]	0.10	-0.11** [-0.18, -0.04]	6.84	-0.01 [-0.02, 0.01]	0.12	0.00 [-0.01, 0.02]	0.11	-0.52*** [-0.59, -0.45]	5.1×10^{37}

Note. Non-matching group estimates (see Table S9) adjust for covariates (age, sex, and general cognitive ability). Participants who reported their sex as 'other' were therefore excluded from non-matched group analyses, i.e., Analysis 3-5. Group coded Non-Autistic (NA) = 0, Autistic (ASD) = 1. *B*s represent the unstandardized mean—or adjusted mean—difference between groups, except for Analysis 5 where AQ scores were treated continuously. *$p<.05$, **<.01, ***$p<.001$

General Discussion

Within the dual process framework, it has previously been proposed that autism is associated with greater deliberative and reduced intuitive thinking. However, across 4 large-scale, methodologically rigorous studies, we consistently found no meaningful contributions of autism to objectively measured intuitive or deliberative thinking, and a single link between autism and subjective, self-reported intuitive thinking. Critically, this pattern of results was clear when, i) measuring autistic traits in non-clinical samples from the general population (Studies 1-3), ii) comparing large groups of age-, sex- and general cognitive ability-matched clinically diagnosed autistic and non-autistic people (Study 4a), and iii) applying inclusion criteria based on AQ thresholds after pooling datasets (Study 4b).

Our findings on performance-based deliberative and intuitive thinking contrast with previous research directly or indirectly invoking dual process theories in understanding autism (e.g., Brosnan et al., 2016; 2017; De Martino et al., 2008; Lewton et al., 2019; Rozenkrantz et al., 2021; Shah et al., 2016). This is surprising given that several studies had pointed towards this phenomenon, but also unsurprising given the limitations of previous studies, particularly the limited and inconsistent measurement of general cognitive ability, small samples sizes, and the lack of replication. Most of these studies were equally limited by only measuring intuition and deliberation processes using numerical measures. Therefore, to advance current knowledge of dual processing in autism, we systematically addressed these limitations through several methodological advancements, which speak to a better understanding of dual process theory in typical and atypical populations.

First, we included a well-validated measure of general cognitive ability across our studies. In accordance with previous literature (e.g., Toplak et al., 2014), we found that general cognitive ability was consistently the strongest predictor of deliberative and intuitive thinking. Notably, even when there were correlations between autism and performance-based intuitive and deliberative thinking (i.e., Study 3), these associations were not significant after accounting for general cognitive ability in the regression models. Thus, our findings reinforce the importance of controlling for general cognitive ability when conducting research on intuitive and deliberative thinking.

Second, we employed robust, newly developed CRTs, which were more sensitive and had less measurement error, to accurately determine the associations between autism and intuitive and deliberative thinking. Further, using separate Verbal and Numerical CRTs, we showed that autism is not associated with intuitive or deliberative thinking irrespective of numeracy skills. Following the conflation of numerical ability and deliberation on the classical CRT (Sirota & Juanchich, 2011), the positive associations between autism and deliberative thinking found in previous research (e.g., Brosnan et al., 2016) could be attributable to superior numerical ability in autistic samples, rather than enhanced deliberation *per se*. Inclusion of the Verbal CRT addressed this issue, eliminating numerical calculation from CRTs, thereby reducing its dependency on numerical and cognitive ability. Indeed, across our studies, general cognitive ability was a larger predictor of performance on the Numerical than Verbal CRT. Thus, our findings reflect recommendations that the Verbal CRT may offer a more optimal performance-based measure of intuitive and deliberative thinking (Sirota et al., 2020). While CRTs remain the optimal measure of intuitive and deliberative thinking, there are fervent debates and an ever-burgeoning literature on their use (e.g., Erceg et al., 2020). Our administration of the newest CRT represents an advance to autism research, but it will be important to keep abreast of non-clinical research on CRTs when designing future studies on dual processing in autism and other clinical conditions.

Third, we measured and accounted for previous exposure to the CRT items. In line with recent findings from the dual processing literature (e.g., Bialek & Pennycook, 2018; Stieger & Reips, 2016), exposure to the CRTs was associated with greater deliberative and reduced intuitive thinking. Critically, however, participant exposure to the CRTs did not change the pattern of (null) relationships between autism and intuitive and deliberative thinking, thereby underscoring the robustness of these relationships. Nonetheless, our results support recommendations that exposure could routinely be accounted for in statistical models to enhance the measurement of intuitive and deliberative thinking (Stieger & Reips, 2016). Our study was the first to find significant effects of exposure on Verbal CRT performance, that is, the same pattern of results for Numerical CRTs. The effect of exposure to the classical CRT appears to have minimal effect on its predictive validity (Bialek & Pennycook, 2018), but this has yet to be examined in recently developed measures. Considering our findings, additional research on this may be warranted, particularly as participant familiarity increases with new CRTs. The current binarized measure of exposure to CRT items is also limited. In future, this could be refined by quantifying the extent of participants' exposure to CRT items or through experimental designs where CRTs are presented on multiple occasions (e.g., Stagnaro et al., 2018).

Following these methodological advancements to previous research, we report consistent evidence for no autism-related contributions to objectively measured intuitive and deliberative thinking or self-reported deliberative processing. In contrast, we consistently found an association between autism and lower self-reported intuition across Studies 2-4. Although this aligns with previously reported findings of lower self-reported intuitive thinking in autism (see Rozenkrantz et al., 2021), this is inconsistent with our otherwise compelling evidence for no relationship between autism and performance-based intuition. One interpretation for this pattern is that self-reported intuition captures intuitive thinking across a wider range of contexts. This contrasts with the CRT, which involves close ended reasoning items in one context, which are not completed under time pressure. Therefore, when reflecting on their intuitive thinking and decision-making abilities, participants are unlikely to consider the scenario represented in the CRT, but rather 'real-world' situations that involve intuitive reasoning that is often constrained by time and cognitive load (e.g., making intuitive judgements in social situations). Further to this idea, it has been suggested the intuitive component of the CRT measures intuitive propensities rather than abilities (see Pennycook et al., 2015). This is due to intuitive and deliberative responses not being measured completely independently and the intuitive responses on the CRT being incorrect. Therefore, while autism was not associated with intuitive CRT performance, it may be associated with reduced intuition in other contexts. This might be in line with growing evidence of lower self-reported interoceptive awareness in autism (e.g., DuBois et al., 2016). Indeed, the perception of internal bodily states is thought to contribute to intuitive decision making (e.g., Dunn et al., 2010), hence atypical interoceptive processes may underlie the lower self-reported intuition found in the present studies.

Alternatively, the discrepancy between the objective and subjective measures of intuition may be due to individuals' lacking insight into their intuitive processing, which may vary as a function of autism severity. Autistic people may in fact underestimate their ability to think intuitively. For example, Sahuquillo-Leal et al. (2020) found that autistic people's self-reported confidence in their decision choices did not predict their accuracy. This issue may be compounded by autistic people self-stereotyping themselves as 'rational' and not 'intuitive' thinkers, following speculation of these putative features of autism (e.g., in current strength-based approaches in clinical, educational, and occupational settings; Huntley et al., 2019). Another explanation for this result is that autistic people may be less inclined to use the abstract terminology in the REI questions (e.g., 'hunches', 'gut feelings') to describe intuitive thinking. The REI may also conflate intuition with interoceptive awareness and other abilities that are atypical in autistic populations. Several items, for example, tap into social skills (e.g., 'I trust my initial feelings about people'). Given these potential limitations of the REI, we suggest that the CRT offers a more accurate assessment of intuitive thinking. Nonetheless, further work is required to clarify the reasons for the discrepant findings, which may, for example, necessitate adapting the REI by ensuring that it measures the same construct in autistic and non-autistic people (e.g., testing measurement invariance; see Clutterbuck et al., 2021).

Clinical and Theoretical Implications

Our findings have important clinical and theoretical implications. Most evidently, they suggest that the dual process account of autism has limited utility for understanding atypical cognition and behaviors in autism. We therefore caution against clinical or educational interventions grounded in dual process theory and the emphasis of enhanced deliberative thinking as a leverageable autistic strength. More broadly, considering our methodological advancements and failure to replicate previous research, future research would benefit from re-examining the robustness of results where dual process theory has been used to understand and manage other clinical conditions, such as schizophrenia, anxiety, and depression (Bronstein et al., 2019; Haeffel et al., 2007; Remmers & Zander, 2018).

Further, following our findings, the seemingly more rational decision-making previously observed in autism is unlikely to be attributable to atypical intuitive and/or deliberative processing as suggested in previous research (e.g., De Martino et al., 2008; Rozenkrantz et al., 2021; Shah et al., 2016). Thus, previous research findings could be better explained by other theoretical accounts of autism. Studies have previously reported that, on cognitive bias tasks, autistic people have a reduced tendency to integrate emotional and contextual information (e.g., Farmer et al., 2017). Within the dual process framework, this finding has been ascribed to reduced intuitive processing in autism, but this finding could also be explained by other cognitive accounts. For example, Central Coherence theory suggests that autistic people tend to focus on small local-level details and have a reduced tendency to integrate information into a coherent whole (Frith, 1989), which is likely to have consequences for judgment and decision-making. This could be formally tested in future research. If enhanced low level visual processing and decision-making (e.g., involving Gabor patches; Maróthi et al., 2019) is associated with higher-order judgement and decision-making in autism, general perceptual and cognitive accounts of autism may help to explain reasoning and decision-making in autism and inform the development of clinical and educational interventions. Another possibility is that, unlike CRTs that solely require reasoning to a correct answer, cognitive bias tasks typically require participants to state a preference for an alternative. Rather than differences in reasoning processes or ability, autistic people may hold stronger preferences over attributes, resulting in more logically consistent choices in line with these preferences (see Farmer et al., 2021).

Strengths, Limitations, & Future Directions

In addition to the aforementioned methodological advancements, the present research had several strengths. By using multiple conceptual replication studies and well-powered analyses, we built cumulative evidence of a consistent pattern of results. This reduces the likelihood that our results were due to unmeasured contextual factors and sampling techniques, inspiring confidence in the results and increasing future independent replication success (Lewandowsky & Oberauer, 2020). The complementary use of trait wise and case-control approaches ensured reproducibility across conceptualizations of autism, mitigating concerns regarding the use of dimensional approaches to study discrete conditions (see Happé & Frith, 2020). We ensured our studies were appropriately powered for planned analyses but also for conceptual replications of previous research (Camerer et al., 2018). This resulted in an overall sample of 1192 participants, with 991 in our largest analysis (Study 4b), which is far greater than most autism-focused cognitive research. Indeed, our group comparisons (Studies 4a and 4b) are some of the largest on autism-related cognition in adulthood.

The novel use of Bayesian modelling was also a strength. Previously, null relationships between autism and deliberative thinking had been reported (Brosnan et al., 2017; Levin et al., 2015), though it remained unclear if this was due to low statistical power or a true null result. Our Bayesian analyses allowed us to interpret these findings, suggesting that the present data offered considerable evidence in support of the null. Bayesian analyses were therefore critical for the interpretation of our findings. Following a growing appreciation of Bayesian hypothesis testing to advance autism-related theories (e.g., Nicholson et al., 2018) and replication efforts (e.g., Colling & Szucs, 2018), we suggest that Bayesian statistics have value in moving beyond the classical focus on differences in abnormal psychology to build knowledge of unaffected processes in clinical populations. Such knowledge is critical for refining theoretical accounts, and a greater emphasis on similarities between clinical and non-clinical populations may improve attitudes and decrease stigma towards psychopathology (Hanel et al., 2019; Hanel & Shah, 2020).

In the present research, we prioritized the examination of the link between autism and intuition and deliberation, as measured using a limited range of cognitive and self-report measures in large online studies. However, these online methods precluded investigation of the neural and psychophysiological processes that have previously shed light on autism-related judgment and decision-making (De Martino et al., 2008; Farmer et al., 2021; Shah et al., 2016). It therefore remains possible that autistic people performed similarly to non-autistic people in the current studies by engaging alternative neurocognitive and intellectual processes, such as compensatory mechanisms (Dawson et al., 2007; Livingston et al., 2019, 2021). Moving forward, although autism-related links to intuitive and deliberative thinking are unlikely to be found, the use of more detailed intelligence and cognitive tasks and neuroimaging methods could interrogate future 'null' results at the neurocognitive level. Another limitation is that we did not account for the presence of other psychiatric conditions or traits that frequently co-occur with autism (Hollocks et al., 2019). Previous work has shown that alexithymia, anxiety, and ADHD traits are independently associated with atypical intuition, deliberation, and susceptibility to cognitive biases (Persson et al., 2020; Remmers & Zander, 2018; Rinaldi et al., 2017). Thus, to ensure our findings are not due to statistical suppressor effects, the relationships between autism and intuition and deliberation should be re-examined whilst also exploring the effects of co-occurring conditions. Having established more robust effect sizes and Bayes Factors, future research could draw on our results to estimate the statistical power required, perhaps increasing the feasibility of such research.

Conclusion

This research presents cumulative evidence that intuitive and deliberative processes are not atypical in autism. This represents a challenge to dual process accounts of autism, suggesting they have limited practical utility, particularly in clinical and educational practice. This research additionally offers broader insights into various methodological considerations, including measurement validity, replicability, and generalizability, towards improving the robustness of investigations on dual processing in clinical populations and atypical cognition more generally. Finally, this work demonstrates the need for the further study of intact processes in clinical populations, which can be facilitated by using Bayesian statistics to test and thereby refine theoretical accounts.

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Supplementary Material

Taylor, E. C., Farmer, G. D., Livingston, L. A., Callan, M. J., & Shah, P.

Rethinking Fast and Slow Processing in Autism. *Journal of Abnormal Psychology*.

Multivariate Outliers and Non-Parametric Analyses

Across all studies, we investigated multiple regression models for potential multivariate outliers (standardized residuals >±3 SDs) and influential data-points (Cook's Distance > 4/N). Using these cut-offs, a small number of potential outliers and influential data-points were identified. On close inspection, these were valid responses (no data entry errors or patterns of apparent random responding from participants), and because there were no 'extremely influential data-points' (Cook's Distances were only slightly over the cut-off and were continuously distributed), the results we report throughout are from analyses with the full dataset. Nonetheless, the same analyses performed using rank scores or non-parametric bootstrapping (see Bakker & Wicherts, 2014) yielded the same conclusions.

Bayesian Modelling

Widely-used conventional statistical methods (i.e., frequentist analyses) involve null-hypothesis significance testing. However, there is a growing appreciation of the shortcomings of this approach, particularly when interpreting null effects (Wagenmakers, 2007). While it is possible to reject the null hypothesis using these tests, it is difficult to find support for the null hypothesis.

Bayesian inference is an alternative statistical approach that addresses this issue. The Bayes Factor (BF_{10}) is a continuous measure of evidence describing the probability of obtaining the data under an explicitly outlined alternative hypothesis (H_1) relative to the probability under the null hypothesis (H_0): $BF_{10} = \Pr(D|H_1) / \Pr(D|H_0)$. A BF_{10} of 0.2, for example, indicates that the data observed are approximately 5× more likely under the null than alternative hypothesis. Following commonly accepted interpretations of BF_{10} (see Table S2), this would indicate '*substantial*' evidence for the null hypothesis.

In Studies 1-3, we conducted Bayesian equivalents of conventional multiple regression analyses to quantify support for the two-tailed alternative hypothesis (H_1 = autistic traits are uniquely predictive of the outcome) relative to the null hypothesis (H_0 = autistic traits are not uniquely predictive of the outcome), by comparing models with and without autistic traits included as a predictor. Likewise, in Study 4, we conducted Bayesian independent samples t-tests to quantify support for the alternative hypothesis that autistic and non-autistic groups show mean differences in intuitive and deliberative thinking, relative to the null hypothesis that there are no group mean differences.

Bayesian inference requires a prior probability distribution for the alternative hypothesis model parameters. *JASP* (JASP Team, 2019) provides default, broadly applicable, uninformative priors (see Quintana & Williams, 2018) that were used throughout our analyses. This approach to multivariate Bayesian analysis is recommended by Rouder et al. (2012) (see also, Wagenmakers et al. (2018) and Quintana and Williams (2018) for recent information regarding Bayesian inference).

REI Subscales

The two scales of the Rational-Experiential Inventory (REI) comprise two 10-item subscales for independent assessment of ability and engagement in each of the two types of processing: Rational Engagement, Rational Ability, Experiential Engagement, and Experiential Ability. Table S10 reports exploratory regression analyses examining the unique contribution of autism (autistic traits in Studies 2 and 3; clinical diagnosis in Study 4a) to each of these REI subscales, after accounting for age, sex, and general cognitive ability. Across studies, autism was not a significant predictor of self-reported deliberative thinking, with Bayes Factors indicating 'anecdotal' to 'substantial' evidence for the null hypothesis. Autism was a significant negative predictor of self-reported deliberative thinking ability in Study 2, with 'substantial' evidence supporting this relationship. However, this finding was not reliably replicated in Study 3 or 4a, with autism only a marginally statistically significant predictor in Study 3 (with this result not robust to bootstrapping), and not consistently a significant predictor in Study 4a. Equally, Bayes Factors indicated 'no' evidence of a relationship and 'anecdotal' evidence in support of the null hypothesis in Studies 3 and 4a respectively. Across studies, autism was a significant negative predictor of both self-reported ability and engagement in intuitive thinking, with all Bayes Factors indicating 'extreme' evidence in support of these relationships.

Exposure to CRT items

Multiple regression analyses were conducted to test whether the (null) relationships between autism (AQ scores in Studies 2 and 3; clinical diagnosis in Study 4) and performance-based intuitive and deliberative thinking were dependent on exposure to CRT items. In addition to the primary predictor variables (autism, ICAR, sex and age), previous exposure and interaction terms for each of the primary predictors × previous exposure were included in the models (Table S11). Across analyses, that pattern of results remained consistent with the primary analyses, and there were no significant interaction effects between autism and previous exposure. Thus, the primary findings are robust to, and not dependent on, previous experience with items on the CRTs.

Supplementary Tables

Table S1.

Descriptive Statistics and Pearson's Correlations – Study 1

Measure	*M (SD)*	1	2	3	4	5
1. Autistic Traits	20.34 (6.78)	-				
2. Deliberative Thinking	1.29 (1.17)	.03	-			
3. Intuitive Thinking	1.37 (1.06)	-.06	-.88*	-		
4. General Cognitive Ability	7.76 (3.51)	-.10	.66*	-.55*	-	
5. Sex (0 = Female, 1 = Male)	0.35 (0.48)	.16*	.22*	-.16*	.17*	-
6. Age (Years)	32.83 (12.25)	.03	.09	-.07	.23*	-.16*

Note. *$p < .05$

Table S2.

Interpreting Bayes Factors

Bayes Factor (BF_{10})	Interpretation
>100	Extreme evidence for H_1
30 - 100	Very strong evidence for H_1
10 - 30	Strong evidence for H_1
3 - 10	Substantial evidence for H_1
1 - 3	Anecdotal evidence for H_1
1	No evidence
$0.3\dot{3}$ – 1	Anecdotal evidence for H_0
0.10 – $0.3\dot{3}$	Substantial evidence for H_0
$0.03\dot{3}$ – 0.10	Strong evidence for H_0
0.01 – $0.03\dot{3}$	Very strong evidence for H_0
< .01	Extreme evidence for H_0

Note. Adapted from Wagenmakers et al. (2011).

Table S3.

Descriptive Statistics and Pearson's Correlations – Study 2

Measure	*M (SD)*	1	2	3	4	5	6	7	8	9
1. Autistic Traits	17.43 (7.18)	-								
2. Self-Reported Deliberative	69.43 (10.22)	-.05	-							
3. Self-Reported Intuitive	67.62 (10.85)	-.22*	.11*	-						
4. Numerical Deliberative	3.71 (2.11)	.05	.28*	-.07	-					
5. Numerical Intuitive	2.16 (1.79)	-.00	-.24*	.00	-.85*	-				
6. Verbal Deliberative	6.98 (2.54)	.03	.19*	.03	.45*	-.40*	-			
7. Verbal Intuitive	2.02 (1.90)	-.06	-.12*	-.03	-.39*	.38*	-.91*	-		
8. General Cognitive Ability	9.61 (3.04)	.12*	.25*	-.06	.54*	-.44*	.31*	-.28*	-	
9. Sex (0 = Female, 1 = Male)	0.14 (0.34)	.14*	.12*	-.12*	.24*	-.21*	.07	-.04	.20*	-
10. Age (Years)	18.70 (1.26)	.04	.06	-.03	.01	.00	-.14*	.19*	.05	.16*

Note. *$p < .05$

Table S4.

Descriptive Statistics and Pearson's Correlations – Study 3

Measure	*M (SD)*	1	2	3	4	5	6	7	8	9
1. Autistic Traits	21.09 (7.91)	-								
2. Self-Reported Deliberative	71.74 (11.81)	-.04	-							
3. Self-Reported Intuitive	67.91 (11.59)	-.31*	-.02	-						
4. Numerical Deliberative	3.18 (2.25)	.14*	.35*	-.28*	-					
5. Numerical Intuitive	2.56 (1.81)	-.11*	-.31*	.26*	-.86*	-				
6. Verbal Deliberative	6.62 (2.85)	.06	.26*	-.14*	.57*	-.54*	-			
7. Verbal Intuitive	2.49 (2.31)	-.07	-.21*	.15*	-.52*	.51*	-.94*	-		
8. General Cognitive Ability	8.16 (3.49)	.13*	.35*	-.27*	.62*	-.49*	.50*	-.43*	-	
9. Sex (0 = Female, 1 = Male)	0.48 (0.50)	.12*	.10*	-.26*	.28*	-.23*	.14*	-.15*	.17*	-
10. Age (Years)	36.38 (11.49)	.01	.06	.01	.02	-.05	.04	-.02	-.05	-.06

Note. *$p < .05$

Table S5.

ANCOVA Comparing Autistic and Non-Autistic Groups Accounting for Age, Sex, and General Cognitive Ability – Study 4a

Measure	**Group Comparisons**			
	F	p	η_p^2	BF_{10}
Numerical Deliberative	2.08	.15	0.005	0.303
Numerical Intuitive	3.65	.057	0.009	0.620
Verbal Deliberative	2.07	.15	0.005	0.306
Verbal Intuitive	1.27	.26	0.003	0.205
Self-Reported Deliberative	0.91	.34	0.002	0.163
Self-Reported Intuitive	40.06	<.001	0.093	1.31×10^7

Table S6.

Group Means and Mean Differences between the Autistic and Non-Autistic Groups – Study 4a

Measure	**Autistic**	**Non-Autistic**	**Group Comparisons**			
			t	p	d [95% CI]	BF_{10}
Numerical Deliberative	3.29 (2.32)	3.13 (2.26)	0.70	.49	0.07 [-0.13, 0.27]	0.140
Numerical Intuitive	2.33 (1.68)	2.54 (1.83)	-1.19	.23	-0.12 [-0.32, 0.08]	0.220
Verbal Deliberative	6.13 (3.29)	6.62 (2.72)	-1.61	.11	-0.16 [-0.36, 0.04]	0.384
Verbal Intuitive	2.80 (2.56)	2.48 (2.23)	1.33	.18	0.13 [-0.06, 0.33]	0.261
Self-Reported Deliberative	68.09 (14.23)	69.47 (11.11)	-1.09	.28	-0.11 [-0.30, 0.09]	0.195
Self-Reported Intuitive	59.10 (14.87)	67.31 (11.74)	-6.13	<.001	-0.61 [-0.81, -0.41]	4.19×10^6

Note. Standard deviations are in parentheses. Independent samples t-tests are reported, and robust t-tests and Mann-Whitney U tests produced the same pattern of results.

Table S7.

Pearson's Correlations after Collapsing across Groups – Study 4a

Measure	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1. Autism Diagnosis	-									
2. Self-Reported Deliberative	-.05	-								
3. Self-Reported Intuitive	-.29*	-.08	-							
4. Numerical Deliberative	.03	.29*	-.24*	-						
5. Numerical Intuitive	-.06	-.23*	.23*	-.85*	-					
6. Verbal Deliberative	-.08	.29*	-.10*	.58*	-.52*	-				
7. Verbal Intuitive	.07	-.26*	.08	-.53*	.48*	-.93*	-			
8. Autistic Traits	.71*	-.03	-.51*	.19*	-.20*	.08	-.09	-		
9. General Cognitive Ability	-.03	.28*	-.21*	.63*	-.54*	.52*	-.46*	.14*	-	
10. Sex	.00	.04	.02	.15*	-.11*	-.02	-.03	-.06*	.03	-
11. Age (Years)	-.02	.07	-.02	-.06	.00	.07	-.04	.09	-.09	-.02

Note. Autistic = 1 and Non-Autistic = 0 when coding Autism Diagnosis. Males = 1 and Females = 0 when coding participant sex. *$p < .05$

Table S8.

Participant Characteristics – Study 4b

Analysis	**AQ Threshold**	***n***	**Age (Years)**		**Sex (*n* females, males, other)**		**General Cognitive Ability**		**Autistic Traits**	
		ASD, NA	ASD	NA	ASD	NA	ASD	NA	ASD	NA
1	ASD ≥26 NA <26	164, 164	28.91 (8.88)	28.57 (9.06)	93, 70, 1	93, 70, 1	8.81 (3.75)	8.55 (3.49)	37.04 (5.95)	16.52 (5.48)
2	ASD ≥32 NA <26	130, 130	29.55 (8.98)	31.40 (11.81)	79, 50, 1	82, 48, 0	9.00 (3.67)	8.62 (3.18)	39.28 (4.40)	16.75 (5.06)
3	ASD ≥26 NA <26	163, 603	28.93 (8.90)	26.77 (11.79)	93, 70	451, 152	8.79 (3.75)	8.60 (3.29)	37.02 (5.96)	16.26 (5.33)
4	ASD ≥32 NA <26	129, 603	29.58 (9.01)	26.77 (11.79)	79, 50	451, 152	8.98 (3.68)	8.60 (3.29)	39.28 (4.42)	16.26 (5.33)
5	None, Continuous AQ score	991	27.68 (11.48)		653, 338		8.77 (3.44)		22.23 (9.88)	

Note. Values represent means with standard deviations in parentheses. Values for Analysis 5 are across the sample.

AQ: Autism-Spectrum Quotient; ASD: Autism Spectrum Disorder; NA: Non-Autistic.

Table S9.

Mean Differences between Autistic (ASD) and Non-Autistic (NA) Groups – Study 4b

Analysis	**AQ Threshold**	***n***	**Age (years)**				**Sex**			**General Cognitive Ability**				**Autistic Traits**			
		ASD, NA	*t*	*p*	*d*	BF_{10}	χ^2	*p*	BF_{10}	*t*	*p*	*d*	BF_{10}	*t*	*p*	*d*	BF_{10}
1	ASD ≥26 NA <26	164, 164	0.34	.73	0.04	0.13	0.00	1.00	0.01	0.66	.51	0.07	0.15	32.49	<.001	3.59	1.6×10^{100}
2	ASD ≥32 NA <26	130, 130	-1.42	.16	-0.18	0.35	0.09	0.58	0.01	0.90	.37	0.11	0.20	38.32	<.001	4.75	2.5×10^{104}
3	ASD ≥26 NA <26	163, 603	2.17	.030*	0.19	0.96	19.61	<.001	1156.73	0.63	.53	0.06	0.12	43.02	<.001	3.80	7.9×10^{201}
4	ASD ≥32 NA <26	129, 603	2.55	.011*	0.25	2.48	9.77	.002	11.77	1.15	.25	0.11	0.20	45.82	<.001	4.44	3.1×10^{212}

Note. AQ: Autism-Spectrum Quotient.

Table S10.

Regression Analyses Predicting Subscale Scores on Self-Reported REI Measures

Criterion **Predictors**	**Study 2**				**Study 3**				**Study 4a**			
	B	SE_B	*β*	BF_{10}	*B*	SE_B	*β*	BF_{10}	*B*	SE_B	*β*	BF_{10}
Rational Engagement												
Autism	-0.03	0.04	-0.04	0.246	-0.06	0.04	-0.07	0.377	-0.04	0.71	-0.00	0.110
General Cognitive Ability	0.43	0.10	0.22*		0.70	0.09	0.36*		0.58	0.10	0.28*	
Sex	0.37	0.90	0.02		0.27	0.65	0.02		-0.55	0.71	-0.04	
Age (years)	0.33	0.24	0.07		0.04	0.03	0.06		0.08	0.04	0.10*	
Rational Ability												
Autism	-0.10	0.04	-0.13*	4.198	-0.08	0.04	-0.10*^	1.074	-1.13	0.67	-0.08	0.454
General Cognitive Ability	0.39	0.09	0.21*		0.51	0.09	0.28*		0.47	0.09	0.24*	
Sex	1.85	0.84	0.11*		1.11	0.62	0.09		1.48	0.67	0.11*	
Age (years)	0.01	0.22	0.00		0.05	0.03	0.09		0.06	0.04	0.08	
Experiential Engagement												
Autism	-0.15	0.04	-0.18*	107.205	-0.18	0.04	-0.23*	1.30×10^{4}	-3.18	0.68	-0.22*	3064.457
General Cognitive Ability	-0.07	0.10	-0.04		-0.38	0.09	-0.21*		-0.42	0.10	-0.21*	
Sex	-1.34	0.87	-0.08		-2.32	0.59	-0.18*		0.41	0.68	0.03	
Age (years)	-0.14	0.23	-0.03		-0.02	0.03	-0.04		-0.04	0.04	-0.05	
Experiential Ability												
Autism	-0.17	0.04	-0.19*	208.738	-0.21	0.04	-0.27*	6.14×10^{5}	-5.12	0.74	-0.32*	5.37×10^{8}
General Cognitive Ability	0.00	0.10	0.00		-0.31	0.08	-0.18*		-0.46	0.10	-0.21*	
Sex	-1.39	0.92	-0.08		-2.07	0.58	-0.17*		0.37	0.74	0.02	
Age (years)	0.11	0.25	0.02		0.02	0.02	0.03		-0.03	0.04	-0.04	

Note. Autism was measured as autistic traits using Autism-Spectrum Quotient scores in Studies 2 & 3, and as a clinical diagnosis (1 = Autistic, 0 = Non-Autistic) in Study 4a. Sex was coded as 0 = Female, 1 = Male. As potential outliers and influential data points were present, bootstrapping with 5000 resamples was performed. Significant differences between OLS and Bootstrapped bias-corrected and accelerated confidence intervals are noted (denoted with ^). * p <.05

Table S11.

Multiple Regression Analyses Predicting CRT Scores Including the Moderating Effect of Exposure – Studies 2-4

Criterion Predictors	Study 2 *B*	Study 2 SE_B	Study 2 *β*	Study 3 *B*	Study 3 SE_B	Study 3 *β*	Study 4a *B*	Study 4a SE_B	Study 4a *β*
Numerical Deliberative									
Autism	-0.01	0.01	-0.03	0.01	0.01	0.04	0.18	0.17	0.04
General Cognitive Ability	0.33	0.03	0.47*	0.37	0.02	0.57*	0.39	0.03	0.60*
Sex	0.78	0.28	0.13*	0.65	0.17	0.15*	0.56	0.17	0.12*
Age (years)	-0.07	0.07	-0.04	0.01	0.01	0.07*	0.00	0.01	0.01
NCRT Exposure	1.04	0.18	0.25*	0.99	0.18	0.21*	0.99	0.18	0.21*
NCRT Exposure * Autism	0.01	0.02	0.02	0.01	0.02	0.02	0.50	0.36	0.05
NCRT Exposure * General Cognitive Ability	0.02	0.06	0.01	0.04	0.05	0.03	0.02	0.05	0.02
NCRT Exposure * Sex	-0.38	0.58	-0.03	0.47	0.36	0.05	0.12	0.36	0.01
NCRT Exposure * Age	-0.08	0.14	-0.02	-0.00	0.02	-0.01	0.01	0.02	0.02
Numerical Intuitive									
Autism	0.02	0.01	0.07	-0.01	0.01	-0.03	-0.23	0.15	-0.07
General Cognitive Ability	-0.22	0.03	-0.37*	-0.23	0.02	-0.45*	-0.26	0.02	-0.52*
Sex	-0.60	0.26	-0.12*	-0.40	0.15	-0.11*	-0.25	0.14	-0.07
Age (years)	0.06	0.06	0.04	-0.02	0.01	-0.11*	-0.01	0.01	-0.07
NCRT Exposure	-1.02	0.16	-0.29*	-1.02	0.16	-0.27*	-0.84	0.15	-0.23*
NCRT Exposure * Autism	-0.02	0.02	-0.04	-0.03	0.02	-0.07	0.13	0.30	0.02
NCRT Exposure * General Cognitive Ability	0.01	0.05	0.01	-0.03	0.05	-0.03	-0.02	0.04	-0.02
NCRT Exposure * Sex	0.34	0.52	0.03	-0.14	0.32	-0.02	0.04	0.30	0.01
NCRT Exposure * Age	0.00	0.12	0.00	0.02	0.01	0.05	0.01	0.02	0.03
Verbal Deliberative									
Autism	-0.01	0.02	-0.04	-0.01	0.02	-0.03	-0.19	0.24	-0.03
General Cognitive Ability	0.23	0.04	0.27*	0.38	0.04	0.47*	0.41	0.03	0.48*
Sex	0.18	0.35	0.02	0.28	0.24	0.05	-0.08	0.24	-0.01
Age (years)	-0.28	0.11	-0.14*	0.03	0.01	0.11*	0.06	0.01	0.17*
VCRT Exposure	1.82	0.32	0.29*	1.52	0.27	0.25*	2.14	0.27	0.33*
VCRT Exposure * Autism	0.02	0.05	0.02	0.04	0.03	0.06	0.56	0.52	0.04
VCRT Exposure * General Cognitive Ability	0.01	0.11	0.01	-0.19	0.08	-0.10*	-0.11	0.08	-0.06
VCRT Exposure * Sex	-0.90	0.98	-0.04	-0.23	0.51	-0.02	-0.36	0.52	-0.03
VCRT Exposure * Age	-0.02	0.19	-0.01	-0.01	0.02	-0.02	-0.04	0.03	-0.06
Verbal Intuitive									
Autism	0.00	0.01	0.02	0.00	0.01	0.02	0.10	0.20	0.02
General Cognitive Ability	-0.15	0.03	-0.24*	-0.26	0.03	-0.39*	-0.28	0.03	-0.41*
Sex	-0.07	0.26	-0.01	-0.33	0.20	-0.07	-0.15	0.20	-0.03
Age (years)	0.21	0.08	0.14*	-0.02	0.01	-0.09*	-0.04	0.01	-0.13*
VCRT Exposure	-1.41	0.23	-0.30*	-1.28	0.22	-0.26*	-1.70	0.23	-0.33*
VCRT Exposure * Autism	0.00	0.03	0.00	-0.05	0.03	-0.07	-0.10	0.44	-0.01
VCRT Exposure * General Cognitive Ability	0.10	0.08	0.06	0.16	0.07	0.10*	0.09	0.07	0.06
VCRT Exposure * Sex	0.60	0.72	0.04	0.66	0.43	0.07	0.36	0.44	0.04
VCRT Exposure * Age	-0.13	0.14	-0.05	0.01	0.02	0.01	0.02	0.03	0.04

Note. Autism was measured as autistic traits using Autism-Spectrum Quotient scores in Studies 2 & 3, and as a clinical diagnosis (1 = Autistic, 0 = Non-Autistic) in Study 4a. Sex was coded as 0 = Female, 1 = Male. Predictors are mean centered, with interaction terms calculated using the centered variables. Bootstrapped analyses (5000 resamples) produced the same pattern of results. NCRT: Numerical Cognitive Reflection Test; VCRT: Verbal Cognitive Reflection Test. * $p < .05$

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