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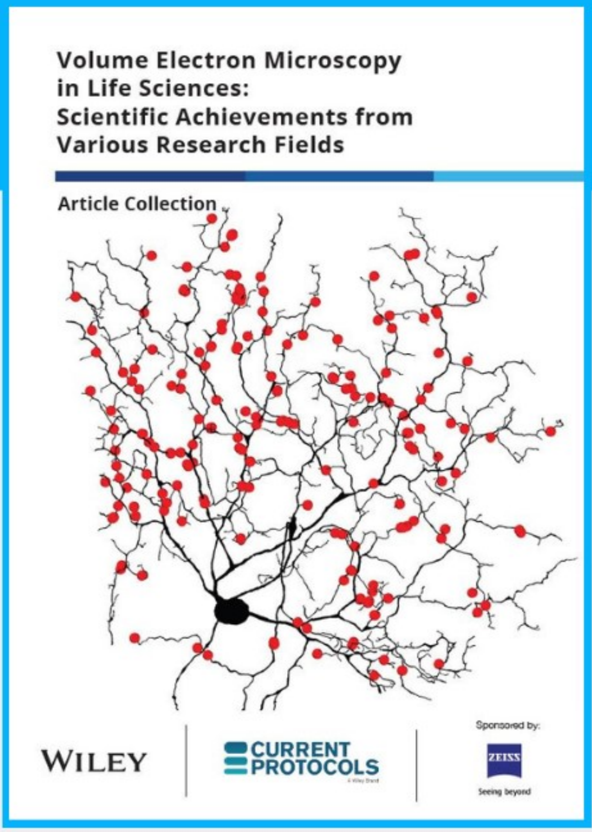

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Through this article collection, we hope to provide researchers with more information on the application of volume electron microscopy techniques, allowing them to further their research in this field.

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Received: 16 May 2023 | Revised: 28 July 2023 | Accepted: 29 August 2023

DOI: 10.1111/ejn.16144

SPECIAL ISSUE ARTICLE

EJN European Journal of Neuroscience FENS

WILEY

Embracing neurodiversity in doll play: Investigating neural and language correlates of doll play in a neurodiverse sample

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Funding information
Funding for this research was provided by Mattel awarded to REV, SAG and SH.

Edited by: John Foxe

Abstract

Doll play may provide opportunities for children to rehearse social interactions, even when playing alone. Previous research has found that the posterior superior temporal sulcus (pSTS) was more engaged when children played with dolls alone, compared to playing with tablet games alone. Children's use of internal state language (ISL) about others was also associated with pSTS activity. As differences in social cognition are frequently observed in autistic people, we were interested in the brain and language correlates of doll play in children with varying levels of autistic traits. We investigated children's ($N = 57$, mean age $= 6.72$, SD $= 1.53$) use of ISL and their pSTS brain activity using functional near-infrared spectroscopy (fNIRS) as they played with dolls and tablet games, both alone and with a social partner. We also investigated whether there were any effects of autistic traits using the parent-report Autism Spectrum Quotient—Children's Version (AQ-Child). We found that the left pSTS was engaged more as children played with dolls or a tablet with a partner, and when playing with dolls alone, compared to when playing with a tablet alone. Relations between language and neural correlates of social processing were distinct based on the degree of autistic traits. For children with fewer autistic traits, greater pSTS activity was associated with using ISL about others. For children with more autistic traits, greater pSTS activity was associated with experimenter talk during solo play. These divergent pathways highlight the importance of embracing neurodiversity in children's play patterns to best support their development through play.

Abbreviations: ALNCo, Additional Learning Needs Coordinator; AQ-Child, Autism Spectrum Quotient—Children's Version; EEG, electroencephalography; fMRI, functional magnetic resonance imaging; fNIRS, functional near-infrared spectroscopy; GEEs, generalized estimating equations; HbO, oxygenated haemoglobin; HbR, deoxygenated haemoglobin; ISL, internal state language; NDAU, Neurodevelopment Assessment Unit; pSTS, posterior superior temporal sulcus; RDoC, Research Domain Criteria.

KEYWORDS
autistic traits, fNIRS (functional near-infrared spectroscopy), internal state language, neurodiversity, play, social processing

1 | INTRODUCTION

Play is a major activity for children, although researchers have struggled to accurately and comprehensively define play in its many forms and variations across children (e.g., Lillard, 2015; Weisberg, 2015). Eberle (2014) argued that at its most elemental, play should be fun. One of the most commonly researched and defined subtypes of play is pretend or symbolic play, which involves some form of representation or acting-as-if, for enjoyment or amusement (Lillard, 1993). Pretend play activities begin to appear around 18 months (Weisberg, 2015) and traditionally were thought to peak at about 6 years of age. However, more recent research suggests that pretend play can continue later in childhood and into adulthood (Smith & Lillard, 2012).

During pretend play, children engage in high-level cognitive and social activities (Smith, 2007) that are important for cognitive and social development. For example, children often use theory of mind, symbolic understanding and language during pretend play (McCune, 1995; Tessier et al., 2016). In previous research, we have found that one form of pretend play, doll play, engages neural regions involved in theory of mind and empathy (i.e., posterior superior temporal sulcus [pSTS]) and is associated with increased use of internal state language (ISL) about others (Hashmi et al., 2020, 2022).

Autism is in part defined by difficulties with social communication (American Psychiatric Association [APA], 2013) and has been associated with a range of social cognitive differences (for reviews, see Sasson, 2006; Sasson et al., 2011). Although pretend play is known to be different in autistic children (Thiemann-Bourque et al., 2019), little is known about the underlying mechanisms of play in these children. In this study, we use the lens of neurodiversity to investigate doll play and its neural and language correlates in children with varying degrees of autistic traits (without a diagnosis).

Neuroimaging has the unique capacity to capture the neural mechanisms activated during play. The recent development of the functional near-infrared spectroscopy (fNIRS) tool overcomes limitations of traditional tools like electroencephalography (EEG) and functional magnetic resonance imaging (fMRI) by affording greater freedom of movement to participants. As a result, fNIRS has become an important tool for understanding neural functioning in neurodivergent populations (Vanderwert & Nelson, 2014). Research using fNIRS has highlighted a potentially important region, the pSTS, to target for capturing the social components of play. For example, fNIRS research showed that social and speech stimuli activated optodes over the pSTS in young infants (Lloyd-Fox et al., 2009, 2015). Activity in similar regions was found during naturalistic social interactions with toddlers (Hakuno et al., 2018) and when 3-year-olds viewed faces (Richardson et al., 2021). The evidence that the pSTS is activated during social interactions and social processing is corroborated by fMRI studies with adults (e.g., Deen et al., 2015; Isik et al., 2017).

Being robust to the effects of movement makes fNIRS ideal for exploring naturalistic activities such as play in children, though few studies have taken advantage of this up until now. An exception comes from a recent study that found activation in the pSTS region as children played with both dolls and tablet games either with a social partner or alone (Hashmi et al., 2020). Regardless of the toy, children engaged the pSTS while playing with a social partner. Children were also found to engage the pSTS more when playing with dolls alone, relative to playing with tablet games alone, with the doll effectively representing a social play partner in their brain. This conclusion was further supported by the language children used during play, as the use of more ISL about others was linked to stronger pSTS activation.

Throughout childhood, children across cultures often use ISL when playing to refer to the thoughts, feelings, and desires of themselves and others (Carpendale & Lewis, 2015; Kristen et al., 2015; Leach et al., 2017; Tardif & Wellman, 2000). Children spontaneously produce ISL when playing with 'traditional' toys such as toy figures and dolls, as well as when playing with electronic games on tablets and computers (Hashmi et al., 2021, 2022). Use of different types of internal states (e.g., cognitions vs. desires) also depends on type of play (Howe et al., 2022). Similarly, children generally use more ISL when playing with another person compared to when they play alone (Hashmi et al., 2022) and use more ISL, particularly to refer to the internal states of others, when playing alone with toys and dolls compared to when playing alone with electronic games (Hashmi et al., 2021, 2022).

The opportunities afforded by toys such as dolls for referencing and appreciating the internal worlds of others may facilitate the development of social understanding compared to playing on electronic devices (Carpendale & Lewis, 2015). In support of this, references to the internal states of others are associated with other aspects of children's social–cognitive development such as their production of humour (Paine et al., 2022) and perspective-taking skills (Howe, 1991; Tessier et al., 2016).

The majority of research investigating play in neurodivergent children has focused on autistic children. This research shows mixed findings in autistic children's engagement in pretend play. A body of studies have found that autistic children are less likely than their peers to engage in spontaneous pretend play (Atlas & Lapidus, 1987; Baron-Cohen, 1987; Charman et al., 1997; González-Sala et al., 2021). Particularly, a recent study found that just over half of the children in their autistic sample exhibited emerging or mastered levels of pretend play (which the authors describe as at least two symbolic play acts), compared to 95% of matched neurotypical children (Thiemann-Bourque et al., 2019). On the other hand, a number of studies have also reported no differences between autistic and neurotypical groups in terms of their engagement in pretend play (Dominguez et al., 2006; Naber et al., 2008; Thiemann-Bourque et al., 2012; Warreyn et al., 2005). These mixed findings may be contextual effects of the types of toys used in studies. For example, autistic children produced fewer original pretend acts (i.e., not prompted or previously demonstrated by an experimenter) for a toy car but performed similarly to a comparison group when producing original pretend acts for a doll (Lewis & Boucher, 1995). The authors suggest that this may be due to the physical features of the doll, which allowed children to move the doll's flexible body and limbs, while there were fewer parts of the car that could be manipulated. However, it is also likely due to the nature of the toys, with dolls arguably affording a greater potential to generate novel and creative play scenarios. Differential findings may also be due to whether pretend play includes elicited or scaffolded elements. When pretend play was elicited and specific instructions were given, autistic children showed similar amounts of pretend play as their matched peers (Jarrold et al., 1996; Lewis & Boucher, 1988). This suggests that autistic and non-autistic children are similarly able to produce pretend play, but autistic children are less likely to spontaneously engage in pretend play, at least in some contexts (Douglas & Stirling, 2012). Importantly, when autistic children do engage in pretence, it may support their social development. For example, autistic children who created imaginary friends had greater parent-reported theory of mind and social skills than autistic children who did not have imaginary friends (Davis et al., 2013).

Research has also examined the neural correlates of social processing and social cognition in autistic individuals. Converging evidence has identified differential activation of the superior temporal sulcus (STS) and other social processing brain regions in autistic individuals relative to non-autistic individuals (Boddaert et al., 2004; Pelphrey et al., 2005; Philip et al., 2012). Autistic children had reduced activity relative to neurotypical children in the superior temporal gyrus (adjacent to the pSTS) while observing ironic social scenarios (Wang et al., 2007). Lloyd-Fox et al. (2013) have also shown that infants at a higher genetic risk for autism showed reduced activity in the STS region when viewing social stimuli compared to infants at a lower genetic risk. Interestingly, individual differences in STS activation have been found in autistic adults that related to their levels of social cognitive functioning. For example, when attributing mental states to geometrical figures, autistic adults with higher theory of mind ability showed greater activation in the pSTS than autistic adults with poorer theory of mind ability (Kana et al., 2009). Given the links between pSTS activity and ISL use during play (Hashmi et al., 2022), it may be that children with higher autistic traits show reduced pSTS activation (relative to children with fewer autistic traits) during doll play if they are less likely to think about and discuss others' internal states (Kauschke et al., 2016; Siller et al., 2014).

1.1 | Current study

In the current study, we aimed to replicate and extend the findings of Hashmi et al. (2020, 2022) by considering play in the context of neurodiversity. Following Hashmi et al. (2020), 4- to 8-year-old children took part in four distinct play sessions: playing with a set of dolls and an electronic tablet, both alone and with a social partner. Previous work indicated that doll play increased the propensity to engage in social processing and discuss the thoughts, feelings and internal worlds of others. In the current study, we were interested in whether doll play had the same neural and language correlates in children with high compared to low levels of autistic traits. The children all attended mainstream primary schools and did not have an autism diagnosis, although some had been identified as experiencing emotional or behavioural difficulties in school. We hypothesized the following: (1) Children would show greater activation of the pSTS for solo doll play than solo tablet play; (2) activation of the pSTS during doll and tablet play would differ according to children's autistic traits, such that children with more autistic traits would show less activation of the pSTS relative to children with fewer autistic traits, particularly during solo doll play; (3) the amount and (4) type of children's talk during social and solo play would differ between doll and tablet play and according to children's autistic traits, such that children with more autistic traits would use less ISL and speak less overall than children with fewer autistic traits; and

(5) children's references to the internal states of others during play would be positively related to activity in the pSTS.

2 | METHODS

2.1 | Participants

To ensure we captured sufficient variation in children's degree of autistic traits, we targeted our recruitment using two different strategies. First, we recruited children ($n = 24$) from the Neurodevelopment Assessment Unit (NDAU) at Cardiff University (Burley & van Goozen, 2020). Children aged 4 to 8 years from local mainstream primary schools are referred by teachers and Additional Learning Needs Coordinators (ALNCos) to the NDAU as having emotional, cognitive and/or behavioural difficulties in the classroom, in the absence of any diagnosed neurodevelopmental condition. The NDAU is not a clinical unit but instead provides detailed assessments of children across different psychological domains (e.g., cognition, language and emotion) in line with the Research Domain Criteria (RDoC) approach (Cuthbert, 2015). From this group, we specifically recruited children who had scored above 66 on the Autism Spectrum Quotient—Children's Version (AQ-Child, Auyeung et al., 2008).

We also recruited $n = 33$ children from a participant database of local families interested in participating in research. These children were recruited for a larger longitudinal study, and the data included in the current study were from each child's first visit. Parents of these children confirmed that their child did not have a neurodevelopmental diagnosis or any developmental delays.

Our full sample consisted of 57 children aged 4 to 8 years (mean age: 6.72 years, $SD = 1.53$, 30 male). The majority of children were White ($n = 53$, 93%), three identified as mixed race and one identified as Asian or Asian British. We were able to acquire full fNIRS data from 49 children. Participants were excluded from fNIRS analyses because of insufficient data ($n = 4$), child non-compliance ($n = 2$) or statistical outliers in haemoglobin concentrations (>2 SD in multiple channels; $n = 2$). We were unable to calculate language data from one child due to experiment error, giving a sample of 56 children for these analyses.

Autistic traits were measured using the AQ-Child (Auyeung et al., 2008). Combining our two samples, we found that autistic traits were normally distributed. To conduct our analyses with two meaningful groups, we, therefore, categorized children as above or below the median for AQ-Child in our sample (med = 71). Unsurprisingly, most children in the high AQ group were from the NDAU sample ($n = 21$ of 29). The demographics of the sample used in fNIRS analysis are included in Table 1 (demographics for the participants used in language analyses are included in Table S1). Written informed consent was obtained from the parent or caregiver prior to the start of the study. Each child received a certificate and a prize worth approximately £5 for participation. Participants recruited through the NDAU also received additional monetary compensation. The study was reviewed and approved by the ethical review panel at Cardiff University.

2.2 | Materials

2.2.1 | Parent questionnaires

Children's experiences with dolls and tablets

Parents completed a short questionnaire on their child's experiences playing with dolls and tablets at home and at school. Parents were also asked how often their child played with dolls/tablets and the types of dolls/tablets their child played with. Results did not differ based on AQ-Child split (above/below median) and are not included in subsequent analyses.

AQ-Child

The AQ-Child (Auyeung et al., 2008) is a parent-report questionnaire designed to identify and quantify autistic traits in 4- to 11-year-old children. Parents were given a series of 50 descriptive statements and were asked to rate their level of agreement using a 4-point Likert scale (0 = '*definitely agree*' to 3 = '*definitely disagree*'). Scores were summed to give a value between 0 and 150; higher scores indicate more autistic traits. A cut-off of 76 is suggested for signposting to clinical services but is not a diagnostic tool (Auyeung et al., 2008). Furthermore, a cut-off of 66 provides .99 sensitivity and .90 specificity for correctly classifying children as autistic or non-autistic (Auyeung et al., 2008). In our analysis, we divided groups based on the median AQ-Child score of 71 to create meaningful, evenly split groups. Cronbach's α was acceptable ($\alpha = .72$).

2.2.2 | Stimuli

Tablet games

Children played two tablet games during the session: Toca Hair Salon 3 (Toca Boca, Stockholm, Sweden) and Hoopa City 2 (Dr. Panda, Chengdu, China). Toca Hair Salon 3 is a hairdressing game in which children can choose characters and wash, cut and style their hair. Hoopa City 2 is a world-building game in which players build cities including roads, buildings and lakes as animated characters wander around the city. These games

TABLE 1 Demographics of participants included in fNIRS analysis.

	Whole sample ($n = 49$)	High AQ ($n = 24$)	Low AQ ($n = 25$)	p value[a]
Age	8.93 (6.85)	7.21 (1.33)	6.52 (1.62)	.109
Sex	27 male, 22 female	11 male, 14 female	16 male, 8 female	.111
Ethnicity	47 White, 1 mixed race, 1 Asian/Asian British	24 White, 1 mixed race	23 White, 1 Asian/Asian British	.368
Annual household income	£41,188 (21,079)	£34,976 (15,772)	£46,625 (23,825)	.064
Parent education	1 = secondary education, 6 = GCSE, 5 = NVQ/ diploma, 6 = A levels/ further education qualification, 20 = bachelor's degree, 9 = master's degree or equivalent, 1 = other	6 = GCSE, 2 = NVQ/diploma, 4 = A levels/further education qualification, 8 = bachelor's degree, 3 = master's degree or equivalent	1 = secondary education, 3 = NVQ/diploma, 2 = A levels/further education qualification, 12 = bachelor's degree, 6 = master's degree or equivalent, 1 = other	.135
AQ total score	71.85 (19.96)	88.28 (11.90)	56.08 (11.49)	<.001

Note: Higher scores on AQ reflect more autistic traits.
Abbreviations: AQ, Autism Spectrum Quotient—Children's Version; fNIRS, functional near-infrared spectroscopy; GCSE, General Certificate of Secondary Education; NVQ, National Vocational Qualification.
[a]Significance of tests comparing high and low AQ groups.

were selected to be complementary to doll play, as they are open-ended without any strict rules or set objectives and include characters. They are also suitable for the age range included in the study. Children played these tablet games on a 12-in. iPad Air (4th Generation, iOS 16.3.1).

Doll sets

Three different doll sets made up of several Barbie dolls and accessories (Mattel Co., El Segundo, CA, USA) were used during the doll play sessions. Each set was made up of a different theme: the family set, animal set, careers set but all included dolls of different genders and a mix of different races.

2.2.3 | Procedure

Once seated on a carpet square on the floor, the fNIRS cap was fitted on the child's head and calibration of the fNIRS equipment was assessed. During this time, an experimenter introduced the child to the two tablet games to ensure that the children knew how to play each game without assistance. This experimenter played with the child for both joint play sessions. Once good signal quality had been achieved and an appropriate amplification factor for each source–detector combination had been determined through calibration, the lighting in the testing room was dimmed and the parent/caregiver was invited to observe the session from an adjoining room. If the parent preferred to stay in the room, they were asked not to interact with their child and to sit on a chair in the corner of the room. We confirmed through video recording that parents did not interfere with the task. Participants remained on the carpet square for the entire session.

The timing and order of each of the 4-min play blocks were controlled by E-Prime 3.0 (Psychology Software Tools, Sharpsburg, PA, USA), and baseline stimuli and indicators of trial type (doll/tablet) for the experimenter's reference were presented on an iiyama ProLite 24″ LCD monitor. The experimenter controlled the beginning of each block through a button press once the child was ready. During each play block, the screen was black with small text in the corner indicating the current block and what the next block would be, to allow the experimenter to prepare and minimize transition time between blocks. Before each play block, the child watched a 10-s baseline of five pseudorandom images of clipart vegetables (broccoli, onions, carrots, pumpkin, aubergine/eggplant, radishes and cucumber) presented on a black background in the centre of the screen for 1.5 s each, interspersed with a white fixation cross displayed for .5 s (Figure 1). Following the baseline, the experimenter set up the materials for the next block.

The testing session began with children watching a 5-min space video, in order to allow the child to acclimate to wearing the cap. In the play blocks, the child first played together with an experimenter with the dolls and with the tablet (joint play). Each joint play block lasted 4 min, during

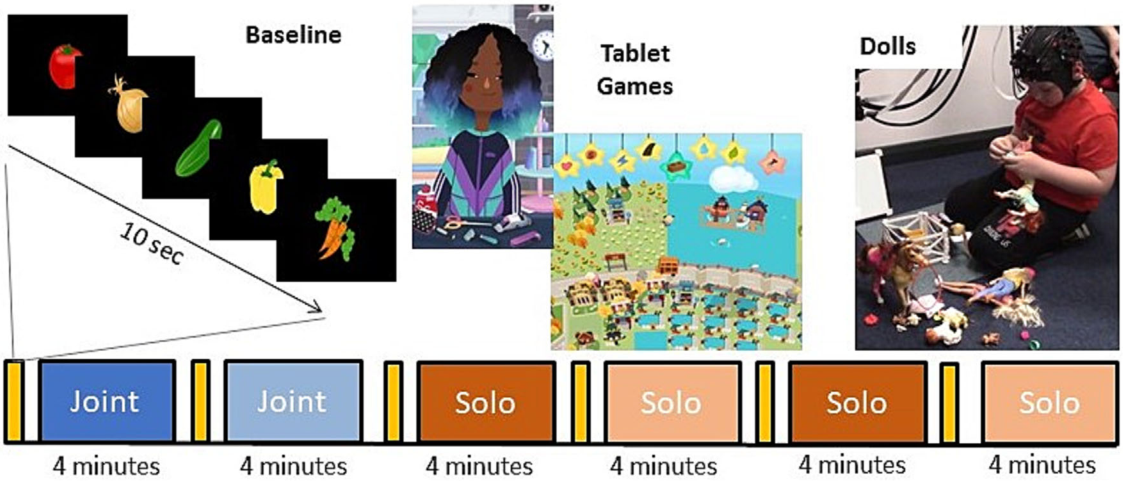

FIGURE 1 Experimental paradigm. Before each play block, children viewed a 10-s baseline consisting of sequentially presented clipart images of vegetables. The session began with two blocks of joint play, followed by four blocks of solo play. Each play block lasted 4 min. Whether the play block was with dolls or a tablet was counterbalanced.

which the child and experimenter played together with a doll set or one of the tablet games. The first doll set was always the same. In all joint play blocks, the experimenter allowed the child to lead the play session. If the child did not interact with the toys or tablet game in a play session, the experimenter prompted play by asking questions (e.g., 'Which doll would you like to be?' or 'What should we build?'). These prompts were open-ended and did not attempt to elicit any particular behaviours or language use (e.g., commenting on mental states). The child then completed four solo play blocks, alternating between dolls and tablet. The order of the presentation of dolls and tablet play blocks was counterbalanced between participants. In these blocks, the experimenter provided the child with the play materials and then sat behind the child and told the child to play by themselves. If the child attempted to interact, the experimenter reminded the child that they should play on their own and responded as briefly as possible. Children were allowed to take breaks or finish the testing session early if they desired. The entire session lasted approximately 50 min. During the play sessions, parents completed questionnaires on their child's experiences with dolls and tablets, as well as the AQ-Child.

2.2.4 | Video recording

The experiment was recorded using both a Logitech C270 720p Webcam attached to the computer monitor and a Canon LEGRIA HF R706 camera mounted on a tripod that was placed in the corner of the room across from the child. This allowed the capture of both the child's facial expressions and actions during play as well as audio recording. Each camera was adjusted prior to the start of each experiment to ensure the angle was capturing the child's play.

2.2.5 | fNIRS acquisition

Concentration changes in oxygenated haemoglobin (HbO) and deoxygenated haemoglobin (HbR) were measured via the NIRScout fNIRS system and NIRStar software (NIRx Medizintechnik GmbH, Berlin, Germany). The system collected data at both 760- and 850-nm wavelengths, with a sampling rate of 3.91 Hz. Sixteen sources and 15 detectors were used for this experiment, making a total set of 40 optodes. The sources and detectors were inserted into a flexible nylon NIRS cap (NIRx) worn by the child. We had a range of different-sized caps to ensure each child wore a well-fitted cap. The distance between the sources and detectors was 3 cm. Sources and detectors were positioned over the frontal, temporal and parietal cortices (Figure 2) to record HbO and HbR measurements from the orbitofrontal cortex (OFC) and bilateral pSTS in the right and left hemispheres. During capping, the cap was placed so that the seam of the cap rested just above the participant's brow line, and the participant's ears were placed through the ear holes to maintain a consistent cap placement.

2.2.6 | fNIRS processing

Processing of fNIRS data was carried out using nirsLAB v2019.04 (NIRx Medizintechnik GmbH, Berlin, Germany),

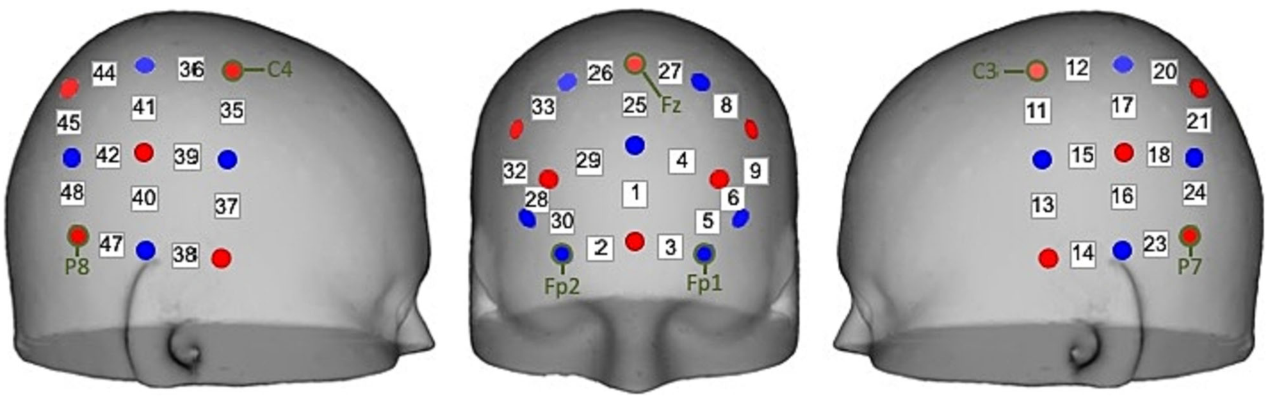

FIGURE 2 Organization of optodes on NIRS cap and the channel locations used for data analysis. Bilateral panels of five sources (red) and four detectors (blue) separated by 3 cm were placed anchored on the international 10–20 system by sites C3/4 and P7/8 resulting in 12 channels (white) per hemisphere. A frontal panel of six sources and seven detectors separated by 3 cm was placed with the bottom row of optodes over the Fp1, Fpz and Fp2 sites.

following the same processing procedure as Hashmi et al. (2020). We manually examined the raw optical time-series data, and any brief spikes or discontinuities in the data (<1 s in duration) were identified and interpolated in all channels. Each channel with a gain setting greater than 7 was then visually inspected, and channels with excessive noise were removed from further analysis. A finite impulse response bandpass filter from .03 to .8 Hz with a 15% roll-off was then applied to the optical data. These filter cut-offs were based on previous research with similar designs (Gervain et al., 2008; Hashmi et al., 2020; Perdue et al., 2014; Ravicz et al., 2015). The optical data were then converted to haemodynamic states using the modified Beer–Lambert law.

Haemodynamic data (both HbO and HbR) were baseline corrected to the 20 s before the onset of each play block (including the vegetable baseline and toy set-up time). Mean HbO and HbR concentrations were averaged across each condition (joint doll, joint tablet, solo doll and solo tablet). Finally, activity was averaged across our regions of interest (ROIs): left pSTS (17, 18, 20 and 21) and right pSTS (41, 42, 44 and 45). These regions were defined based on previous fNIRS research and research that co-registered MRI with fNIRS to identify underlying regions (Lloyd-Fox et al., 2009, 2015).

2.2.7 | Coding children's language and behaviour

Talkativeness

Children's and experimenter's speech was transcribed verbatim from the video recordings into 5-s segments for each session of play (Hashmi et al., 2022). A proportional measure of children's talkativeness was calculated by dividing the number of 5-s segments that contained child speech by the total number of 5-s segments in each session (i.e., joint doll, joint tablet, solo doll and solo tablet). All speech was included in these calculations other than any instances of non-word vocalizations or speech that was not intelligible. This resulted in scores between 0 and 1 reflecting the proportion of each session during which the child talked.

Talk to the experimenter or talk by the experimenter was *task relevant* during joint play (as the experimenter was the play partner) but irrelevant during solo play (as the child was told not to interact with the experimenter). Therefore, we removed children's speech during solo play that was directed towards the experimenter from the calculation of talkativeness scores and analysed this separately. As experimenter speech could be a confound if it differed across contexts or groups, we also calculated the proportion of experimenter talk during each segment, using the same method as for child talkativeness.

References to internal states

Children's use of ISL was coded from the transcripts of children's speech using a coding scheme developed by Paine et al. (2019) and used in a previous study with the same experimental procedures (Hashmi et al., 2022). This scheme captures both the category of internal state (*cognition*, *desire*, *emotion*, *intention*, *preference*, *perception* and *physiology*) and the referent of the internal state (*self*, *character* or *other* [e.g., experimenter]). Within each 5-s segment, multiple categories and referents could be coded, and where there was ambiguity as to the referent, this was coded as 'other'.

An independent observer coded the frequency of children's use of ISL for a random subsample of 12 (20%;

6 from each sample) of the transcripts of children's play: mean intraclass correlation coefficient (ICC) = .94 (range = .78–1) for joint doll play, mean ICC = .97 (range = .75–1) for solo doll play, mean ICC = .93 (range = .75–1) for joint tablet play and mean ICC = .90 (range = .78–1) for solo tablet play.

For the present analyses, children's ISL was collapsed across internal state categories, and we combined children's references to the internal states of 'characters' and any 'other' individual to contrast these from references to the self. The frequency counts were averaged across the two solo doll play and two solo tablet play conditions.

2.2.8 | Analytic plan

Post hoc power calculations with an effect size of $f = .22$ and $\alpha = .05$ using G*Power 3.1.9.7 (Faul et al., 2007) revealed a $\beta = .95$. To address our first two research questions and examine pSTS activity, we first conducted a repeated measures analysis of variance (ANOVA) with HbO over pSTS regions as the dependent variable and hemisphere (left vs. right), play type (doll vs. tablet) and social context (solo vs. joint) as repeated measures. We then added AQ-Child scores as a covariate to investigate whether there were any main effects or interactions with autistic traits. Raw data from this study are available at https://osf.io/mkzpy/.

To assess whether child talkativeness differed based on session type or AQ traits, we conducted a repeated measures ANOVA. The proportion of each session that the child spoke (not including speaking to the experimenter during solo sessions) was the dependent variable, with play type (doll vs. tablet) and social context (solo vs. joint) as repeated measures. To assess whether there were effects of autistic traits, AQ-Child scores were then added as a covariate. Based upon a three-way interaction with this covariate, subsequent analyses that included any form of talking measures used a median split of AQ-Child scores to ease interpretation of interactions. Due to differences in age and trends of differences in some socioeconomic status (SES) factors for the subset of participants whose talkativeness data were used when an AQ median split was considered, we included age, income and education as covariates in analyses. These were removed when not significant but included when significant. We separately analysed the proportion of each solo play segment that the child spent talking to the experimenter using a repeated measures ANOVA with play type (doll vs. tablet) as a repeated measure and median AQ split as a between-subjects factor. Experimenter talk was analysed using a repeated measures ANOVA with play type (doll vs. tablet) and social context (joint vs. solo) as repeated measures and median AQ split as a between-subjects factor.

Due to the differences in talkativeness based on AQ group in the above analyses, subsequent analyses were conducted separately for each group. Based on skew in the data (with a large proportion of children not using any ISL), we created binary codes for whether children used any ISL about self and other or not and entered these into two separate binomial logistic generalized estimating equations (GEEs) for each AQ group using model-based estimators and unstructured working correlation matrices. Play type and social context were entered as within-subjects factors.

Our fifth hypothesis was that children's references to the internal states of others during play would be related to activity in the pSTS. We used GEEs to examine relations between pSTS activity and ISL about others, with play type, social context and a binary categorization of use of ISL about others as factors (model-based estimators; unstructured working correlation matrices).

All significant interactions and main effects were followed up with post hoc comparisons. All statistics were conducted using IBM SPSS Statistics (Version 27). The significance value was set at $p < .05$.

3 | RESULTS

3.1 | Brain activation: pSTS activity

A repeated measures ANOVA revealed a main effect of play type ($F(1, 48) = 5.57$, $p = .022$, $\eta_p^2 = .10$) and a three-way interaction between hemisphere, play type and social context ($F(1, 48) = 4.49$, $p = .039$, $\eta_p^2 = .085$). No other main effects or interactions were significant ($ps > .05$). Follow-up pairwise comparisons of the three-way interaction revealed that, in the left hemisphere, there was an interaction between play and social context such that the difference between doll and tablet play was not significant for joint contexts ($p = .32$) but was significant for solo contexts (mean difference = 1.74 [SEM = .78], $p = .030$; see Figure 3). In the right hemisphere, differences between doll and tablet play were not significant for joint contexts ($p = .24$) and showed a similar, though less robust pattern, in solo contexts (mean difference = .58 [SEM = .28], $p = .048$). When AQ was added to the model as a covariate, no main effect ($p = .87$) or interactions with AQ were revealed ($ps > .53$).

Talkativeness

For child talkativeness, there were main effects of play type ($F(1, 55) = 28.25$, $p < .001$, $\eta_p^2 = .34$) and social context ($F(1, 55) = 116.04$, $p < .001$, $\eta_p^2 = .68$), as well as an interaction between play type and social context (F

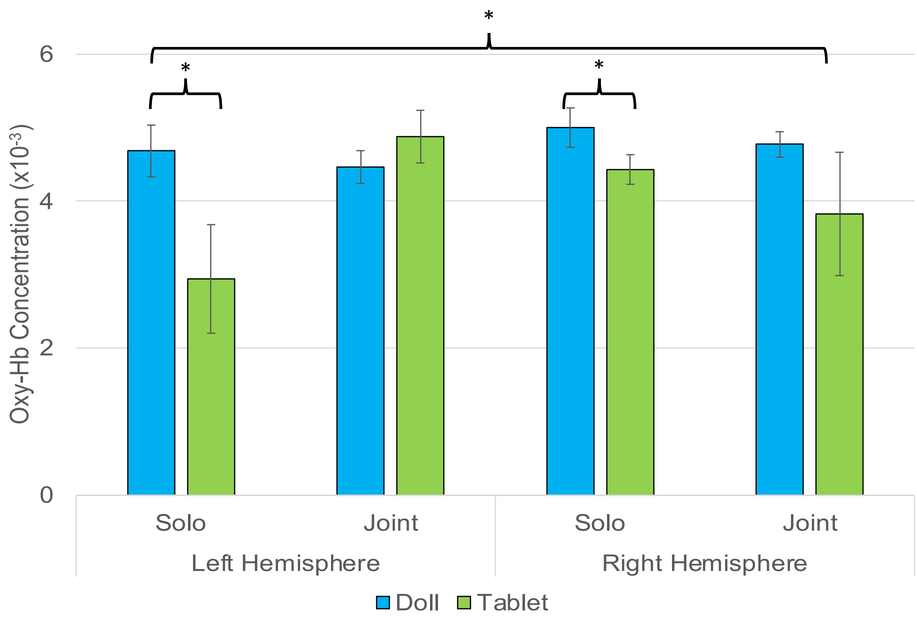

FIGURE 3 Posterior superior temporal sulcus activity across left and right hemispheres for joint and solo doll and tablet play. Significance bars highlight both the interaction effect (hemisphere × play type × social context) and the pairwise comparisons of solo doll and tablet play. *$p < .05$.

(1, 55) = 6.15, $p = .016$, $\eta_p^2 = .10$). Pairwise comparisons revealed that talk was higher in joint contexts than solo contexts for both doll (mean difference = .06 [SEM = .02]) and tablet (mean difference = .14 [SEM = .027]) play, but this difference was greater for tablet ($p < .001$) than doll ($p = .005$) play. When AQ-Child scores were added to the model as a covariate, main effects of play ($p = .002$), social context ($p = .004$) and the two-way interaction between the two ($p = .010$) remained, and a three-way interaction between play, social context and AQ was also revealed (F(1, 54) = 4.15, $p = .046$, $\eta_p^2 = .071$).

To follow up on this three-way interaction, we then created a median split of AQ scores (median score = 71) and reran the ANOVA with AQ median split as a between-subjects factor. Because of differences in these two AQ groups in terms of age and SES metrics in this subsample (see Table S1), we also included age, income and parental education as covariates in this model. As income ($ps > .19$) and education ($ps > .13$) had no main effects or interactions, they were removed from the model. Although there was no significant effect of age ($p = .086$), an interaction between play and age emerged (F(1, 53) = 4.86, $p = .032$, $\eta_p^2 = .084$) in addition to the expected main effect of play ($p = .002$), main effect of social context ($p = .030$), and three-way interaction between play, social context and AQ median split (F (1, 53) = 6.14, $p = .016$, $\eta_p^2 = .104$; see Table 2). The interaction between play and age was followed up with correlations revealing that age was positively correlated to talkativeness during both solo ($r = .32$, $p = .016$) and joint ($r = .28$, $p = .034$) tablet play but not during solo or joint doll play ($ps > .21$).

When the same ANOVA with median split of AQ was conducted for child talk to experimenter during solo play, there were no main effects or interactions with income ($ps > .12$), parent education ($ps > .41$) or age ($ps > .68$). When removing these factors, there was a main effect of play type (F(1, 54) = 7.24, $p = .009$, $\eta_p^2 = .12$) and a main effect of AQ split (F(1, 54) = 5.04, $p = .029$, $\eta_p^2 = .085$). For experimenter talk, there were no effects of income ($ps > .18$), parent education ($ps > .54$) or age ($ps > .51$). When removing these factors, there were main effects of play type (F(1, 53) = 9.80, $p = .003$, $\eta_p^2 = .16$) and social context (F(1, 53) = 1790.18, $p < .001$, $\eta_p^2 = .97$) and an interaction between social context and AQ split (F(1, 53) = 8.46, $p = .005$, $\eta_p^2 = .14$).

3.1.1 | ISL

ISL about others

For the low AQ group, there were no effects of age, income or parental education ($ps > .22$). Without these variables, the GEE revealed a main effect of play type (Wald $\chi^2 = 19.86$, $p < .001$) for ISL about others, with no other main effects or interactions ($ps > .28$). The main effect of play type was driven by children using more ISL about others during doll play than tablet play (see Figure 4). For the high AQ group, there were no effects of age, income or parental education ($ps > .13$). Without these variables, main effects of play type (Wald $\chi^2 = 4.41$, $p = .036$) and social context (Wald $\chi^2 = 5.78$, $p = .016$) were found, with no significant interaction ($p = .46$). Children used more ISL about others during doll play than tablet play. They also used more ISL about others during joint play than solo play.

TABLE 2 Results of analyses of child talkativeness and experimenter talk.

Child talkativeness	High AQ Mean (SE)	Low AQ Mean (SE)	Effects	Sig.	Effect size
JD	.44 (.054)	.52 (.054)	Dolls > tablets[a]	$p = .002$	.173[c]
JT	.35 (.050)	.33 (.050)	Joint > *solo*[a]	$p = .030$	.086[c]
SD	*.21 (.046)*	*.19 (.046)*	Low AQ: JD > JT[b]	$p < .001$	.68[d]
ST	*.12 (.037)*	*.15 (.037)*	*High AQ: SD > ST* JD > JT[b]	$p = .006$ $p = .026$	.39[d] .31[d]
Child talk to experimenter during solo play	**High AQ Mean (SE)**	**Low AQ Mean (SE)**	**Effects**	**Sig.**	**Effect size**
SD	*.08 (.016)*	*.05 (.016)*	*Doll > tablet*[a]	$p = .009$	.121[c]
ST	*.06 (.011)*	*.02 (.011)*	*High AQ > low AQ*[a]	$p = .029$	.085[c]
Experimenter talkativeness	**High AQ Mean (SE)**	**Low AQ Mean (SE)**	**Effects**	**Sig.**	**Effect size**
JD	.65 (.027)	.72 (.026)	Dolls > tablets[a]	$p = .003$	.156[c]
JT	.63 (.031)	.61 (.030)	Joint > *solo*[a]	$p < .001$	.971[c]
SD	*.11 (.014)*	*.05 (.014)*	*High AQ solo > low AQ solo*[b]	$p = .002$	.45[d]
ST	*.09 (.014)*	*.03 (.014)*			

Note: Estimated marginal means (controlling for age when necessary) and SEMs for child and experimenter talk during each session type and for each AQ group are presented in the left two columns. Directions of main effects and pairwise comparisons of interactions are presented in the right-hand side of the table. Main effects refer to speech type, and pairwise comparisons are compared by AQ group.

Abbreviations: AQ, Autism Spectrum Quotient—Children's Version; JD, joint doll; JT, joint tablet; SD, solo doll; ST, solo tablet.

[a]Main effects.

[b]Pairwise comparisons.

[c]η_p^2.

[d]Cohen's *d*.

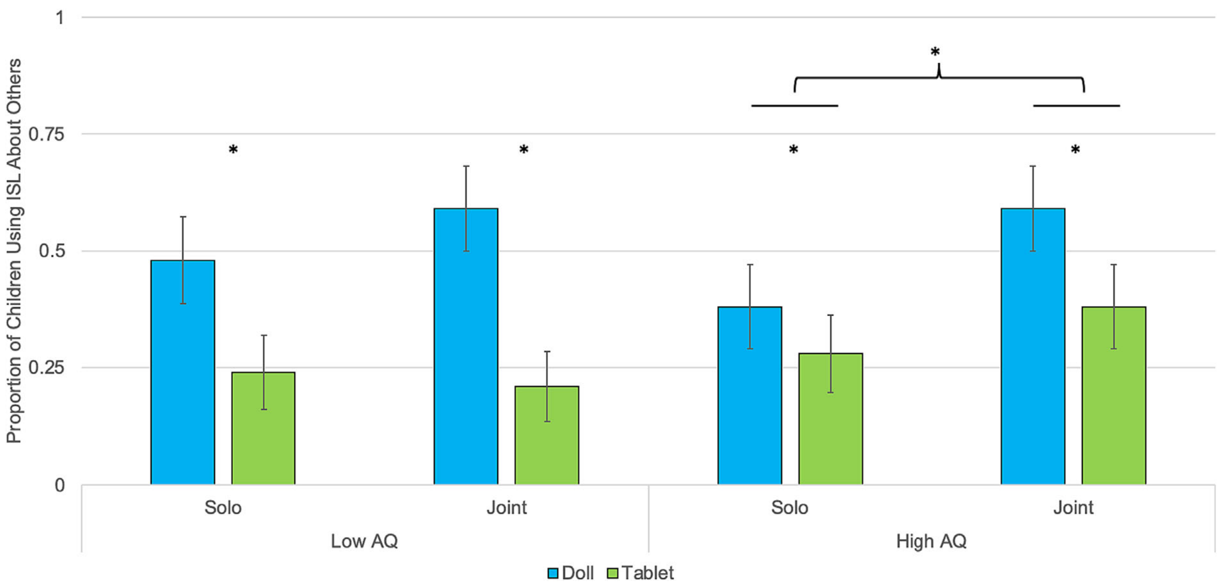

FIGURE 4 Proportion of internal state language (ISL) about others across play blocks for high and low Autism Spectrum Quotient—Children's Version (AQ) groups.

ISL about self

For the low AQ group, this revealed a main effect of social context (Wald $\chi^2 = 9.51$, $p = .002$) for ISL about the self, with no other main effects or interactions ($ps > .16$). The main effect of social context was driven by children using more ISL about themselves during joint play (M = .73 [SEM = .065]) than solo play (M = .55 [SEM = .088]). For the high AQ group, no main effects or interactions emerged (*ps* > .08).

3.1.2 | Relations between language and brain activation

Relations with ISL about others

Given that the effect of trial type in the pSTS was strongest in the left hemisphere, we entered pSTS activity (i.e., HbO) in the left hemisphere as the dependent variable in the GEEs investigating the association between individual differences in ISL and pSTS activity for each AQ group. In the low AQ group, this revealed a main effect of ISL about others, an interaction between play type and ISL about others, and a three-way interaction between play type, social context and ISL about others (see Table 3). Pairwise comparisons revealed that children who used ISL about others showed more pSTS activity than children who did not use ISL about others in solo doll play, joint tablet play and solo tablet play (see Relations Between Language and Brain Activation in the supporting information for full analyses). There was no association between pSTS activity and ISL about others for joint doll play. In the high AQ group, there was no main effect of or interactions with ISL about others (see Table 3).

Exploratory analyses: Relations with experimenter talk

Although not part of our initial analytic plan, given the differences in experimenter talk between AQ groups (particularly during solo play), we conducted some exploratory analyses to assess whether individual differences in experimenter talk were related to pSTS activity. To ensure that the difference in effect of ISL about others discussed above was not a function of a confound of experimenter talk, we conducted the same GEEs described in the above paragraph but added experimenter talk as a covariate. When we do so, we find a main effect of experimenter talk in the low AQ group ($\chi^2 = 236.86$, $\varphi_c = 3.078$, $p < .001$), but the main effect of ISL about others remains significant ($\chi^2 = 11.71$, $\varphi_c = .68$, $p < .001$). In the high AQ group, there was no main effect of experimenter talk ($\chi^2 = .13$, $\varphi_c = .07$, $p = .72$) and no other main effects or interactions emerged (*ps* > .07).

We then conducted separate GEEs with pSTS activity (i.e., HbO) in the left hemisphere as the dependent variable and play type, social context and a median split of experimenter talk as factors. For the low AQ group, this revealed a main effect of experimenter talk and a social context × experimenter talk interaction (see Table 3). The interaction revealed a more robust effect of experimenter talk in joint than solo contexts for this group. For the high AQ group, a main effect of play and several interactions emerged (see Table 3). In this group, the interaction between experimenter talk and social context had the opposite pattern as the low AQ group, with experimenter talk only relating to increased pSTS activity during solo, but not joint, contexts. Additionally, the three-way interaction between play type, social context and experimenter talk revealed that, during tablet play, experimenter talk was related to more engagement of the pSTS during solo sessions but was related to less pSTS

TABLE 3 Summary of GEE results and effect sizes of left pSTS activation and speech type across high and low AQ groups.

	ISL		ExpTalk	
Speech type	**Low AQ**	**High AQ**	**Low AQ**	**High AQ**
Play	.36 (.12)	.83 (.19)	.035 (.04)	4.68* (.44)
Context	.67 (.16)	1.16 (.22)	.11 (.07)	2.88 (.35)
Speech (ISL or ExpTalk)	56.65*** (1.51)	1.69 (.27)	139.71*** (2.41)	.55 (.15)
Play × context	1.86 (.27)	3.32 (.37)	.28 (.11)	4.45* (.43)
Play × speech	.047 (.04)	.16 (.08)	.49 (.14)	.11 (.07)
Context × speech	14.69*** (.77)	.071 (.05)	23.56*** (.99)	8.56** (.60)
Play × context × speech	8.35** (.58)	1.18 (.22)	1.21 (.22)	7.42** (.56)

Note: Play: doll or tablet. Context: joint or solo. Speech type: ISL or ExpTalk. Wald χ^2 reported from GEEs (with φ_c effect size) for each of the main effects and interactions with speech type (and left pSTS activity for each AQ group).

Abbreviations: AQ, Autism Spectrum Quotient—Children's Version; ExpTalk, experimenter talk; GEEs, generalized estimating equations; ISL, internal state language; pSTS, posterior superior temporal sulcus.

*$p < .05$.

**$p < .01$.

***$p < .001$.

activity during joint sessions (see Relations Between Language and Brain Activation in the supporting information for full analyses).

4 | DISCUSSION

The aim of the current study was to explore brain activity and language during naturalistic play in a group of children who varied in their degree of autistic traits. We found that all children showed greater activation in social processing areas of the brain (i.e., pSTS) when they played with a social partner and with dolls alone, compared to when they played with a tablet alone. This effect did not vary as a function of autistic traits. We also observed differences in children's talkativeness based on social context, play type and autistic traits. When looking at the content of children's talk, all children used more ISL about others during doll play than tablet play. Finally, we observed different associations between pSTS activity that related to play and language depending on the children's degree of autistic traits. Greater pSTS activity was associated with talking about the internal states of others in children with fewer autistic traits and with talking with the experimenter in children with more autistic traits. Thus, regardless of autistic trait differences across these children, social processing regions were activated during doll play, albeit for different reasons.

4.1 | Social processing in the brain during social and solo doll play

In terms of brain activity, we found an interaction between play and social contexts in the left hemisphere, such that there was less pSTS activity for solo tablet play than solo doll play. This difference was not found for the right hemisphere. This replicates earlier findings that children engage the pSTS more when playing with a partner, regardless of toy type, and when playing with dolls alone than when playing with a tablet alone (Hashmi et al., 2020). Importantly, the current study captured a broader range of neurodiversity by purposefully including children experiencing emotional or behavioural difficulties in the classroom. The current study suggests that social processing is lateralized to the left hemisphere, in line with previous research suggesting stronger activation for the left pSTS in social cognitive tasks. For example, in Lloyd-Fox et al. (2009), despite bilateral activation, 5-month-old infants showed a trend of more posterior temporal activity in the left than right hemisphere. A similar trend of stronger activation in the left pSTS was found in Hashmi et al. (2020); however, this did not reach a significant difference. Claims that pretend play is inherently social and allows the rehearsal of social interactions were first made nearly 60 years ago (Piaget, 1952). In light of the current findings, and consistent with prior research, doll play may provide an avenue for the rehearsal of social interactions even when a child is playing by themselves.

4.2 | Talk during play differed according to play type, social context and autistic traits

4.2.1 | Child talkativeness

Prior research found main effects of both type of play (children talked more during doll play than tablet play) and social context (children talked more during joint play than solo play) on child talkativeness (Hashmi et al., 2022). We replicated these main effects in the current study, but the main effects were qualified by more nuanced patterns in the different groups of children. Children with fewer autistic traits spoke more during joint doll play than joint tablet play but showed no difference between play types when playing alone. One reason for this could be that these children generally spoke more overall during joint contexts, and so there was more potential for variability between joint tablet and doll play. An added source of variance could also have been that the child was frequently holding the tablet themselves during joint play, as in the solo play condition, but in joint doll play, the multiple dolls and accessories meant that both child and experimenter could hold items. Thus, having ownership of the tablet in the joint condition may have impeded conversation compared to doll play. The fact that these children spoke more during joint doll play than joint tablet play implies that doll play increased the extent to which these children socially and linguistically engaged with their social partner. Previous research has reported that non-digital toy play is associated with greater quality and quantity of language in parent–toddler and parent–child dyads compared to digital play (Ewin et al., 2021; Sanders, 2020; Sturman et al., 2022; Venker & Johnson, 2022). In contrast, children with a higher degree of autistic traits talked more during solo doll play than solo tablet play but showed no differentiation in joint contexts. This may be because social scaffolding from the experimenter and/or the 'masking' of neurodivergent traits (Cook et al., 2021) on the part of the child, such as the child mimicking the language of the experimenter or using the experimenter as a guide, during social interactions mutes the effects of toy type when playing jointly.

4.2.2 | ISL

Both children high and low in autistic traits used more ISL about others (i.e., characters or other people) during doll play than tablet play. This supports previous research indicating that playing with toys like dolls affords children an opportunity to refer to different types of internal states (Howe et al., 2022) and refer to the internal states of others more (Hashmi et al., 2021, 2022) compared to close-ended and digital toys. Children that were in the low autistic trait group showed similar levels of ISL about others regardless of whether they were playing by themselves or with the experimenter. In contrast, the children high in autistic traits used more ISL about others during joint play compared to solo play. The increased production of ISL during joint play in these children could be a function of masking autistic traits during social interactions (Cook et al., 2021) and/or being socially scaffolded by the experimenter. For example, a child may have learnt that it is socially typical to talk about what a doll thinks or wants, or they may rely on copying the types of comments that their social partner makes. In contrast, in the context of solo play, they would have reduced social pressure and the absence of social scaffolding opportunities. However, limited previous research has directly contrasted solo and social play in children with high autistic traits (e.g., Holmes & Willoughby, 2005; Kangas et al., 2012, have examined this in autistic children), so further research is needed to better understand the nature of this difference.

4.2.3 | Child talk with experimenter during solo play

Unexpectedly, we found that children with more autistic traits were talking with the experimenter more during solo sessions than children with fewer autistic traits. There are a variety of reasons this may have occurred, including documented difficulties with executive functions and task switching (Geurts et al., 2009; Hill, 2004; Mostert-Kerckhoffs et al., 2015), differences in conversational adaptation (Cola et al., 2022; Ratto et al., 2011), or a lack of interest or familiarity with playing on their own (Jarrold et al., 1996; Lewis & Boucher, 1988). Regardless, the paradigm attempted to isolate social interaction to the joint play conditions so that any social processing during solo play would implicate imagined, rather than real, social interactions. As a result, we need to be cautious about how we interpret findings related to social processing within these contexts. These individual differences in the degree to which children integrate social interactions into their play should be acknowledged to better understand the brain correlates of different kinds of play and interactions.

4.2.4 | Individual differences in pSTS activation

Although we observed similar patterns of activity in the pSTS during doll play for children with both high and low autistic traits, this appears to be happening for different reasons for the two groups. Previous research found that increased pSTS activity during play was associated with the use of ISL about others (Hashmi et al., 2022). We replicated this effect in children with fewer autistic traits, revealing a main effect of ISL about others on pSTS activation across sessions. This finding provides confidence that the pSTS activation we observe during play in these children is a function of thinking and talking about others' mental states and thus rehearsing social cognitive skills like theory of mind and empathy. This notion is further corroborated by other studies evidencing pSTS activation when both adults and children are asked to think about other people's thoughts (Saxe et al., 2009; Saxe & Powell, 2006) and suggests that this activation can also occur with unprompted social processing.

Our hypothesis that pSTS activity would be related to the use of ISL about others was not supported for the group of children with more autistic traits. This lack of support for an association between ISL about others and pSTS activity may partially be a result of the method in which ISL was assessed in our study. Previous research found that both elicited and spontaneous references to internal states were related to individual differences in theory of mind for neurotypical children (i.e., non-autistic children; Kristen et al., 2015). In contrast, Kristen et al. found that *elicited*, but not *spontaneous*, references to internal states were related to individual differences in theory of mind in autistic children. Given that we only measured ISL during spontaneous play, it may be that we would see a similar relation between ISL about others and pSTS activity in children with higher autistic traits if ISL was elicited during play. This is consistent with evidence that elicited, but not spontaneous, pretend play is similar between autistic and non-autistic children (Jarrold et al., 1996; Lewis & Boucher, 1988) and highlights questions for future research regarding relations between pretend play, ISL and neural and behavioural correlates of social processing in neurodivergent children.

An alternative reason for the lack of relation between ISL about others and pSTS activity in the children with more autistic traits is that pSTS activation was instead related to other factors in this group. Exploratory analyses revealed that pSTS activity was related to experimenter talk in these children, particularly during solo play. This suggests that interactions with others (i.e., talk with the experimenter) relate to pSTS activity when the children were meant to be playing by themselves. It may be that dolls encourage children with more autistic traits to interact with others, even when engaging in solo play. This is supported by recent research that having an imaginary friend is associated with greater parent-reported theory of mind and social skills in autistic children (Davis et al., 2013). In this way, doll play may support social interaction with others for this group of children. It would be interesting to see if a similar pattern of language use emerges if children are playing with peers rather than an adult experimenter.

The findings of this study have implications for training programmes designed to improve children's social understanding through encouraging the use of ISL (Bianco et al., 2019), particularly for children with fewer autistic traits for whom the association between ISL and activation of the pSTS was clear. As playing with dolls alone can encourage children to talk about others' internal states, this is one route through which to promote skills in social understanding for children with fewer autistic traits. Solitary play with dolls may also offer children the opportunity to practice social skills without a threat of exclusion or peer rejection (Luckey & Fabes, 2005). For children with more autistic traits, the amount of talk during solo play and the association between experimenter talk and pSTS during solo play are a reflection that these children are at the divergent end of neurodiversity. Framing within the context of neurodiversity (Pellicano & den Houting, 2022), it is important to recognize that this pattern represents a difference rather than a deficit. Similarly, there is no externally defined 'right' way to play; the style of play that a child chooses to engage in is the right way for them. However, although we see differences in the way in which children play alone, all children engage the same social processing brain regions when playing. As such, children's spontaneous play with dolls by themselves could provide benefits for their social development, albeit through different behavioural pathways.

4.2.5 | Strengths, limitations and future directions

The present study replicates the findings of Hashmi et al. (2020, 2022) with a broader, more diverse sample. Participants had a wider range of parent education than is typical in convenience sampling with developmental samples (Bornstein et al., 2013; Fernald, 2010), and over 40% of children who visit the NDAU come from low SES backgrounds, as measured by the Welsh Index of Multiple Deprivation (WIMD, Welsh Government, 2019). Children who visit the NDAU have been flagged by their school as having emotional, behavioural and cognitive difficulties in the classroom, which may also influence the play patterns these children like to engage in and their propensity to engage with the experimenter during solo play. That we find similar activity in the pSTS in this more inclusive sample gives further support that these patterns of brain activation are fundamental correlates of social engagement across neurodiverse samples. A further strength of the study was that children were able to play freely with the dolls and tablet games in whichever way they wanted, an affordance of fNIRS and the openness of the stimuli. Whether different play patterns were associated with individual differences in autistic traits, fantasy orientation or a broader range of emotional or behavioural differences was beyond the scope of the current study but would be an important avenue for future research.

Although the methodological decisions we made in measuring brain activity during spontaneous play have many advantages, some also limit the conclusions we can draw. We were unable to make direct comparisons between instances of ISL about others and pSTS activity that would support causal conclusions. Additionally, in our fNIRS analyses, we used an ROI approach, as has been used in other studies (Skau et al., 2022; Zhou et al., 2022), rather than specific channels of activation. This results in less precision but is a more conservative approach as it is more theoretically driven than data driven. During the testing session, the experimenter remained in the room during solo play blocks. This was done to ensure the safety of the children and the equipment and for practical reasons of setting up each session, but it also created the opportunity for children to attempt to engage with the experimenter. Previous research has reported associations between lower SES and language development (e.g., Pace et al., 2017). While we did not find an effect of parental education or income, SES may have played a more nuanced role in the development of children from lower economic backgrounds and influenced their language development and production. This may be particularly true for the high AQ group, who were more likely to come from families with lower SES in our sample. Finally, it is possible that the participants were thinking about the internal states of themselves and others without verbalizing their thoughts. In this way, our estimates of social cognition are conservative and do not fully capture the extent of ISL in this sample but are consistent with previous work using children's private speech during non-social play as an indication of the different features and quality of the play (Davis et al., 2013; Krafft & Berk, 1998; Winsler et al., 2007).

In conclusion, this study replicated and extended previous findings (Hashmi et al., 2020, 2022) that children engage social processing areas of the brain more when playing with dolls or a tablet with a partner and when playing with dolls alone, compared to when playing with a tablet alone. Importantly, this pattern was found in a neurodiverse sample of children, including those with both high and low levels of parent-reported autistic traits. For children with fewer autistic traits, we replicated the findings that talking about others' mental states is related to more pSTS activity (Hashmi et al., 2022). For children with more autistic traits, talk with others during solo play, as measured via experimenter talk, was related to more pSTS activity. Thus, regardless of autistic trait differences across these children, social processing regions were activated during doll play, albeit for different reasons. Further research is required to explore individual differences in the way children play and the different potential these play patterns have for supporting children's development. Crucially, a neurodiversity-affirmative approach is needed to support all children in flourishing through play.

AUTHOR CONTRIBUTIONS

Jennifer Keating: Methodology; investigation; formal analysis; writing—original draft; writing—review and editing. **Salim Hashmi:** Conceptualization; formal analysis; writing—review and editing. **Ross E. Vanderwert:** Conceptualization; methodology; formal analysis; supervision; funding acquisition; writing—review and editing. **Rhys M. Davies:** Investigation; writing—review and editing. **Catherine R. G. Jones:** Supervision; writing—review and editing. **Sarah A. Gerson:** Conceptualization; methodology; formal analysis; supervision; funding acquisition; writing—review and editing.

ACKNOWLEDGEMENTS

We would like to thank Georgina Burchell, Zoe Wallace, Matt Hamman, Katy-May Price, Cerys Thomas and Heidi Rood for their assistance in collecting and coding the data and all of the families who participated.

CONFLICT OF INTEREST STATEMENT

Mattel funded the equipment, stimuli and some personnel for this project and was advised of the study design. Mattel did not have final say in the study design or measures used nor played a role in the collection or analysis of the data, interpretation of the results or writing of the manuscript.

PEER REVIEW

The peer review history for this article is available at https://www.webofscience.com/api/gateway/wos/peer-review/10.1111/ejn.16144.

DATA AVAILABILITY STATEMENT

Data is available at https://osf.io/mkzpy/.

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How to cite this article: Keating, J., Hashmi, S., Vanderwert, R. E., Davies, R. M., Jones, C. R. G., & Gerson, S. A. (2023). Embracing neurodiversity in doll play: Investigating neural and language correlates of doll play in a neurodiverse sample. *European Journal of Neuroscience*, 1–18. https://doi.org/10.1111/ejn.16144