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Time contingency and social engagement shape interaction choices in autism and neurotypical development

Laura Carnevali[1,2], Irene Valori[3,4], Letizia Della Longa[1], Giulia Mantovani[1], Giorgia Mason[5,6], Franco Bin[7] & Teresa Farroni[1]✉

In social interactions, the coordination of biobehavioural rhythms – interpersonal synchrony (IS) – fosters cooperation, enhances prosocial behaviours, and moulds lifelong social attitudes. At the core of synchronous interactions is the ability to detect and respond contingently to communicative signals. Atypicalities in these processes may emerge along diverse developmental trajectories and contribute to socio-communicative difficulties commonly observed in Autism Spectrum Disorder (ASD), where social disconnection is often reported. Our exploratory research simulates interactions to delve into factors influencing IS in ASD and typically developing (TD) peers, examining the impact of time contingency and social engagement on preferences for social partners across the lifespan. Using a tablet-based task, 116 participants ($n = 58$ ASD, $n = 58$ TD; age range: 3.8–33 years) repeatedly interacted with faces that transitioned from side to front upon selection. Stimuli responses varied in time contingency (immediate or delayed response) and social engagement (smiley direct gaze vs. neutral averted gaze). Our results show that TD participants consistently prioritized social engagement, even in the absence of time contingency. In contrast, ASD participants prioritized contingency as a cue but only when this was paired with social engagement. We argue that the combination of time contingency and social engagement enhances social agency, which is particularly relevant for ASD. We discuss how creating predictable and engaging social environments could help autistic individuals feel more connected in social settings.

Coordinating our behaviour and physiology to those of the people we are interacting with is crucial for optimal social communication across the lifespan. This ability has often been referred to as interpersonal synchrony (IS) and has been shown to promote social attitudes across different age ranges as well as to contribute to positive child outcomes[1–3]. Research has highlighted its role in fostering feelings of similarity and closeness between individuals, enhancing attention towards others' actions and increasing emotional contagion[4–10]. Such processes contribute to cooperation and prosocial behaviours, which are crucial for maintaining social attitudes all throughout life in typically developing (TD) populations[11–13]. If interpersonal synchrony serves as a "social glue" [14], it is plausible to hypothesize that socio-communicative difficulties may be accompanied by lower dyadic synchrony. In line with this, previous research has suggested that interpersonal synchrony develops differently and may be reduced in individuals with Autism Spectrum Disorder (ASD)[15] a condition characterized by socio-communicative challenges alongside atypical sensory, motor, and cognitive functioning. Understanding the drivers of interpersonal synchrony across the lifespan is thus essential to ultimately support social interactions.

Our recent meta-analysis showed that synchronisation of actions during social exchanges differs in dyads where at least one autistic participant is involved[16]. Although the direction of the effect is consistent across studies, the high heterogeneity highlights the complexity of synchrony, emerging from the dynamic interplay between partners, with each participant bringing their own individual characteristics into the social exchange. Many intra-personal (e.g., age, sensorimotor, social and cognitive profiles) and inter-personal factors (e.g., type

[1]Department of Developmental Psychology and Socialization, University of Padova, Padova, Italy. [2]Department of Psychology, University of Cambridge, Cambridge, UK. [3]Chair of Acoustics and Haptics, Technische Universitat Dresden, Dresden, Germany. [4]Centre for Tactile Internet with Human-in-the-Loop (CeTI), Technische Universitat Dresden, Dresden, Germany. [5]Department of Psychology, Sapienza University, Rome, Italy. [6]IRCCS Fondazione Santa Lucia, Rome, Italy. [7]Department of Neuroscience, Sapienza University, Rome, Italy. ✉email: teresa.farroni@unipd.it

of synchrony, similarity between the dyad members) may in fact contribute to reduced synchrony found in ASD-TD exchanges. Both in TD and ASD, synchrony could be influenced not only by individual characteristics but also by how these align interpersonally[15,17–19]. For instance, research shows that in TD dyads, greater similarity in autistic traits is associated with increased closeness, acceptance, and prosocial behaviours[20]. Additionally, the perception of the other's ability to synchronize positively influences the subjective perception of one's own capacity to understand others' thoughts and intentions, both in TD and ASD[21]. This could suggest that similarity in individual functional profiles might contribute to increased interpersonal synchrony. However, limited evidence currently exists to answer this question.

Some authors emphasize that interpersonal synchrony hinges upon the intertwining of lower- and higher-level factors[22]. The former involves grasping temporal patterns and interaction-specific rhythms, while the latter includes assigning value to oscillatory stimuli and considering socio-emotional aspects such as the relationship's nature and associated emotions. The ability to respond to others' communicative signals appropriately in terms of social content and in a time-contingent manner is also crucial for synchronous interactions to happen[23,24].

The temporal proximity between our actions and subsequent environmental changes is essential for perceiving ourselves as active agents in the physical world, recognizing our actions as the primary cause of the effects that follow[25]. This concept extends into social interactions, where our actions elicit reactions from others[26,27]. When responses are swift and closely aligned with the initial action, individuals tend to feel more influential in shaping the interaction: this heightened sense of social agency enhances the quality of the interaction and in turns fosters mutual perceptions of agency[26,28].

The sense of agency can be defined as the perception of control over one's own actions and the external world and can be traced back to the ability to recognize oneself as the cause of an event[29–31]. A key mechanism underlying agency perception is intentional binding, where voluntary actions and their outcomes are perceived as temporally compressed[32]. Recent theories suggest the sense of agency is a motivational driver in TD populations, where action-outcome temporal contingency may facilitate action execution[33]. However, research indicates that ASD is characterized by a reduced sense of agency and widened multisensory temporal binding windows[34,35], meaning that autistic individuals process sensory events over a broader time frame. This may reduce the precision of contingency detection, leading to a weaker preference for time-contingent interactions.

Sensitivity to time contingency in social contexts is observed early in life. For instance, the speed at which a social partner responds to infants' communicative requests significantly influences how the interaction is perceived, with babies preferring contingent partners[27]. Infants react negatively to delayed caregiver responses[36], detect and prefer stimuli that move in synchrony with them, and distinguish between social and non-social contexts[37], and exhibit negative expressions when mutual communication is interrupted[38]. Individual differences in early patterns of social attention may have cascading effects on later developmental outcomes.

Social attention and social brain theories show that humans have an early tendency to prioritize social agents over non-social or non-interactive stimuli[39,40], and such experience contribute to the specialization of neural networks that support social information processing[41]. While TD individuals tend to show a preference for social stimuli, research on social preferences in ASD suggests diminished attention to social stimuli[42]. Despite a reduced preference for social vs. non-social stimuli[43], research also showed that autistic individuals still prioritize highly salient social stimuli over less salient ones[44].

Some authors tried to delve into early differences in attention towards social communicative cues in those infants at increased familial risk for ASD and found that they are less responsive to social stimuli, such as voices, faces, or eye contact with their parents, and struggle with the automatic orientation toward human faces, especially the eyes. For instance, infants who later develop ASD show a gradual decrease in making eye contact with their caregivers already between 2 and 6 months of age[45], they are less responsive than low-risk children when interacting with emotional faces that respond to their gaze, such as through smiling and imitation[38] and tend to focus more on faces that respond invariantly to their gaze rather than variably[46]. A study by Klin and colleagues[47] investigated contingency detection in 2-year-old toddlers with and without ASD using point-light displays of biological motion accompanied by human vocalizations. The study presented two versions of the same animation side by side: one upright (preserving biological motion) and the other both inverted and played in reverse (disrupting biological motion while maintaining comparable motion complexity and speed). The same audio soundtrack was played for both versions. Results showed that TD toddlers preferred the upright biological motion displays, indicating an early-developing bias for social stimuli. In contrast, autistic toddlers did not show a preference for biological motion but instead oriented towards animations that featured strong audio-visual synchrony, such as a point-light figure clapping in perfect time with a hand-clapping sound. This suggests that rather than prioritizing social over non-social stimuli, autistic toddlers may be more attuned to contingent sensory cues[47]. However, because the only condition with audio-visual contingency also contained social content (a human figure clapping), it remains unclear whether the observed preference reflects a general sensitivity to contingency or a selective preference for contingent social stimuli. A general preference for time contingency in ASD can be interpreted through the lens of a predictive processing account of autism, which posits that autistic individuals rely more heavily on sensory input than on prior expectations, leading to difficulties in anticipating events and a preference for stimuli that are less uncertain[48].

This exploratory study investigates which characteristics ASD and TD individuals prioritize when selecting an interaction partner: is it the promptness of their responses, their level of engagement in the interaction, or a combination of both? We examine the combined influence of time contingency and social engagement on individuals' preferences for interacting with social stimuli, particularly faces, across TD and ASD, and across different developmental stages. Specifically, we ask whether participants are more likely to interact with faces that respond promptly to their actions, whether such time contingency plays a particularly critical role in socially engaging interactions, and how these factors shape subsequent social preferences. With this study, we aim to extend the existing literature on infants and toddlers by exploring how these processes unfold later in childhood, adolescence, and adulthood, with a focus on potential divergences between TD and ASD populations. To address these questions, we designed a tablet-based task that simulates interactions by manipulating response to participant's actions both in terms of time contingency and social engagement. These two aspects – time contingency and social engagement – are continually intertwined in everyday interactions. Responses to communicative requests can indeed vary in immediacy and congruity. While sensitivity to both these aspects is shown from early development, the extent to which they jointly contribute to interpersonal synchrony across the lifespan and in the context of neurodiversity remains unclear. This raises questions about which aspect we place greater value on and how they shape our social preferences, especially in the context of neurodiversity and at different ages. In doing so, we aim to gain deeper insight into the mechanisms underlying interpersonal synchrony and their implications for optimal social interaction.

Methods
Participants
The current study has been carried out as part of a broader protocol that included two additional tasks which have been published[49], therefore the sample largely overlaps with the cited paper. Data collection for this study took place in collaboration with several autism centres in northern Italy that offer various services to individuals on the autism spectrum and their families. The opportunity to participate in the study on a voluntary basis was offered to all regular visitors of these centres. Child neuropsychiatrists from each centre confirmed the diagnoses of all participants that took part in the study. Recognizing the inherent heterogeneity of autism and aiming to include participant across the autism spectrum, the study did not set inclusion or exclusion criteria based on IQ, level of support required, or the presence of co-occurring medical conditions. The final sample size, comprising children and adults diagnosed with ASD, was determined by the total number of autistic children and adults whose participations was consented to by their parents or guardians when necessary, and the individuals themselves. ASD participants carried out the experiment at their respective local centres. A control group of TD children and adults within the same age range was tested at the Department of Developmental Psychology and Socialization of the University of Padova. This comparison group was recruited based on a one-to-one matching with the autistic participants, ensuring each pair had an age difference of less than two years. TD participants had no medical or neuropsychological conditions as confirmed by parent reports for children and self-reports for adults.

Our final sample is composed of $n = 116$ participants ($n = 58$ TD, $n = 58$ ASD), aged between 3.8 and 33 years (mean = 15.73, SD = 7.74). An additional 14 participants were tested but have been excluded because they did not complete the task ($n = 3$ ASD, $n = 4$ TD) or because their primary diagnosis was not Autism Spectrum Disorder ($n = 7$). Given the breadth of the age range considered, to explore our data across different developmental ages we divided our sample into 3 subgroups based on chronological age: younger children ($n = 32$, mean = 7.4, SD = 1.91, range = 3.8–9.6); older children ($n = 34$, mean = 12.6, SD = 2.03, range = 9.7–16.3); adults ($n = 50$, mean = 23.19, SD = 4.77, range = 17–33).

We set the age group boundaries with reference to evidence that cognitive control, social cognition and response speed follow nonlinear trajectories, with marked inflection points near 10 and 16 years that coincide with synaptic proliferation and pruning at puberty[50]. Similar inflection points were also used in one of our previously published works[49]. Regarding the definition of children age groups, we aimed to separate children below the age at which key developmental changes typically emerge (around 10 years). We therefore included in the younger group those aged up to approximately the first half of their tenth year, using the distribution in our sample to place participants closest to 9.5 in the younger group and those closer to 10 in the older group. This resulted in a practical boundary between 9.6 and 9.7 years, affecting at most one or two participants.

Details on autistic and non-autistic participants are specified for each of the three age groups Table 1 and a graphical representation of age distribution is depicted in Fig. 1.

Stimuli and procedure
The study received ethical approval from the Research Ethics Committee of the School of Psychology at the University of Padova (protocol no. 3251). The experiment was carried out in accordance with the approved guidelines and regulations. Adult participants and children's parents signed a written consent form before taking part in the experiment.

Age group	Group	N	Age		M: F
			Mean (SD)	Range	
Younger children	ASD	13	7.11 (1.99)	3.8–9.2	12:1
	TD	19	7.6 (1.88)	3.8–9.6	13:6
Older children	ASD	19	12.7 (2.16)	9.9–16.3	10:0
	TD	15	12.47 (1.93)	9.7–15.6	10:5
Adults	ASD	26	22.98 (4.85)	17–33	24:5
	TD	24	23.42 (4.79)	17.3–32	18:6

Table 1. Sample description.

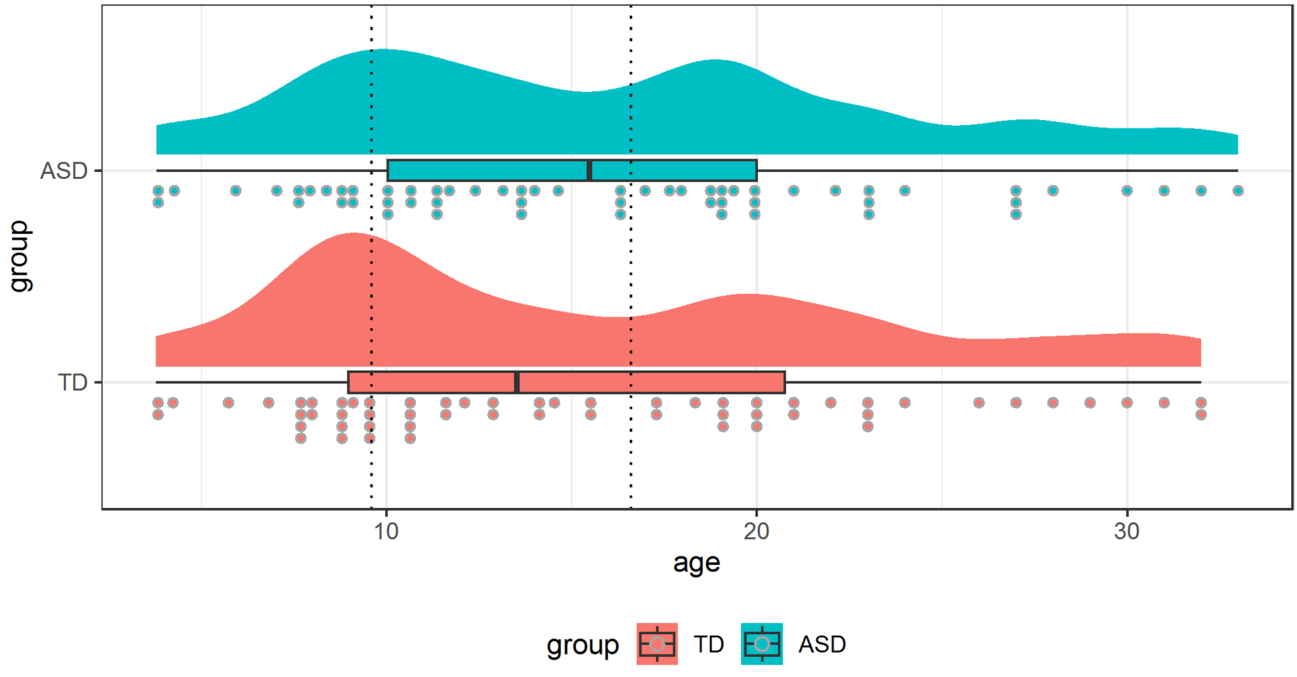


Fig. 1. Raincloud plot of participants' age by group. Dotted vertical lines represent the boundary of each age group category (i.e. between younger and older children, between older children and adults).

During the experiment, participants were seated at a desk and given access to a reversible touchscreen laptop configured in tablet mode (Lenovo Yoga, 14" IPS Full HD 1920 × 1080, Intel® Core™-U i7). The experimental design consisted of two preference evaluation phases and one interaction phase (Fig. 2).

In the *preference evaluation phase(s)*, four smiling faces were presented, and the participant was asked to select the person to whom they would like to give a present. When the face is chosen, a gift appeared, and then both the face and the gift disappeared. The order of choice of the four faces was used as an index of preference. This evaluation was conducted both before and after the interaction with the stimuli themselves.

In the *interaction phase*, a screen displaying four closed windows was presented to the participants, with the instruction to freely select and press one of the windows. The task was designed to be feasible for people with limited verbal communication skills, ensuring accessibility across a broad range of developmental and communicative profiles. While all participants in the current sample demonstrated at least minimal verbal skills, instructions could be flexibly adapted and complemented by a demonstration as needed to support comprehension. Upon choice, the window would open and a 3-second video of the face moving from the side position to the front position was displayed. Time contingency and social engagement were manipulated and combined in a 2 × 2 within-subjects design. Manipulating time contingency meant that the faces could either move immediately after the participant's choice or after a variable time delay (contingent vs. non-contingent condition, respectively). The delay spanned from 1000 to 1500ms to ensure the stimulus was perceived as non-contingent (mean = 1250.33, SD = 145.29, distribution plot in Supplementary Materials). In fact, previous literature suggests that delays exceeding one second disrupt social interaction dynamics[51] and that perceived responsiveness of a virtual agent decreased when delays were longer than 750ms[52]. In all conditions the window opened upon participant choice, so as not to disrupt the sense of agency on the functioning of the game itself. In addition, social engagement varied across stimuli, with faces either displaying direct gaze and a positive expression or averted gaze and a neutral expression (engaging vs. non-engaging condition, respectively). Thus, the participant would be presented with four different conditions: contingent and engaging (C_E); non-contingent and engaging (NC_E); contingent and non-engaging (C_NE); non-contingent and non-engaging (NC_NE). If the participant did not choose which window to open within 2500ms, a hand icon appeared in the centre of the screen and had to be touched to move to the next trial.

We used four female faces (aged 25–28) in the stimuli to maintain consistency and manage the number of trials. Including both male and female faces would have substantially increased the complexity of counterbalancing. All video stimuli were custom recorded to ensure precise control over movement, gaze direction, and facial expression across conditions. Videos were trimmed with iMovie to ensure they were of the same duration. The combination of each of the four face identities and the corresponding condition was randomised between participants. To reduce potential preference bias arising from the spatial location of faces, each participant was presented with two blocks of trials (30 trials each). Within each block, the spatial location of each stimulus on the screen remained constant, whilst it was pseudo-randomised across blocks. For example, a participant could see the C_E face in the top left window for the first 30 trials, and in the next 30 trials the same stimulus would be in the bottom right window.

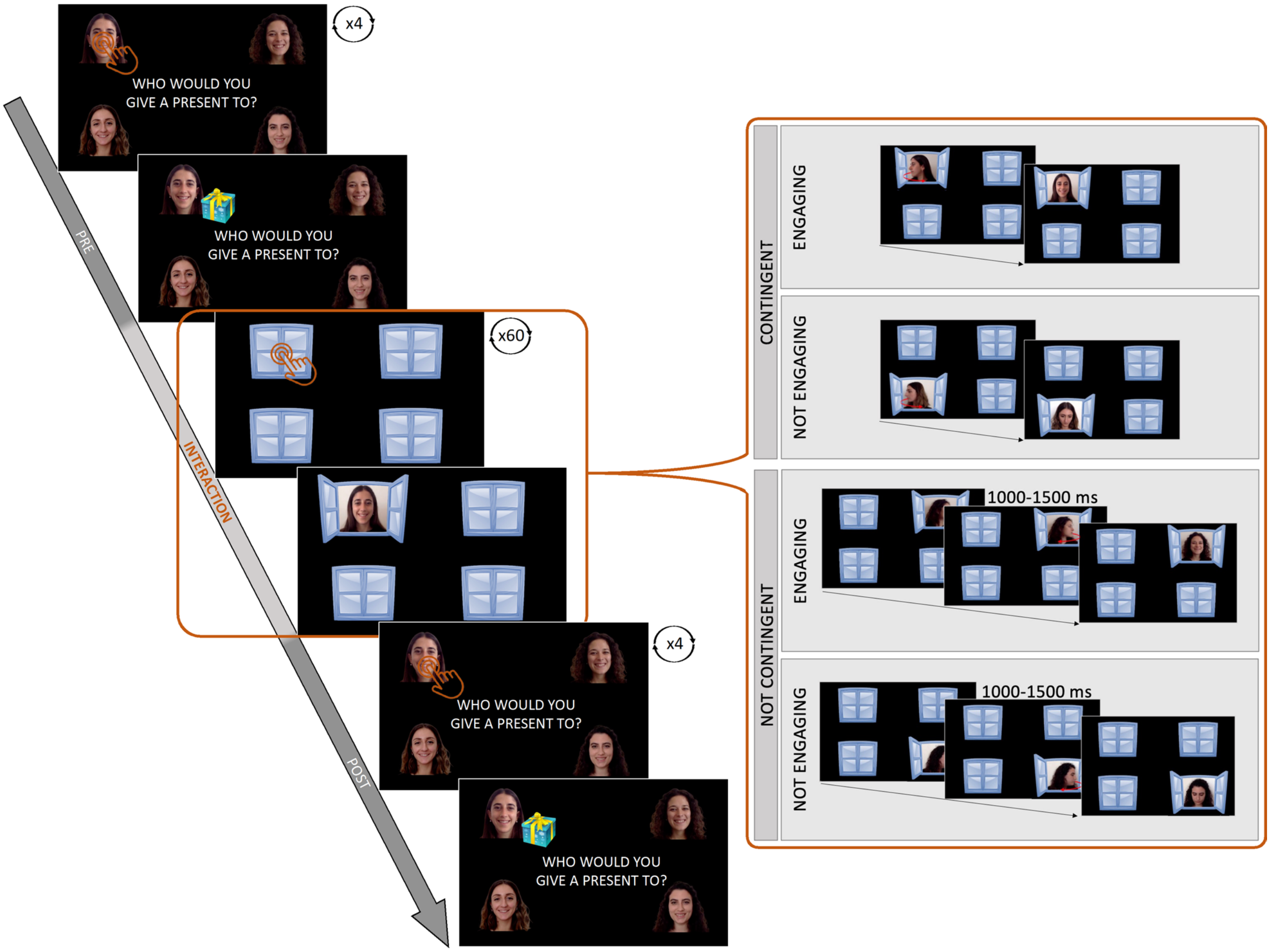


Fig. 2. Experimental paradigm. The task consisted of a preference evaluation phase (before and after the interaction), where participants selected one of four smiling faces to give a present, and an interaction phase, where they freely chose among four windows to reveal short face videos. The videos varied in time contingency (contingent vs. non-contingent response) and social engagement (engaging vs. non-engaging gaze/expression), resulting in four within-subject conditions (C_E, NC_E, C_NE, NC_NE). The paradigm was designed to be accessible to participants with limited verbal abilities.

Data reduction

Participants provided a total of n = 6960 trials. Raw data were first cleaned from omissions (i.e., participants' response not within 2500ms from stimulus presentation), with 9.22% trials being rejected (642/6960 trials). Afterwards, we applied a filter on Reaction Times (RT). Specifically, we excluded those responses whereby RT was less than 150ms, being ascribable to anticipations[53]. Filtered responses (354/6318 = 5.60%) were removed and not further analysed. The final dataset included n = 5964 observations. We further examined this separately for younger children, older children, and adults, as well as for ASD and TD separately, to check whether data loss rates were consistent across populations and age groups (Table 2).

Statistical approach

All analyses were conducted in R (version 4.2.0), a software environment for statistical computing and graphics[54]. For each dependent variable, a set of models were compared to select the model fitting our data best (model comparison approach[55]. While no model can perfectly represent reality, the goal is for the model to uncover the latent process behind the data and for the researcher to choose the most effective model for the purpose: as George E.P. Box (1976) aptly noted: "*All models are wrong, but some are useful*"[56].

Two separate sets of models were tested for the two dependent variables: *interaction choices* and *first choice after interaction*. The first is a factor variable that indicates which of the four response categories (C_E, C_NE, NC_E, NC_NE) is chosen by the participant in each trial. The second is a factor variable that indicates which of the four response categories (C_E, C_NE, NC_E, NC_NE) is chosen first in the post-interaction phase. This reflects the participant's preference following interaction. For both variables, the reference category was set to C_E (contingent engaging) meaning that the models would compare the likelihood of choosing each of the other

	Younger children ($n=32$)	Older children ($n=34$)	Adults ($n=50$)
Trials completed	**1920**	**2040**	**3000**
ASD	780	1140	1560
TD	1140	900	1440
Omissions	**283 / 1920 (14.74%)**	**127 / 2040 (6.23%)**	**232 / 3000 (7.73%)**
ASD	201 / 780 (25.8%)	81 / 1140 (7.11%)	158 / 1560 (10.1%)
TD	82 / 1140 (7.19%)	46 / 900 (5.11%)	74 / 1440 (5.14%)
Anticipations	**106 / 1637 (6.48%)**	**130/ 1913 (6.79%)**	**118 / 2768 (4.26%)**
ASD	62 / 579 (10.7%)	93 / 1059 (8.78%)	72 /1402 (5.13%)
TD	44 / 1058 (4.14%)	37 / 854 (4.33%)	46 / 1366 (3.37%)
Included observations	**1531**	**1783**	**2650**
ASD	517	966	1330
TD	1014	817	1320

Table 2. Data reduction. Sample sizes by group as follows: $n=13$ ASD, $n=19$ TD for younger children; $n=19$ ASD, $n=15$ TD for older children; $n=26$ ASD, $n=24$ TD for adults.

Predictor	Description	Variable type
Group	refers to participants belonging to the TD or ASD population	2-level factor: TD, ASD
Age group	refers to the age range in which participant's age falls	3-level factor: 1, 2, 3
Block	refers to the trials pertaining to the first half or second half of the experiment	2-level factor: first, second
Chosen pre	indicates whether the first choice after interaction was also chosen first before interaction, to account for a-priori preferences	2-level factor: chosen, not chosen. Used as a predictor for post-interaction preferences
Perc of choice	percentage of choice of each stimulus across the interaction phase of the experiment	Numeric ranging 0-100. Used as a predictor for post-interaction preferences

Table 3. Description of independent variables.

categories against the reference. Details on the independent variables included in the models as predictors are summarised in Table 3.

A Bayesian approach with semi-informative priors has been adopted for computational reasons. In fact, Bayesian modelling allows more robust estimates of parameter values and their credible intervals[57]. We used *brm()* function with *family* = *categorical()* from *brms* package (version 2.18.4)[58]. Multinomial mixed effect models were used to analyse *Interaction choice* and *First choice after interaction*. Indeed, the combination of contingency and engagement gives rise to four intrinsically different categories – that are the response options. Being these more than 2, a multinomial distribution family was required to model our data.

$$A\ Multinomial(N, p)\ whereN = A + B + C + D$$

This means that the relative counts of ways to realize A in N trials with probability *p* on each trial comes from the multinomial distribution, and the unobserved parameter *p* similarly gets:

$$p\ Uniform(0, 1)$$

Therefore, *p* has a uniform (flat) prior over its entire possible range, from zero to one[55]. Using a flat uninformative prior is, however, not recommended as "flat priors are hardly ever the best priors" [55, p139]. Therefore, we decided to use a student t prior (mean = 0, sd = 2.5, df = 3). The selected parameters for the student t distribution ensure we have a large prior with high tails, without it being flat *brms::brm()* adopts for intercept and standard deviation. Rather than a non-informative prior, we then have a semi-informative prior (Fig. 3).

The multinomial logistic model structure yields estimates as contrasts between a reference category and all other response options. This formulation limits the direct interpretability of all pairwise stimulus comparisons, both within and between groups. Therefore, we describe and quantify the similarity of the posterior probability distributions (within groups between categories, as well as between groups within categories) using the overlapping index (η) via the *overlap()* function from *overlapping* package (version 2.1) [59]. The η is a distribution-free index that ranges from 0 (total separation) to 1 (total overlap); thus, it should be interpreted as other normalized effect sizes[59,60]. The area of non-overlap (ζ = 1 - η) is reported as an index of separability between distributions. Additionally, we computed posterior differences between stimulus pairs within each group (e.g., among stimulus types within the TD and ASD groups), as well as between-groups differences for each stimulus type. This allows more complete inferential contrasts beyond the model's baseline parameterization. We provide Highest Posterior Density Intervals (HPDIs), Maximum A Posteriori estimate (MAP), and probability of the differences lying above or below zero (with zero meaning no differences between groups). To determine whether a difference is credible, a threshold needs to be set. Some authors question the arbitrariness of the conventional

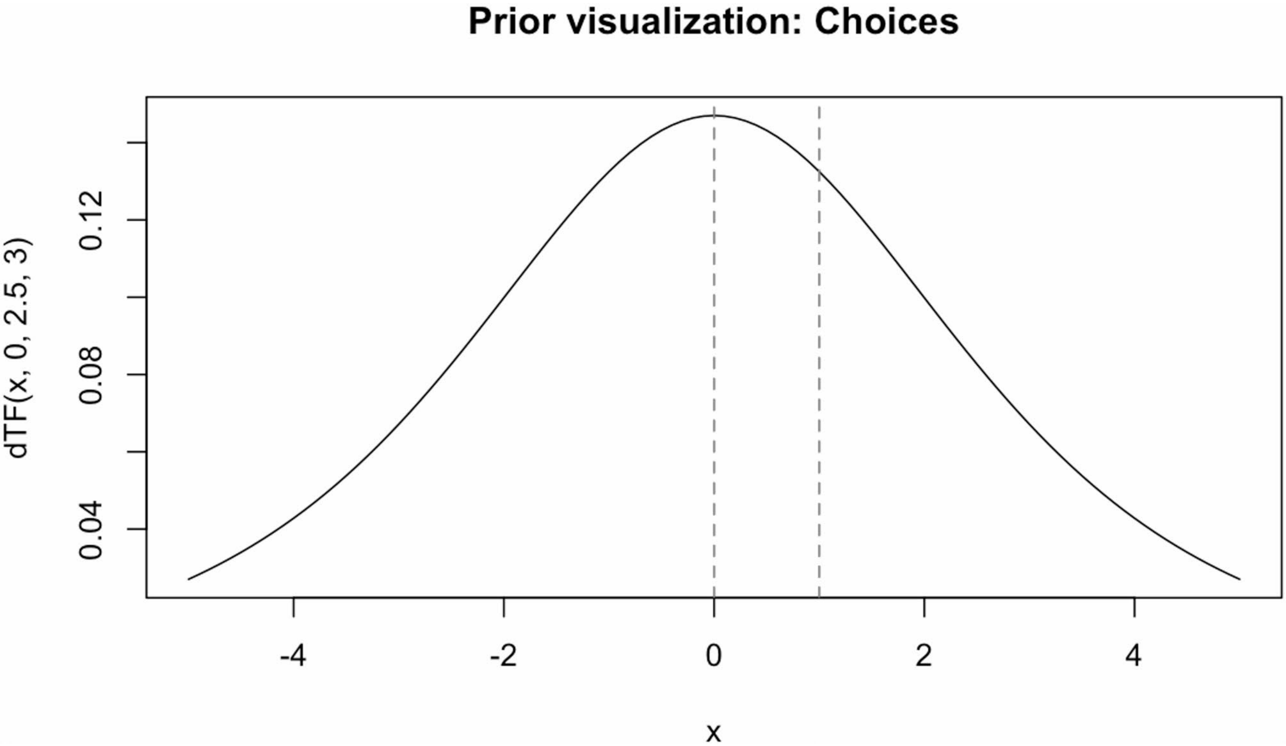


Fig. 3. Prior visualization, with red dotted lines indicating the boundaries of our prior (values falling between 0 and 1).

95% and rather encourages using 89% credible intervals[55]. Others further caution against reducing rich posterior information to a single binary decision and advocate for reporting the full posterior distribution so that different readers can apply their own criteria when assessing evidence[60–62]. Based on such considerations and given the exploratory nature of our study, results are reported as the proportion of posterior samples supporting each inference. For ease of interpretation, we colour code in figures which contrasts are to be considered credible based on 95% or 89% thresholds, which are however intended to as guidelines for exploratory interpretation, not as definitive cutoffs. As a supplementary analysis, we further computed the posterior probability of choices differing (either being lower or higher, separately) from chance level (in our case 25%, having four response categories to choose amongst), which is reported in the supplementary materials.

Model selection was based on a comprehensive evaluation of model performance indexes carried out via the *compare_performance()* function from the *performance* package (version 0.11.0) [63]. The function provides a comprehensive index that indicates the best overall model performance based on *Widely Applicable Information Criterion (WAIC)* and *Leave-One-Out cross validation Information Criterion (LOOIC)* weights[58,64]. Higher performance values correspond to a better model fit. Importantly, mixed models allowed us to account for fixed effects related to experimental manipulations as well as random effects, which are associated with individual units randomly drawn from the population[65,66]. Notably, to guide model construction, we adopted a theory-driven hierarchical strategy rather than an exhaustive model comparison approach. Predictors were entered incrementally based on their theoretical relevance to our central research questions, with group and age group included first given their central role in our hypotheses. Additional predictors and interactions were added only when theoretically justified, to maintain model parsimony and avoid overfitting. We deliberately excluded a model with all possible interactions between fixed effects, as such complexity would exceed the interpretive scope of our study and is not supported by our design. This approach aligns with current recommendations to prioritize theoretically grounded models over purely data-driven selection strategies[55,67,68].

Results
Interaction choices
A set of 6 nested Bayesian logistic mixed model (estimated using MCMC sampling with 4 chains of 3000 iterations and a warmup of 1500) was fitted to our dataset. All models included participant as random effect. The null model only included a random effect of participant as a predictor, while group (2 levels: TD, ASD), age group (3 levels: younger children, older children, adults) and block (2 levels: 1, 2) were gradually added as predictors in the subsequent models. Based on the performance index, model 1 – with group as a fixed effect and participant as the random component – was shown to be the best at predicting the collected data (Table 4). As the selected model did not include the age group as a predictor, no effect of age emerged.

Although the absolute fit gains between m0 and m1 are small, m1 yields higher predictive performance and aligns with our theory-driven question regarding group effects; we therefore report results from m1, whose

Model		WAIC weight	LOOIC weight	Performance
m0	(1|id)	0.558	0.370	0.794
m1	**group + (1|id)**	**0.440**	**0.629**	**0.894**
m2	group + age group + (1|id)	0.002	0.000	0.002
m3	group * age group + (1|id)	0.000	0.000	0.000
m4	group * age group + block + (1|id)	0.000	0.000	0.000
m5	group * age group + group * block + (1|id)	0.000	0.000	0.000

Table 4. Comparing model performance for choices.

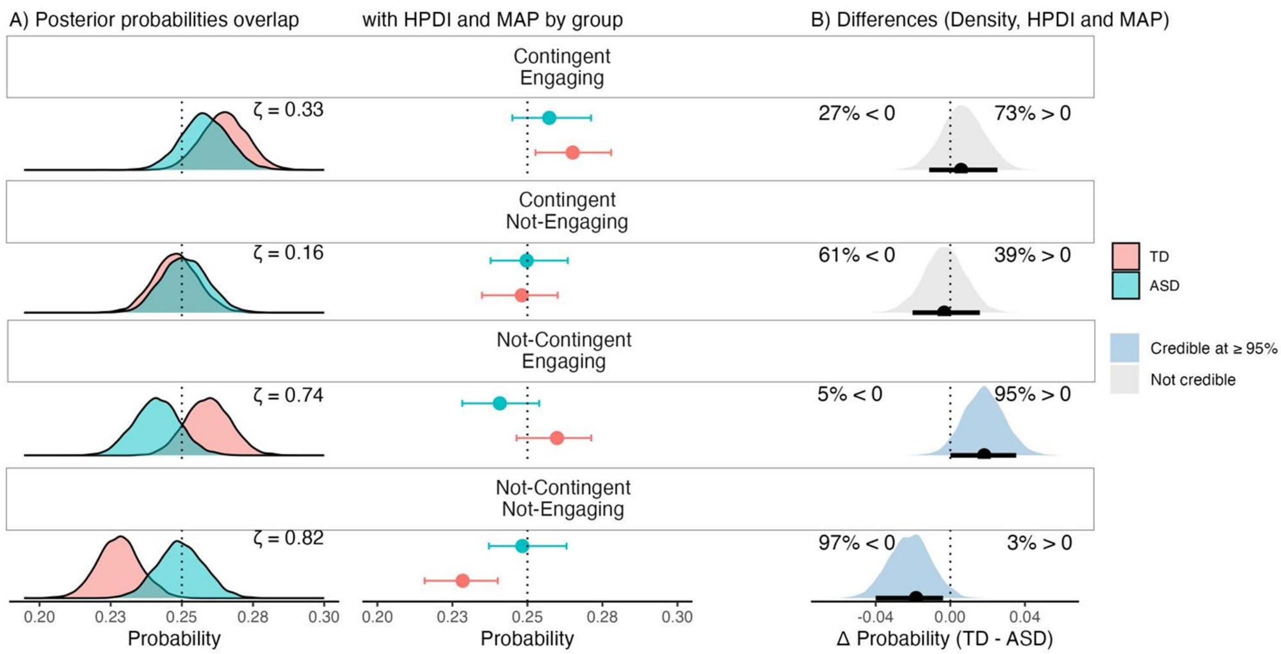


Fig. 4. Between-group differences for each stimulus category. The first column of **Panel A** depicts the posterior distributions of choices across groups, with ζ indicating the non-overlapping area of the two distributions. Dotted lines represent chance level. The second column of Panel A shows HPDI and MAP of choice by group. **Panel B** shows the difference between posterior probabilities distributions of choice by group, with the densities on each side of 0 (with 0 indicating no difference) annotated in each subplot. Note that each row refers to a specific choice category. Credibility is colour coded based on the percentage of posterior distribution falling on one side of zero when assessing a contrast.

posterior analyses pinpoint where the groups are more likely to differ and where they are less likely so. All reported results based on posterior estimates for interaction choices stem from the selected model (m1).

Our results indicate distinct choice patterns between ASD and TD groups for certain stimulus categories but not for others (Fig. 4).

Contingent engaging (C_E). Posterior distributions overlapped considerably, and the group contrast was not credible ($\zeta = 0.33$, $P(\Delta > 0) = 73\%$). This suggests that ASD and TD did not differ in the extent to which they chose faces that were both contingent and socially engaging (Fig. 4, row 1), which had indeed the highest probability to be chosen (TD: HPDI[0.252; 0.278], MAP = 0.265, $P(\Delta > 0.25) = 97\%$; ASD: HPDI[0.245; 0.271], MAP = 0.257, $P(\Delta > 0.25) = 84\%$). As a caveat, the proportion of posterior mass exceeding chance levels was numerically higher for TD than ASD.

Contingent non-engaging (C_NE). Posterior distributions overlapped and the group contrast was not credible ($\zeta = 0.16$; $P(\Delta > 0) = 39\%$), indicating no credible group difference for faces that were contingent but socially neutral (Fig. 4, row 2). The likelihood of choosing this category hovered around chance levels in both groups (TD: HPDI [0.235; 0.259], MAP = 0.246; $P(\Delta < 0.25) = 62\%$; ASD: HPDI [0.237; 0.263], MAP = 0.250; $P(\Delta < 0.25) = 46\%$)

Non-contingent engaging (NC_E). The group contrast was credible ($\zeta = 0.74$; $P(\Delta > 0) = 95\%$), showing a reliable group difference for stimuli that were socially engaging but temporally non-contingent (Fig. 4, row 3). Nevertheless, evidence that either group deviated from chance was modest (TD: HPDI [0.247; 0.271], MAP = 0.260; $P(\Delta > 0.25) = 89\%$; ASD: HPDI[0.229; 0.254], MAP = 0.241; $P(\Delta < 0.25) = 87\%$).

Non-contingent non-engaging (NC_NE). Posterior distributions diverged markedly, and the group contrast was credible ($\zeta = 0.82$, $P(\Delta < 0) = 97\%$), indicating that TD participants showed a lower likelihood of choosing faces lacking both time contingency and social engagement more than ASD participants (Fig. 4, row 4). TD's probability of choosing this category lay well below chance (HPDI[0.216;0.240], MAP = 0.229; $P(\Delta < 0.25) = 100\%$), whereas the ASD distribution hovered around the chance threshold (HPDI[0.237;0.262], MAP = 0.248; $P(\Delta < 0.25) = 53\%$).

Taken together, group differences emerged most clearly for the NC_NE category, with TD participants being less likely to choose these faces than ASD participants, who selected them at chance levels. A credible group difference also appeared for the NC_E category; however, this result should be interpreted with caution, as while the direction of the effect differed across groups, neither group showed a strong deviation from the chance level. No credible group differences were observed for the C_E and C_NE category. To elucidate group-level divergences, we examined specific within-group differences for individual stimulus categories (Fig. 5).

First, we consider the two most polar categories (C_E vs. NC_NE). The C_E condition combines both the presence of time contingency and social engagement, while the NC_NE condition lacks them entirely (Fig. 5B, row 1). TD participants displayed a clear preference for the C_E stimuli over NC_NE, choosing not to choose the latter; in fact, the two posterior distributions overlapped for only a 2% ($\zeta = 0.98$) and their difference was entirely distributed above zero. In contrast, participants with ASD showed a less differentiated response, with the two posterior distributions overlapping for 61% ($\zeta = 0.39$) and only 74% of their difference falling above zero, which indicates a reduced polarity in preference patterns across these extremes.

Second, we explore whether either contingency or engagement alone could drive preferences within each group, by examining the contrast between C_NE vs. NC_E (Fig. 5B, row 2). In both groups, neither contingency nor engagement alone were sufficient to produce a credible preference shift. In fact, in TD groups the two posterior distributions overlapped for 47% ($\zeta = 0.53$), with 81% of the density of their difference falling below zero. For ASD, the two distributions overlapped for 66% ($\zeta = 0.44$) with 77% of the density of their difference falling above zero. Although the differences of such categories within groups are not credible, it is worth noting that between groups the likelihood of choosing stimuli that are engaging although non-contingent is credibly higher for TD than ASD (Fig. 4, row 3).

Third, we compared categories that shared equal levels of either contingency or engagement (Fig. 5B, rows 3–6).

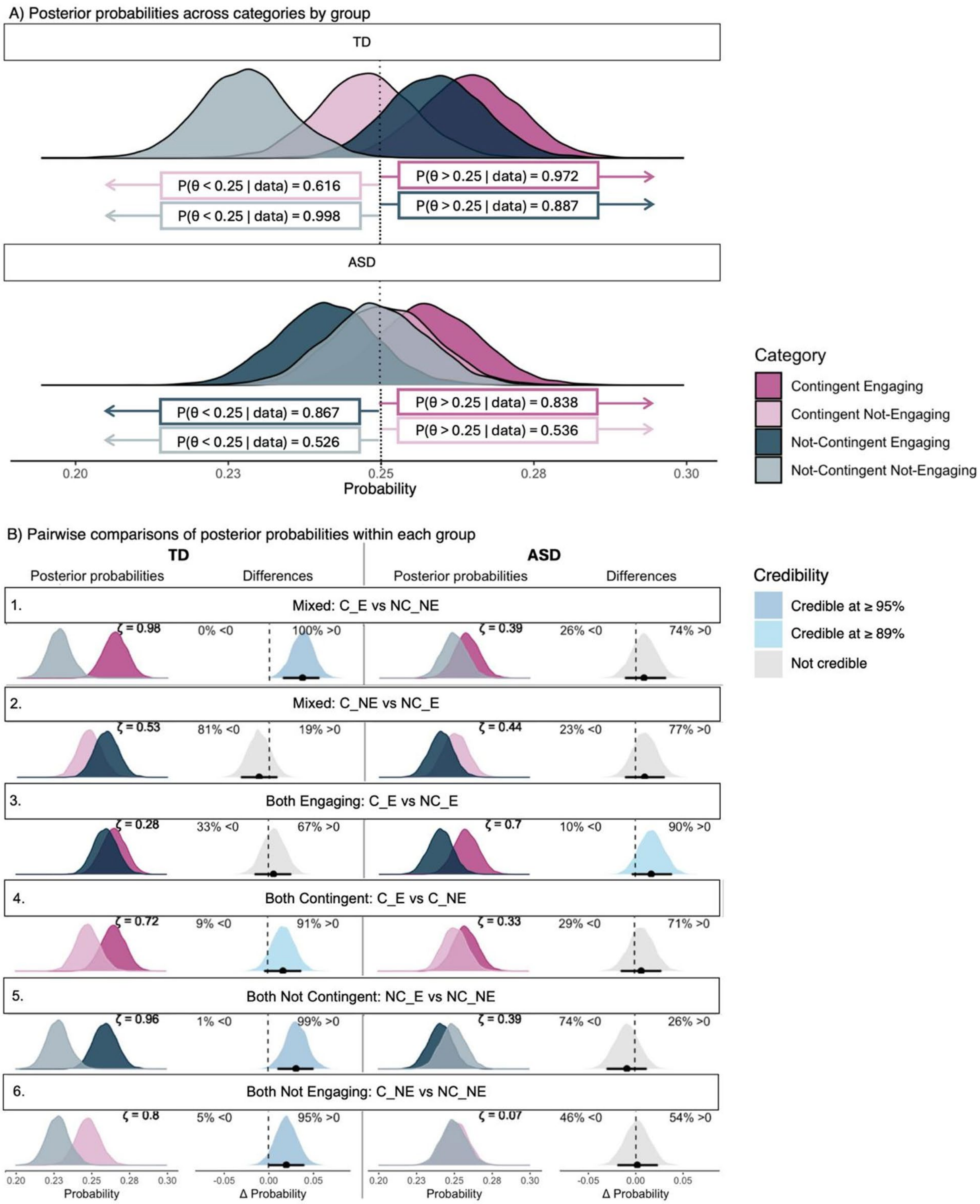
In TD, a preference for socially engaging stimuli emerges. When comparing two contingent stimuli (C_E vs. C_NE), the engaging one was more likely to be chosen. The two posterior distributions overlapped by only 28% ($\zeta = 0.72$), with 91% of the density of the difference falling above zero (Fig. 5B, row 4, columns 1–2). While the credibility of such difference could be considered modest, it still indicates a preference for social engagement. In line with this, when contrasting stimuli that were both non-contingent and varied by engagement (NC_E vs. NC_NE), the two posterior distributions only overlapped for 4% ($\zeta = 0.96$), with 99% of the density of their difference falling above zero (Fig. 5B, row 5, columns 1–2). This indicates strong evidence in favour of TD preferentially selecting stimuli whereby social engagement was present, even if those were non-contingent. Similarly, when both stimuli were engaging but vary by contingency, there appeared to be no difference in the likelihood of choosing one over the other. In fact, the posterior distributions of C_E and NC_E overlap for 71% ($\zeta = 0.28$), with 67% of the density of their difference falling above zero (Fig. 5B, row 3, columns 1–2). Interestingly, when social engagement was absent, contingency seemed to be prioritised. When comparing C_NE to NC_NE categories, TD would preferentially choose C_NE, with the posterior distributions overlapping by only 20% ($\zeta = 0.80$) and 95% of the density of their difference fall above zero (Fig. 5B, row 6, columns 1–2). This is strong evidence in favour of time contingency being prioritised by TD only when social engagement lacks.

In ASD, the only contrast that showed modest evidence of a difference was between two engaging stimuli differing in contingency, with one of them being contingent and the other not. Specifically, the posterior distributions of C_E and NC_E categories are overlapping for 30% in ASD ($\zeta = 0.70$) and 90% of the density of their difference falls above zero (Fig. 5B, row 3, columns 3–4), indicating modest evidence that time contingency is prioritized when the stimuli are socially engaging. On the other hand, the influence of time contingency was negligible when comparing stimuli that are both non-engaging, that is the contrast between C_NE vs. NC_NE (Fig. 5B, row 6, columns 3–4). Specifically, the posterior distributions of C_NE and NC_NE overlap for 93% ($\zeta = 0.07$), with 54% of the density of their difference falling above zero. Notably, MAP estimates for both non-engaging conditions in ASD hovered around chance level, suggesting contingency had no effect on choice behaviour when social engagement is absent. Similarly, no credible differences within the ASD group were found when contrasting stimuli that differ in social engagement but are matched on contingency. Specifically, the posterior distributions of C_E and C_NE categories are overlapping for 67% in ASD ($\zeta = 0.33$) and 71% of the density of their difference falls above zero (Fig. 5B, row 4, columns 3–4). Also, the posterior distributions of NC_E and NC_NE categories are overlapping for 61% in ASD ($\zeta = 0.39$) and 74% of the density of their difference falls below zero (Fig. 5B, row 5, columns 3–4). This pattern suggests that variations in engagement level did not influence choices in ASD when contingency (or its absence) was held constant. Taken together, this suggests there is modest evidence concerning the peculiar role of contingency in socially engaging contexts in ASD.

It is important to note that the ASD group's choice proportions did not strongly deviate from chance when considered in isolation (see Sect. 1.2 Supplementary Materials). However, consistent trends – particularly the credible differences between groups within specific categories and between categories within the ASD group – warrants discussion of these patterns, albeit with appropriate caution.

Social preferences after interaction

A set of 7 nested Bayesian logistic mixed model (estimated using MCMC sampling with 4 chains of 3000 iterations and a warmup of 1500) was fitted to our dataset. All models included participant as random effect (formula: ~1



| id). Priors over parameters were all set as student t (mean = 0, sd = 2.5, df = 3) distributions. The null model only included a random effect of participant as a predictor, while other predictors were gradually added in the subsequent models. Based on the performance index, model 6 was shown to be the best at predicting the collected data (Table 5).

As with interaction choices, we examined post-interaction preferences for potential group differences. Posterior distributions for all categories – except for contingent and engaging – are markedly skewed toward zero, indicating substantially lower selection probabilities. Moreover, the overlap between groups in the posterior distributions is considerable across all categories, suggesting no credible differences in post-interaction preferences between ASD and TD participants. While we cannot pursue further interpretation of group-level effects in this context, for completeness we report the results of the selected extended model including group ×

Fig. 5. Posterior probabilities of choice categories within-groups. Dotted vertical lines represents chance level. **Panel A** depicts distributions by group. For each distribution, we report the posterior probability that the interaction choice differs from chance, denoted as either $P(\theta > 0.25 \mid data)$ or $P(\theta < 0.25 \mid data)$, depending on which is greater. This value reflects the strength of evidence for above- or below-chance responding. For example, $P(\theta > 0.25 \mid data) = 0.972$ means that there is a 97.2% posterior probability that the true value of choice probability exceeds 25%, given the observed data, indicating strong evidence for above-chance responding. **Panel B** shows within group contrasts across different stimulus categories. The first two columns refer to TD, while the last two refer to ASD. The first and third column depicts the posterior distributions of choices across groups (column 1 for TD, column 3 for ASD), with ζ indicating the non-overlapping area of the two distributions. The second and fourth columns show the differences between posterior probabilities distributions of choice by group, with the densities on each side of 0 annotated in each subplot. Credibility is colour coded based on the percentage of posterior distribution falling on one side of zero when assessing a contrast.

Model		WAIC weight	LOOIC weight	Performance
m0	(1|id)	0.000	0.000	0.000
m1	group + (1|id)	0.000	0.000	0.000
m2	group + age_group + (1|id)	0.000	0.000	0.000
m3	group + age_group + chosen_pre + (1|id)	0.000	0.000	0.000
m4	group + age_group + chosen_pre + perc_choice + (1|id)	0.000	0.000	0.000
m5	group * age_group + chosen_pre + perc_choice + (1|id)	0.037	0.081	0.064
m6	**group * age_group + group * chosen_pre + perc_choice + (1|id)**	**0.963**	**0.919**	**1.000**

Table 5. Comparing model performance or first choice after interaction. To note that *chosen_pre* is a 2-levels factor that indicates whether the first choice after interaction was also chosen first before interaction; while *perc_choice* indicates the percentage of choice for each response category across the interaction phase of the experiment.

age and group × pre-interaction choice interaction terms as figures in the Supplementary Materials, along with the corresponding summary table that includes HDPIs and MAPs.

Discussion

In this exploratory study, we used a tablet-based task to simulate social interaction and examine how the combination of time contingency and social engagement influenced participants' preferences for interacting with different faces. Our aim was to explore how these features jointly shaped interaction choices and whether patterns differed between TD and ASD individuals. Our sample included participants aged 3.8 to 33 years. The strength of observed effects varied across comparisons: some yielded credible between- or within-group differences, some showed only modest trends, and others revealed no credible differences. Within the ASD group, choice proportions did not credibly differ from chance across conditions, which should be considered when interpreting group-level findings.

When looking at between-group differences, we found strong evidence that the groups diverged most sharply on the wholly non-responsive faces: TD participants were less likely to choose non-contingent and non-engaging faces, whereas ASD participants selected them at chance. A second more nuanced difference emerged for noncontingent engaging faces: TD leaned toward engaging yet non-contingent faces, whereas ASD participants were less likely to select them. No credible group differences were observed for either contingent engaging (both groups leaned towards choosing it) or contingent nonengaging (both groups hovering around chance).

Within-group comparisons across categories support the idea that social engagement is prioritised over time contingency by the TD group. Indeed, strong evidence showed TD choosing contingent engaging faces more frequently compared to non-contingent non-engaging, as well as non-contingent engaging vs. non-contingent non-engaging. In TD, engagement outweighed contingency even when comparing two contingent stimuli, with modest yet credible support for contingent engaging faces being chosen over contingent non-engaging ones. Only when engagement was absent did contingency become decisive, with a strong TD preference for contingent non-engaging over non-contingent non-engaging.

For ASD participants, while choice proportions did not credibly differ from chance across conditions, one reliable within-group contrast suggested that contingency may play a meaningful role when paired with social engagement. Specifically, modest evidence indicated a preference for contingent engaging over non-contingent engaging faces, which aligns with the absence of group differences in the contingent engaging category. This suggests that time contingency may increase the likelihood that ASD individuals would choose a contingent socially engaging stimulus over an equally engaging but non-contingent alternative, a pattern similar to TD participants'.

No credible group differences emerged in post-interaction patterns. This could suggest a convergence of preferences across groups. However, alternative interpretations are also possible. It may be that the changes in social preferences before and after the simulated interaction were too subtle to detect, or that the amount and nature of the interaction were insufficient to elicit measurable changes. Future work could address these possibilities by extending the duration of interaction, including more ecologically valid paradigms, or using alternative preference measures with greater sensitivity to social engagement dynamics.

While interpretations should remain cautious given the exploratory design and the varying strength of evidence, the findings from the interaction phase of our task provide meaningful insights into how social engagement and temporal contingency may jointly influence social interaction choices, and how these patterns may diverge across TD and ASD populations. They offer a basis for developing targeted hypotheses in future confirmatory studies.

Findings from our investigation might be explained with earlier evidence on the ability to detect contingency in social contexts regardless of being or not in the autism spectrum[69]. One possible interpretation is that temporal closeness between a participant's action and the stimulus response promotes positive engagement, amplified when the stimulus also displays communicative signals (in this case, smiling expression and direct gaze). This view aligns with reports that contingent social stimuli are more attractive and motivating[70]. Still, we emphasize that our data provide only initial evidence for this pattern. Since our stimuli are faces, they are inherently social in nature and thus what makes them different is the extent to which they are socially engaging, other than promptly responsive. One could speculate that the zero-lag engaging responses in the contingent engaging condition supported a sense of social agency in both groups.

A seemingly compensatory effect of social engagement in the absence of contingency was observed only in TD participants. One speculative explanation draws on the *social hyper-binding* account, where larger temporal binding occurs for events that include another person[71]. Prior studies suggest that this effect, while present both in ASD and TD groups, is attenuated in autism[72]. Our exploratory results are consistent with this: ASD participants showed modest preference for contingent engaging over non-contingent engaging stimuli. This raises the hypothesis that contingency might increase the attractiveness of engaging stimuli for some autistic individuals, though confirmatory work is needed. One could argue that the feeling of causing an external event makes one feel in control of the environment, which in turns can be better predicted[73]. This is something that autistic individuals actively seek, as evidenced by their preference for predictable and invariant gaze-contingent interactions[46], as well as stereotyped behaviours to manage social unpredictability[74–76]. Repetition of contingent social episodes, and the computer-mediated nature of our task, may have provided a simplified, predictable context that supported social information processing. An exploratory analysis[77] increased joint attention and eye contact between ASD participants and virtual partners led to those interactions being rated as purposely interactive (compared to non-interactive). Such repetition might reduce the perceptual/cognitive load of live interactions[69] and increase predictability of the social context. Not-contingent social stimuli may be less attractive to the ASD population due to a difficulty in picking up structural regularities of the environment, that therefore results highly unpredictable[78].

Therefore, one could ask whether participants prefer contingent, engaging faces because they can predict responses, or because they can control them. While contingency and predictability are often interrelated, they are not synonymous with social agency, nor does either necessarily entail the other. Contingency does not necessarily cause a sense of agency, and a sense of agency can arise even without strict contingency. Nonetheless, our design allowed participants to perceive that their actions influenced others' behaviour, an experience that may foster a sense of social agency. By design, our task was built to be highly predictable, in fact the stimuli would not vary in their response across the session. Yet, future research should try to further disentangle the joint contribution of agency and predictability in the observed response. In fact, previous studies showed that predictability of the environment matters when it comes to interaction choices for ASD.

For example, researchers using gaze-contingent eye-tracking found that 2-year-olds later diagnosed with ASD responded differently to variability in social interactions compared to low-risk controls and high-risk non-ASD peers[46]. When one stimulus always responded in the same way and another responded variably (e.g., by saying different phrases like "hello" or "good job"), only the non-ASD groups showed a selective preference for the variable interaction. As the authors point out, their results suggest that social interaction is inherently rewarding for individuals with ASD, but their level of engagement may be influenced by the variability of the interaction. This aligns with the broader idea that social responses must be not only engaging, but also predictable to sustain interest. However, this study focused solely on predictability, without manipulating the extent to which participants' actions influenced the responses they received – that is, social agency.

Ultimately, our results expand on those of Klin and colleagues[47], who showed autistic toddlers' preference for time contingency. However, this might seem to contrast evidence on atypical temporal processing in autism found across multiple domains such as audio-visual, audio-motor, visuo-tactile, visuo-motor, and social motor interaction (see[79] for a *systematic review*). This discrepancy might stem from task differences: while prior studies focused on asynchrony detection in passive contexts, our design actively engaged participants in choosing interaction partners. Perceiving others' responses as contingent on one's own behaviour fosters social agency[26]. Our actions are shaped by their consequences, especially when these are rewarding[80]. Experiencing social agency reinforces the feeling of being an active interaction participant. We propose that this sense of control enhances social motivation, as contingent responses act as social rewards. Though often studied separately, agency and reward are deeply interconnected in social contexts. When a voluntary social action leads to a self-attributed, positive outcome, both social agency and the rewarding value of the interaction are heightened[81]. In autism, the interplay between agency and reward is likely central[49,80]. Although ASD participants' overall choices hovered around chance and they completed fewer trials than TD peers, some trends suggest that contingency, particularly when paired with social engagement, may still shape preferences. This aligns with growing evidence that social stimuli are not inherently uninteresting to ASD individuals[44,82,83]. Rather, the degree to which social interactions are perceived as controllable or responsive may influence choice patterns.

Despite the wide age range of our sample, our data do not provide evidence for marked developmental changes across age groups. One could have suggested that older ASD participants, particularly if their phenotype was less severe as in symptoms, might have developed strategies over time to better align with typical social norms, leading to performance more similar to that of TD participants. However, while such compensation – if it occurs – might rely on top-down strategies learned over time, the processes at play in the current task are thought to be low level. This would explain the absence of an age-related effect in our task.

While our study was not designed to evaluate intervention approaches, the mechanisms explored may be relevant to the principles underlying Naturalistic Developmental Behavioural Interventions (NDBIs), which emphasize contingent and engaging social interactions as a means to foster social motivation and communication in autistic individuals[84,85]. By adapting social exchanges to an individual's natural interaction patterns, NDBIs promote social learning through structured yet dynamic engagement, reinforcing the idea that social agency is a crucial component of effective social engagement[86]. In particular, interventions such as the Early Start Denver Model (ESDM) leverage shared control and natural contingencies to create an interactive and rewarding social environment, emphasizing child-led learning and contingent reinforcement of spontaneous social behaviours[87,88]. Our findings raise the possibility that contingent social responses may play a role in shaping social preferences. This could be relevant for understanding why contingent, responsive social environments are central to such intervention models.

Limitations and future directions

While our study provides novel insights into how contingency and engagement influence social interaction choices, several limitations should be acknowledged to contextualize our findings and guide future research.

First, although the ASD group did engage with the task it is important to note that the ASD group's choice proportions did not strongly deviate from chance when considered in isolation. Despite credible differences between groups within specific categories and between categories within the ASD group warranted discussion, this caveat limits the extent to which we can generalize our interpretations. Future studies should more directly assess engagement with and processing of the stimuli through complementary measures such as trial-level gaze data, physiological or neural indices.

Second, our paradigm intentionally prioritised experimental control over ecological complexity. While this allowed for the precise manipulation of contingency and engagement, it may not fully capture the richness of real-life social interactions, which involve more fluid reciprocity, shared attention, and turn-taking. Future studies should complement this approach with naturalistic paradigms to assess how these mechanisms operate in everyday social contexts.

Third, although we included participants across a wide age range and performed grouping based on broad age categories (using a pragmatic cutoff around 9.6 to 9.7 years to approximate developmental transitions), our current sample size limits the ability to examine age effects in a more fine-grained manner. Group assignment by age was done using a pragmatic boundary between 9.6 and 9.7 years to separate children likely to be before or after a key developmental transition, based on literature indicating inflection points around age 10. However, we acknowledge that this threshold is approximate, with a larger, more age-balanced sample, future studies could treat age as a continuous variable or create multiple narrower age groups to more precisely investigate how preferences for contingency and social engagement evolve over development. This approach would also enable a better understanding of potential compensatory strategies, which may be more common among older autistic individuals or those with milder symptom profiles. Incorporating detailed individual difference measures (such as social skills, sensory processing, executive functioning) would further help clarifying developmental trajectories within the autism spectrum.

Fourth, given the considerable heterogeneity of autism, future research should move beyond categorical diagnostic labels and instead examine how individual differences shape responsiveness to contingency and engagement. For example, autistic individuals with more pronounced repetitive behaviours or heightened sensory sensitivities might display narrower choice ranges or reduced tolerance for variability in interaction partners. Similarly, differences in social motivation or cognitive flexibility could influence engagement preferences. The inclusion of parent- or self-report measures on social responsiveness, sensory processing, and executive functioning could help clarify these individual differences. Furthermore, because social engagement likely exists on a continuum, it would be valuable to explore how autism-related traits (such as social responsiveness and sensory sensitivities) vary across both ASD and typically developing populations. Large-scale dimensional studies could then relate individual propensities for valuing time contingency or engagement to broader social behaviour profiles across neurodevelopmental conditions, offering a more nuanced understanding of social interaction styles irrespective of diagnostic categories.

Conclusions

Our exploratory findings offer preliminary evidence that while social engagement is prioritised over time contingency in TD, ASD participants may be more likely to engage with faces that respond contingently to their actions. If supported by future confirmatory studies, needed to validate and extend our observations, this pattern could suggest that contingency-based cues facilitate social engagement in autism. The present study highlights the importance of understanding how individual differences shape responsiveness to social contingencies and how these insights might inform more tailored intervention strategies. Rather than assuming a uniform reduction in social motivation, our results raise the hypothesis that social interest in autism may depend on the predictability and interactivity of the exchange. Designing social environments that provide clear, timely responses could therefore enhance engagement for autistic individuals. This perspective encourages a shift away from viewing social engagement as inherently diminished in autism and instead towards understanding the conditions under which it flourishes.

Data availability

Open data and script to reproduce the analyses are available in Open Science Framework (OSF), at [https://osf.io/vstwn/](https:/osf.io/vstwn).

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Author contributions
L.C., I.V., L.D.L. and T.F. conceived the experiment; L.C., I.V., G.M., and G.M. collected the data, L.C. analysed the results and wrote the original draft of the manuscript, T.F. supervised the project and acquired fundings. I.V., G.M., G.M. L.D.L., F.B. and T.F. reviewed the manuscript. All authors approved the submitted version.

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Declarations

Competing interests
The authors declare no competing interests.

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Correspondence and requests for materials should be addressed to T.F.