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PAPER

Doll play prompts social thinking and social talking: Representations of internal state language in the brain

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Abstract

Doll play provides opportunities for children to practice social skills by creating imaginary worlds, taking others' perspectives, and talking about others' internal states. Previous research using functional near-infrared spectroscopy (fNIRS) found a region over the posterior superior temporal sulcus (pSTS) was more active during solo doll play than solo tablet play, implying that doll play might present opportunities for rehearsing theory of mind and empathy skills, even when playing alone. In this research, we addressed this more directly by investigating 4–8-year-old children's ($N = 33$) use of internal state language (ISL; i.e., references to emotions, desires, and cognitions) when playing with dolls and on tablets, both by themselves and with a social partner, and their associated brain activity in the pSTS using fNIRS. We found that children used more ISL about others when playing with dolls than when playing on tablets, particularly when they were playing alone. This mirrored the patterns seen in pSTS activity in previous research. When individual variability in ISL about others was considered, more ISL about others was linked to stronger pSTS activation. Thus, variability in pSTS activity during play is not about the perceptual or physical differences between toys (e.g., dolls are more human-like) but about what children think about when they engage in different kinds of play. This is the first research to investigate brain activity during spontaneously occurring ISL and indicates that children have a tendency to take and discuss others' perspectives during doll play, with implications for social processing in the brain. A video abstract of this article can be viewed at https://youtu.be/58HgxbuhBzU.

KEYWORDS
functional near-infrared spectroscopy, internal state language, play, posterior superior temporal sulcus, social understanding

1 | INTRODUCTION

Play is a key aspect of the childhood period that is argued to promote aspects of development, including emotion regulation and social processing skills (Lillard, 2017). Specifically, children who regularly play with others demonstrate advantages in their perspective taking abilities (Dunn & Cutting, 1999; Harris, 2000), empathy (Brown et al., 2017), and language about their own and others' minds (Howe et al., 2014; Tessier et al., 2016; Youngblade & Dunn, 1995). Of course, children play in a variety of ways, both with others and alone, and with a variety of toys and digital devices (Lillard, 2014; Ofcom, 2019). It is important to understand when and whether different play contexts

differentially recruit perspective taking, empathy, and language about mental states. In our previous work, we found that the posterior superior temporal sulcus (pSTS), an area of the brain associated with social processing and understanding (e.g., Deen et al., 2015), was equally active when children played with dolls and tablet games with another person, but when playing alone, this region was more active when the children played with the dolls than on tablets (Hashmi et al., 2020). We hypothesized that this difference was due to children thinking more about others' mental states (and thus engaging mentalizing brain regions) when playing with others or playing alone with dolls than on a tablet. In the present investigations, we test this hypothesis more directly by examining how children played in each of these contexts. In particular, we focused on children's internal state language (ISL) during different kinds of play and investigated how this related to pSTS activity.

RESEARCH HIGHLIGHTS

- This study investigated whether activation in the posterior superior temporal sulcus (pSTS) during play could be explained by children's use of internal state language (ISL).
- We found that playing with dolls prompted more ISL than playing with tablet games and using ISL about others was related to increased pSTS activation.
- These novel findings, using spontaneously produced ISL during play, expand previous research demonstrating a direct link between behaviour and pSTS activation for social understanding.

1.1 | Play, ISL, and social understanding

When playing, children from the pre-school age (3–4 years old) through to the middle childhood period (around age 7) often use *internal state language* to refer to the thoughts, emotions, and desires of themselves and others (Carpendale & Lewis, 2015; Leach et al., 2017). This type of language is consistently used by children from different western countries in their native languages (e.g., Italian, German, English, and French; Kristen et al., 2014), as well as children from some eastern countries (Tardif & Wellman, 2000). The use of ISL during play is thought to reflect children's understanding of the internal world of themselves and others, and is therefore an indicator of their social understanding, and its accurate use is associated with their later *theory of mind* (Bianco et al., 2016; Carpendale & Lewis, 2015; Ruffman et al., 2002). Children can refer to both their own and others' internal states, but referring to the internal states of *other* people, both real and fictional, might be particularly important for children's developing social understanding as it is associated with perspective taking skills (Howe, 1991; Tessier et al., 2016). Indeed, children may begin appreciating the minds of others through adopting their perspectives and simulating their inner states (Bartsch & Wellman, 1995; Goldman, 2006; Harris, 2000). Therefore, in the present study, we considered children's references to their own internal states and the internal states of others.

Individual differences in the frequency of children's overall use of ISL are relatively consistent over time (Carr et al., 2018) and across different activities in which ISL is assessed (Hashmi et al., 2021; Longobardi et al., 2014). However, there are subtle differences in *how* children use ISL across development and contexts. For example, in early childhood, more references are made to desires, but in middle childhood (around age 7), references to complex internal states, such as thoughts and knowledge, become more common (Ruffman et al., 2002). Although younger children refer to their *own* internal states more than the internal states of others (Brown & Dunn, 1991), referring to a play partner's internal states becomes more common by around 7 years of age (Leach et al., 2017). In terms of play contexts, although children's use of ISL when they play alone with toys is associated with their ISL when they play video games alone, they use more ISL when playing on their own with Playmobil toy figures than when playing video games alone, particularly in terms of references to the internal states of the toys/fictional characters (Hashmi et al., 2021). Similarly, subtle differences in the *type* (or category, e.g., cognitions, desires, preferences) of ISL used by 7-year-old children have been noted when children play with different types of toys (Howe et al., 2020). Children refer to *goal* related internal states (e.g., desires ['want'] and intentions ['try']) more when playing with closed-ended toys (e.g., a train set) compared to open-ended toys (e.g., a village set), but referred to slightly more *cognitions* (e.g., beliefs, thoughts and knowledge) when playing with the open-ended toys (Howe et al., 2020). Although children use ISL when playing with others (Howe et al., 2020; Leach et al., 2015, 2017, 2019) and when playing alone (Davis et al., 2014; Hashmi et al., 2021; Krafft & Berk, 1998), to our knowledge, no studies have directly compared whether the use of ISL differs depending on whether play is social or solitary. Therefore, we compared children's use of ISL when they played with dolls and on tablets both socially and on their own.

1.2 | Brain correlates of children's social understanding

In addition to investigating how ISL differs between different play types and contexts, our research presents a unique opportunity to investigate how the use of different ISL during play differentially engages mentalizing brain regions. Previous research in both adults and children indicates that tempo-parietal brain regions are activated when processing others' internal states (Sekine et al., 2019). In fact, Saxe and colleagues argue that ISL, relative to non-mentalistic language, is a valid and powerful stimulus for engaging these brain regions and probing individual differences (Saxe, 2006; Saxe and Kanwisher, 2003; Saxe & Powell, 2006). They have found that reading narratives that involve internal stage language about others is more likely to activate the region surrounding the pSTS than reading non-mentalistic texts, suggesting that social brain processing is malleable to experimenter manipulations of types of language. In children, listening to

stories about beliefs (rather than desires or physical information) similarly activates these same regions, as evidenced by both fMRI and functional near-infrared spectroscopy (fNIRS; Bowman et al., 2015; Saxe et al., 2009).

But what about more spontaneous, participant-driven differences in social processing? In previous research, we found evidence that the pSTS is more active when children engage in play that seems to involve more social processing. Specifically, the pSTS region was more engaged during play with a social partner and solo play with dolls than during solo tablet play (Hashmi et al., 2020). We speculated that this difference could be due to the propensity to think about others' internal states when playing with a social partner (with dolls and on a tablet) and when playing alone with dolls, more so than during solo play on a tablet. If this were true, it might also be borne out in terms of the language children spontaneously use during play, with children using more ISL about others in conditions that induce more social processing in the brain. This differentiation in the use of ISL during different types of play and different contexts would provide a parsimonious explanation for why differences emerge in social processing brain regions during different types of play. It would suggest that the differences in brain activity seen during reading of experimenter-manipulated narratives (Saxe, 2006; Saxe and Kanwisher, 2003; Saxe & Powell, 2006) can also be generated as a result of ISL spontaneously produced during children's play. We directly tested this hypothesis in this research by examining children's vocalizations from video recordings taken during our previous study (Hashmi et al., 2020).

1.3 | The present study

In the present study, we examined 4- to 8-year-old children's references to internal states as they freely played with dolls and tablet games by themselves and with a social partner. The tablet games that were chosen allowed creative and open-ended play (i.e., they contained no set rules), and allowed the children to cut and style hair or build towns. We utilized fNIRS to capture changes in brain haemodynamics as children played with the dolls and tablet games on their own and with a partner. fNIRS is an indirect measure of neural activity that relies on the absorption of infrared light, emitted through the scalp, by changes in blood oxygenation as a result of cortical activation (Vanderwert & Nelson, 2014). Light emitter and detector pairs are fixed within a cap worn by the participant and positioned over specific cortical regions of interest, including the pSTS, affording participants greater freedom of movement relative to other neuroimaging techniques. Our study capitalizes on these advantages to measure ongoing activity in the pSTS while children engaged in play. We hypothesized that playing with dolls would elicit more ISL from the children than playing with tablet games, based on previous research regarding the use of ISL when children played with toys and video games on their own (Hashmi et al., 2021). We also hypothesized that children's references to internal states would be associated with activity in the pSTS (Deen et al., 2015). This would provide a behavioural explanation for our earlier findings that activation in the pSTS was similar when playing with another person regardless of the type of play, but higher when children played with dolls on their own compared to tablet games alone (Hashmi et al., 2020).

2 | METHOD

2.1 | Participants

Forty-two typically developing 4- to 8-year-olds (M = 5.5 years, SD = 1.2 years; 22 females) were recruited through a participant database in a mid-sized British city. The children's caregivers provided written informed consent before the start of the experiment, and participants were given a certificate and prize at the end of the session. All procedures were reviewed and approved by the ethical review panel in the School of Psychology at Cardiff University (EC.19.06.11.5631RA; see Hashmi et al., 2020 for more details about the study).

Of the 42 children recruited, five children were excluded as they did not provide sufficient data. A further four children had their fNIRS data excluded due to experimenter or equipment failure resulting in low-quality fNIRS recordings (n = 3), or a statistical outlier in haemoglobin concentrations (>2 SD in multiple channels; n = 1). Therefore, 33 children had both speech and fNIRS data available for analysis and were thus included in the present study.

2.2 | Procedure

After informed consent procedures were carried out and children were acclimated to the laboratory and experimenters, the child was fitted with an fNIRS cap while they were introduced to the tablet games they would be playing (to ensure they could play without assistance). Parents could be in the testing room with the child during cap placement but were encouraged to observe from a neighbouring room once good signal quality was achieved and the task began. While children were engaging in the tasks, parents completed a short questionnaire regarding their child's experience with tablets and dolls (see Hashmi et al., 2020 for more information). Most parents completed this in an adjoining room out of sight of the child (but where they could still observe their child through a one-way mirror). However, those who chose to stay in the room with the child sat in the corner of the room and we confirmed through the video recordings that they did not interfere with the task.

At the beginning of the session, children were asked to watch a 5-min space video to get a resting measure of fNIRS activity. They then participated in a series of play blocks that alternated between doll and tablet play. All sessions began with two joint play sessions (one for each: doll and tablet play) in which the child played with an experimenter. The order of doll and tablet blocks was counterbalanced between participants. The child then engaged in solo play with the dolls and tablet for six alternating blocks (Figure 1). In the last two blocks, the child again played with the experimenter. Children were allowed to take breaks during testing or could stop the session early if desired. The testing session lasted approximately 60 min.

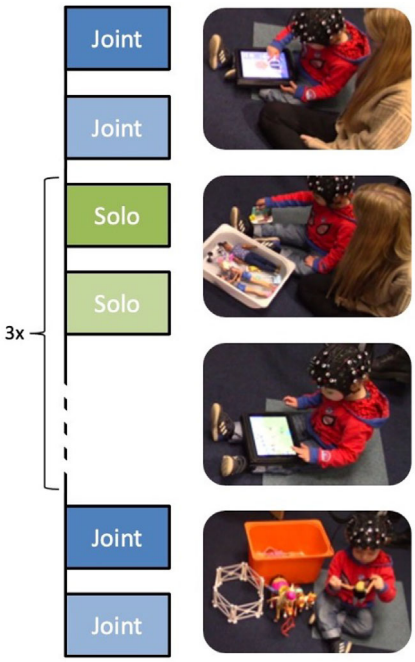

FIGURE 1 Testing procedure. Play sessions alternated between doll and tablet play (denoted by darker and lighter coloured boxes) with the order of doll-first or tablet-first counterbalanced between children. Each session began and ended with two joint play blocks with six solo play blocks in the middle. Photos from top to bottom are example joint tablet, joint doll, solo tablet, and solo doll play

2.3 | Materials/tasks and stimuli

2.3.1 | Task and stimuli

E-Prime 3.0 (Psychological Software Tools, Sharpsburg, PA, USA) was used to present stimuli on an Ilyama ProLite 24-in. LCD monitor. During play blocks, the screen was black except for small text indicating the current and subsequent condition for the experimenter's reference. In between each block, children were asked to watch the screen for 10 s while clipart images of vegetables were shown to allow time for haemodynamic responses to return to baseline.

Joint play

The first and last two play blocks involved 4-min sessions in which the child and an experimenter played together with either dolls or the tablet. The experimenter took a passive role in play and allowed the child to lead the sessions in terms of the direction of play and the involvement of the experimenter (e.g., their role). If the child became distracted and focused on other things (e.g., the fNIRS equipment), experimenters directed their attention back to the play.

Solo play

Children engaged in six 4-min blocks of solo play, alternating between doll and tablet play. Which doll sets and which tablet games the children played in each block was pseudorandomly assigned and counterbalanced between participants. During these sessions, the experimenter sat behind the child and remained silent. If the child tried to interact with the experimenter, they encouraged the child to keep playing.

Tablet games

Toca Hair Salon 3 (Toca Boca, Stockholm, Sweden) and Hoopa City 2 (Dr Panda, Chengdu, China) were selected as tablet games to match doll play in terms of their open-ended (e.g., no rules and no set order of activities), engaging, and creative play possibilities. In Toca Hair Salon 3, children can wash, cut and style the hair of characters. When playing Hoopa City 2, children could place roads, buildings, and parks onto a map in a city building game which also featured characters who were inhabitants of the city. The tablet games were played on a 12-in. iPad 3 IOS 9.3.5.

Doll sets

Four different sets of dolls were used: the family set, the careers set, the estate set, and the animals set (see Hashmi et al., 2020, for more details). The sets were made up of several Barbie (Mattel Co., El Segundo, CA, USA) play sets (e.g., a house, ambulance, baby bath) and multiple dolls of a variety of races, sizes, and sexes.

2.4 | Video recording

The experiment was recorded using both a Logitech C270 720p Webcam attached to the monitor and a Canon LEGRIA HF R706 camera mounted on a tripod in the corner of the room to view play over the child's shoulder. This allowed the capture of both the child's facial expressions and actions during play and the auditory recording of language.

2.5 | fNIRS data acquisition and processing

A complete description of acquisition, processing, and analysis of the fNIRS data is reported elsewhere (Hashmi et al., 2020). Here we briefly describe our acquisition and processing procedures. Based on those previous findings, we focused our analyses on the contrast that showed the greatest differentiation between social play and solo play with dolls or with tablets, specifically, changes in oxygenated haemoglobin (oxyHb) in the pSTS region.

OxyHb was measured via the NIRScout fNIRS system and NIRStar software (NIRX; Medizintechnik, GmbH, Berlin, Germany). The system operated at both 760 and 850 nm wavelengths, with a scan rate of 3.91 Hz. Sixteen sources and 16 detectors were used for this study, making a total set of 41 source-detector pairs. The sources and detectors were inserted into a flexible nylon NIRScap (NIRX) worn by the participant for the duration of the study. The distance between the sources and detectors was fixed at 3 cm.

For this study, we focused on activity from source-detector pairs over the parietal cortices corresponding roughly to P3/CP5 and P4/CP6 in the international 10–20 system (Figure 2). The cap was placed so that the front seam rested just above the participant's

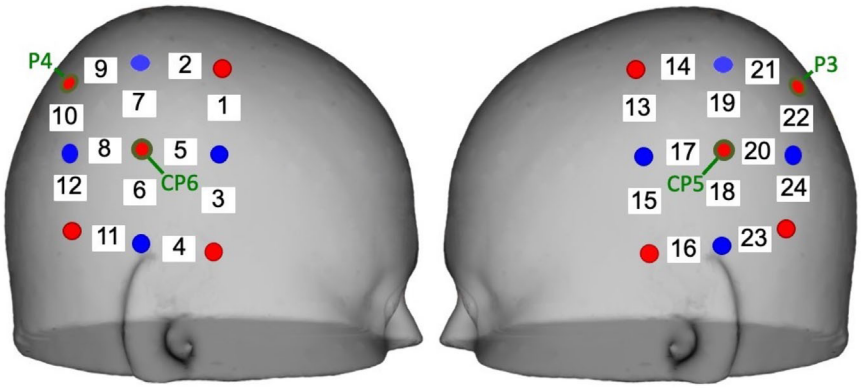

FIGURE 2 fNIRS channel locations over the left and right hemispheres. Red and blue circles represent source and detector locations, respectively. Green outlines correspond to International 10–20 location names

eyebrows and the participant's ears pulled through the ear holes on both sides maintaining a consistent cap placement.

Processing of the fNIRS data was carried out via nirsLAB v.2019.04 (NIRX; Medizintechnik, GmbH, Berlin, Germany) following the reporting recommendations by Pinti et al. (2019). Brief spikes or discontinuities (i.e., <1 s in duration) were manually identified and interpolated and channels with a gain setting greater than 6 (maximum system gain = 7) were then visually inspected and channels with excessive noise were removed from further analysis. A finite impulse response bandpass filter from 0.03 to 0.8 Hz was then applied to the optical data with a 15% roll-off. These filter cut-offs were based on previous research with similar designs (Gervain et al., 2008; Ravicz et al., 2015) and were aimed to remove slow drift and higher heart rate fluctuations. The optical data were then converted into haemodynamic states using the modified Beer-Lambert law.

Haemodynamic data were baseline corrected to the preceding 20-s before the onset of each play block (including baseline and setup for subsequent block). Mean oxyHb concentrations were first averaged across similar blocks of joint and solo doll or tablet play, then the concentrations were averaged across the 4-min blocks. Finally, we averaged the activity in emitter-detector pairs overlying the pSTS (left: 14, 18, 19, 20, 21, 22; right: 2, 6, 7, 8, 9, 10; Hashmi et al., 2020). Supplemental Figure 1 shows the grand averaged oxyHb and deoxyHb for each play block type.

2.6 | Coding child language

2.6.1 | Children's talkativeness

Video recordings of the children's speech as they played with the dolls and on the tablet games on their own and with the experimenter were transcribed into 5-s segments. All speech was included, whether directed towards the experimenter, themselves, or the toys/game. A proportional measure of children's talkativeness was computed by dividing the number of 5-s segments that contained the child's speech by the total number of 5-s segments during the duration of the task, resulting in a score between 0 and 1. Any instances of non-word vocalizations were excluded from these calculations.

2.6.2 | Children's references to internal states

Children's references to internal states were coded from the transcripts of children's speech using a coding scheme developed by Paine et al. (2019). This coding scheme captures both the category (*cognitions*, *desires*, *emotions*, *intentions*, *preferences*, *perceptions*, and *physiology*) and the referent (*self, character, other* [e.g., the experimenter]) of the ISL in each 5-s segment. Multiple categories and referents could be coded within a single segment. For the following analyses, children's references to internal states were collapsed across categories, and we combined children's references to the internal states of characters and any other people (e.g., the experimenter, sibling, caregiver etc.) but distinguished these from references to the self. The frequency counts were averaged across the 3 × solo doll, 3 x solo tablet, 2 x joint doll, and 2 x joint tablet blocks.

An independent observer coded the frequency of children's use of ISL for a random sub-sample of 10 (27%) of the transcripts of children's play: median *ICC* = 0.94 (range = 0.76–1) for joint doll play, median *ICC* = 0.98 (range = 0.78–1) for solo doll play, median ICC = 1 (range = 0.86–1) for joint tablet play, median *ICC* = 1 (range = 0.78–1) for solo tablet play.

2.7 | Statistical analysis

To examine the relations between children's social context (*Joint* vs. *Solo)* and play types (*Doll* vs. *Tablet)* on language production, we used model-based generalized estimating equations (GEEs) with unstructured working correlation matrices. GEE allows us to account for repeated measures in the data and use non-continuous or non-normal data as the dependent variable (i.e., we used linear GEEs for linear data and binomial logit GEEs for binomial data; Ballinger, 2004). The social context and play type were entered as within-subjects repeated measure factors and children's language production was the outcome variable. After running the initial model, we then explored whether relations were moderated by the sex (entered as a between-subjects factor) or the age of the child (entered as a covariate). Following the behavioural analyses, we then explored the relations between ISL about the self or about others during the task on activation

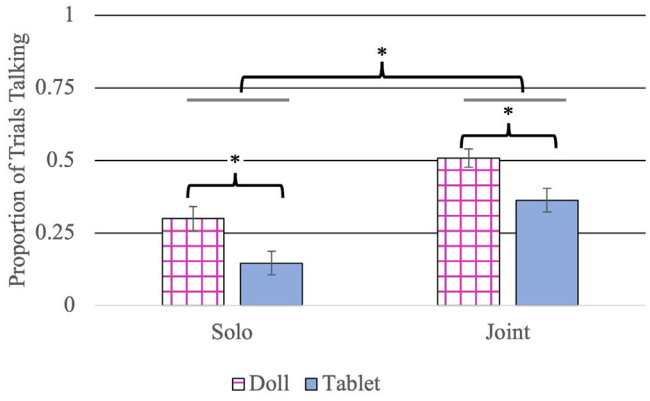

FIGURE 3 Mean proportion of segments children talked in each condition. Error bars represent standard errors

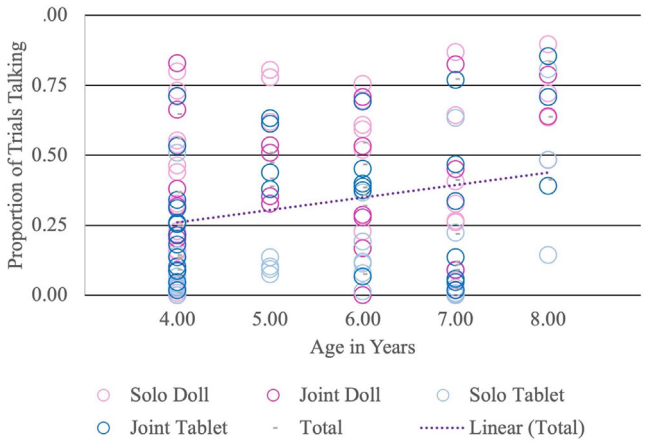

FIGURE 4 Across conditions, children's talkativeness increased with age. Different conditions are represented by different coloured markers, but the linear trend is collapsed across conditions

of the pSTS (using binomial logit models, as described below). In our previous study (Hashmi et al., 2020) we found no differences and preliminary analyses confirmed no differences between hemispheres. As a result, oxygenated haemoglobin was collapsed across the left and right hemispheres over the pSTS region to create an average pSTS activation score for each social context and play type. This value was entered as the outcome variable in separate GEEs. Although our previous research found no effect in deoxygenated haemoglobin, we also conducted a second set of GEEs (replicating that described above) with deoxygenated haemoglobin as the outcome variable.

3 | RESULTS

3.1 | Talkativeness

Children's talkativeness (i.e., average proportion of 5-s segments during which children talked) in both play types and social contexts is presented in Figure 3. All children spoke in at least one segment in the joint conditions for both doll play and tablet play, and 88% of children ($n = 29$) spoke in at least one segment in the solo condition for doll play and tablet play.

A linear GEE with talkativeness as the outcome and social context and play type as repeated measures revealed main effects of both social context ($\chi^2(1) = 76.08$, $p < 0.001$) and play type ($\chi^2(1) = 61.94$, $p < 0.001$). This was driven by a larger proportion of segments with speech in joint conditions ($M = 0.43$ [$SEM = 0.04$]) than solo conditions ($M = 0.23$ [$SEM = 0.04$]), and more talking in doll play ($M = 0.41$ [$SEM = 0.04$]) than tablet play ($M = 0.25$ [$SEM = 0.04$]; see Figure 3). No significant interaction emerged ($p = 0.96$). When sex was added as a factor, significant effects of social context and play type remained and no significant effects of sex were found ($ps > 0.06$). When age was added as a covariate, a significant effect of age emerged ($\chi^2(1) = 6.99$, $p = 0.008$; see Figure 4).

TABLE 1 Frequency of internal state language use according to experimental condition

	Solo doll	Solo tablet	Joint doll	Joint tablet
Total	2.99 (2.90) 0–10.00	1.53 (2.39) 0–11.00	5.50 (4.69) 0–16.00	4.11 (4.32) 0–6.00
ISL attributed to the self	1.88 (1.85) 0–6.67	1.36 (2.13) 0–10.00	2.91 (2.89) 0–11.50	3.33 (3.99) 0–14.50
ISL attributed to others[a]	1.14 (1.57) 0–6.00	0.16 (0.32) 0–1.00	2.59 (2.71) 0–10.00	0.74 (0.88) 0–4.00

Note. Mean (SD) and range for scores reflecting children's frequency of ISL use averaged across the 3 × solo doll, 3 × solo tablet, 2 × joint doll, and 2 × joint tablet blocks.

[a]This category represents references to characters' and others' internal states.

3.2 | Internal state language

Descriptive statistics for children's use of ISL in all conditions and for different referents (self and others) are presented in Table 1. When playing with dolls alone, 82% ($n = 27$) of children used ISL at least once. When playing tablet games alone, 64% ($n = 21$) of children referred to at least one internal state. When playing with dolls socially, 85% ($n = 28$) of children referred to at least one internal state. When playing tablet games socially, 82% ($n = 27$) of children used ISL at least once.

Further examination of the ISL data revealed that talkativeness was significantly related to both ISL related to the self ($r_s = 0.81$, $p < 0.001$) and others ($r_s = 0.72$, $p < 0.001$). In order to account for this, we created proportion scores for ISL that represented the proportion of segments in which children spoke that included ISL. However, although all children spoke in at least one segment during joint sessions and only 12% of children ($n = 4$) did not speak at all in either solo doll or solo tablet sessions, there were a large proportion of children who did not

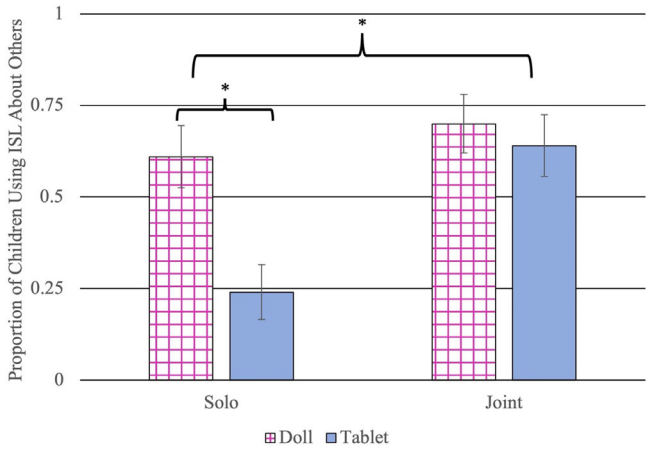

FIGURE 5 Proportion of children using ISL about others in each of the conditions. Data represent estimated marginal means from the GEE and error bars represent standard errors

use ISL at all during the sessions. Across sessions, approximately 24% of children used no ISL about the self and approximately 45% used no ISL about others. Given this skew in the data (one sample Kolmogorov-Smirnov tests for normality, $ps < 0.001$), binary scores were created for each referent: children were either coded as using ISL about the self (or not) and using ISL about others (or not) for each condition. Children who did not produce any language during a particular condition ($n = 4$ in solo doll and solo tablet) were coded as not using ISL. GEEs with a binomial logit distribution and an unstructured correlation matrix were then conducted separately for each referent with these binary scores as dependent variables and social context and play type as within-subjects effects.

A GEE with ISL about the self as the (binary) dependent variable indicated a significant main effect of play type ($\chi^2(1) = 3.98$, $p = 0.046$) such that more children used ISL about the self during doll play ($M = 0.80$ [$SEM = 0.06$]) than tablet play ($M = 0.72$ [$SEM = 0.06$]). When sex was added a between-subjects variable, the effect of sex was not significant ($p > 0.12$). When age was added as a covariate, there was no significant effect of age ($p > 0.56$).

A GEE with ISL about others as the (binary) dependent variable revealed main effects of both social context ($\chi^2(1) = 19.65$, $p < 0.001$) and play type ($\chi^2(1) = 9.96$, $p = 0.002$) and a significant interaction between social context and play type ($\chi^2(1) = 5.53$, $p = 0.019$). Pairwise comparisons revealed that the proportion of children who used ISL about others was higher during solo doll play than solo tablet play (*mean difference* = 0.36 [$SEM = 0.08$], $p < 0.001$) but did not differ between joint tablet and doll play (*mean difference* = 0.06 [$SEM = 0.09$], $p = 0.51$; see Figure 5). When sex was added to the model, these effects remained and a significant interaction between play type and sex also emerged ($\chi^2(1) = 8.43$, $p = 0.004$). Pairwise comparisons revealed that there was no difference in ISL about others between tablet and doll play for boys (*mean difference* = 0.01 [$SEM = 0.10$], $p = 0.95$), but girls used more ISL about others during doll play compared to tablet play (*mean difference* = 0.36 [$SEM = 0.074$], $p < 0.001$; see Figure 6). When age was added as a covariate, a three-way interaction between social context, play type, and age was revealed ($\chi^2(1) = 5.57$, $p = 0.018$). We probed this three-way interaction by conducting independent samples *t*-tests within each condition to see if age differed for children categorized as using or not using ISL about others. Although no significant age differences were found, trends revealed that children who used ISL about others were older in the joint doll condition ($t(31) = 1.87$, $p = 0.07$) and in the solo tablet condition ($t(31) = 1.79$, $p = 0.08$) but not in the solo doll or joint tablet conditions.

3.3 | Relations between ISL and brain activation

3.3.1 | ISL about the self

The first GEE (linear) included the binary value of self-directed ISL as a between-subjects factor and oxygenated haemoglobin as the outcome variable. This analysis yielded a significant interaction between social context and play type ($\chi^2(1) = 4.94$, $p = 0.026$) that replicated the effect found in the original manuscript investigating brain activity (Hashmi et al., 2020) such that pSTS activity was greater in the doll condition than tablet condition during solo play ($p = 0.037$) but did not differ between doll and tablet during joint play ($p = 0.30$). No main effect of or interaction with ISL about the self was discovered. When age and sex were added to this model, they were not significant. The same GEE model with deoxygenated haemoglobin as the outcome variable revealed no significant main effects or interactions ($ps > 0.21$).

ISL about the other

Because age and sex modulated ISL about others, we included sex and age as factors in the model investigating the role of ISL about others on pSTS activation. The model therefore included pSTS activity as the outcome variable (oxygenated), social context and play type as within-subjects repeated factors, sex and the binary value for ISL about others as a between-subjects factor, and age as a covariate (linear model). Interactions between sex, play type, and ISL about others were included in the model due to the interaction found. This analysis revealed a main effect of ISL about others ($\chi^2(1) = 8.68$, $p = 0.003$) driven by children who used ISL about others showing more pSTS activation than children who did not use ISL about others; see Figure 7). No other main effects or interactions were significant ($ps > 0.12$). When deoxygenated haemoglobin was entered as the outcome variable in the same model, the main effect of ISL about others was not significant ($\chi^2(1) = 0.11$, $p = 0.74$), nor were any other main effects or interactions ($ps > 0.18$). Additional analyses with talkativeness as the predictor confirmed these associations were not due to greater talkativeness more generally.

4 | DISCUSSION

We investigated children's use of ISL and pSTS activity as they freely played with dolls and tablet games on their own and with a social partner. We found that ISL about the self was used by more children when

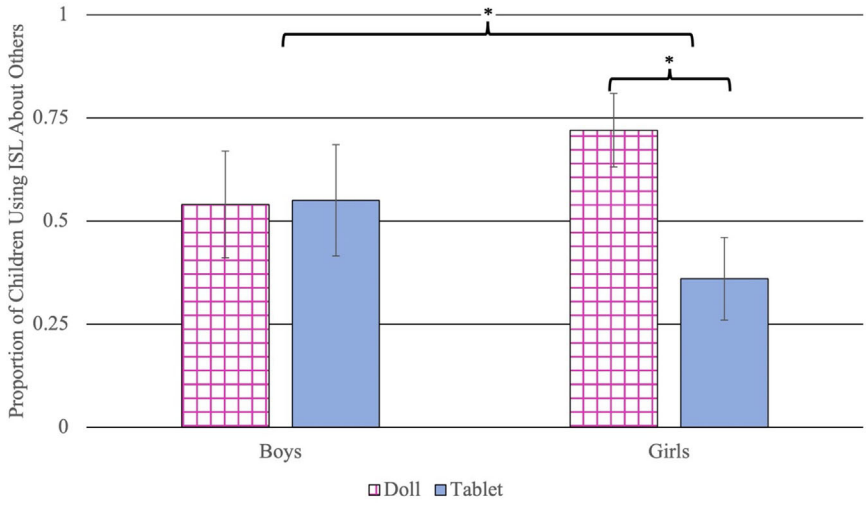

FIGURE 6 Proportion of girls and boys using ISL about others during the different types of play. Data represent estimated marginal means from the GEE and error bars represent standard errors

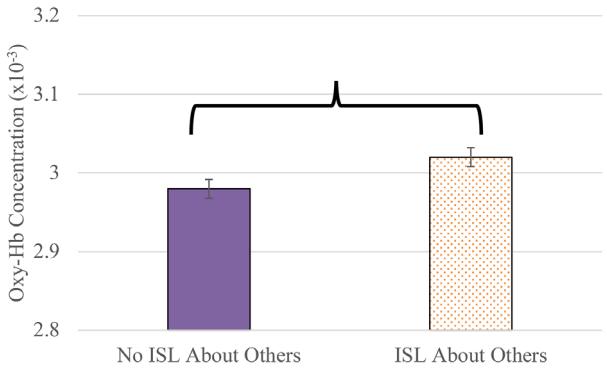

FIGURE 7 Estimated marginal means of oxygenated activity over the pSTS region during play during segments with no internal state language about others relative to segments with internal state language about others (error bars represent standard errors of the mean). *$p = 0.003$. pSTS, posterior superior temporal sulcus

playing with dolls than when playing tablet games, in line with previous findings demonstrating children use more ISL when playing with Playmobil figures compared to a video game (Hashmi et al., 2021). Children also referred to the internal states of *others* when playing with dolls on their own more than when playing tablet games on their own, mirroring our earlier pattern of findings related to pSTS activation (Hashmi et al., 2020). Finally, we found that the use of ISL about others was related to increased pSTS activation regardless of play type, social context, age, or sex, supporting previous research highlighting this region as important for social understanding (Saxe, 2006; Sekine et al., 2019).

That more children used ISL when playing with the dolls than when playing with tablet games, particularly in terms of referring to the internal states of others when playing alone with dolls, is in line with claims that some toys can act as a 'prod to the imagination' and encourage pretend play (Cohen & MacKeith, 1991, p. 24; Singer & Singer, 1990). In support of this, children in our study attributed internal states to the dolls when playing with the dolls alone as they enacted roles with the dolls: 'Thank you for coming over my house, do you *want* a sleepover?', and as a part of their pretend stories: 'There's a mermaid…*hurt* and they're *tired*'. They also vocalized queries in the second person regarding where toys should be placed: 'Where do you *think* this should go?'. In contrast, when playing alone on the tablet games, in the rare instances internal states were attributed to characters, it was in the form of a commentary of what was on the tablet screen: 'he can't even *see*' or were related to the specific theme of the game: 'I don't even know which hair she *wants*.' This shows that children were taking advantage of the open-ended form of play afforded by dolls to generate creative and different patterns of ISL use compared to tablet play (Howe et al., 2020).

To our knowledge, this was the first study to directly investigate the association between children's brain activity and spontaneously produced ISL during their play (but see Sekine et al., 2019 for relations between ISL during play and fNIRS activity during a different task). In accordance with previous fMRI research showing that social brain processing regions are uniquely activated when individuals are prompted to read about internal states (relative to perceptual or physical information; Saxe, 2006; Saxe & Kanwisher, 2003; Saxe & Powell, 2006), we found that the use of ISL about others was related to individual differences in pSTS activation. This is important because it shows that this social brain processing can be naturally produced in a bottom-up manner during play rather than induced via experimenter manipulation. Further, it provides strong support for the notion that certain kinds of play (i.e., doll play) naturally incline children to engage in social processing. We previously hypothesized that the pSTS activity that is uniquely prominent during solo doll play (relative to solo tablet play) suggested that children were rehearsing theory of mind and empathy skills. That children use more ISL about others during this kind of play *and* that social processing brain activity is related to variability in ISL about others provides strong support for the proposal that when playing with dolls, children play in a way that allows them to reflect on the thoughts, feelings and internal worlds of others. That is, rather than simply engaging social processing brain regions due to the humanoid nature of dolls, or some perceptual or physical features of the toys presented compared to tablet games, we now have evidence that doll play uniquely

prompts children to reflect and comment on others' inner states, even when playing alone.

A promising aspect of this research is that we found relatively consistent results for boys and girls and across ages. Although we found an interaction between sex and play type for ISL about others suggesting that girls use more ISL about others during doll play than tablet play (whereas boys did not show this pattern), both the interaction between play type and social context and the patterns of brain activity were consistent across sexes. Whether this is true of all boys and girls or only for those interested in and/or willing to play with dolls in an open question. Because our sample reflected convenience sampling, it may be that those who volunteered to take part were more open to doll play. We previously found that about 25% of children who participated in the research had not previously played with dolls (Hashmi et al., 2020), suggesting that prior doll play was not necessary for the outcomes observed in this research.

Similarly, although talkativeness unsurprisingly increased with age, ISL about others was only marginally higher for older children in some of the conditions, implying that age did not drive the patterns seen. Age and sex (or general talkativeness) were also not significant predictors of pSTS activity, whereas ISL about others was a significant predictor even when controlling for these factors. We thus have robust evidence that the ISL spontaneously produced during play relates to pSTS activation across sex and our broad age range (4 to 8 years). Despite the ubiquity of the findings across these factors, we did not collect any additional demographic data to assess the representativeness of the sample or control for variables like race, socio-economic status (SES), or culture in analyses. The sample was largely recruited from the surrounding area of one British city and reflected convenience sampling. Despite this limitation, previous research suggests that children's use of ISL is relatively consistent in native languages of western countries (Kristen et al., 2014), and while the evidence related to cross-cultural similarities in the patterns of ISL use in the native languages of eastern countries is mixed (Suzuki & Nomura, 2020; Wang et al., 2010), there is support for there being consistency in the use of ISL between the native languages of western and eastern countries (Tardif & Wellman, 2000).

Demographic factors, such as SES, have been found to influence the development of social understanding (Cole & Mitchell, 2000), but we note that the individual differences found in our study were not explained by other characteristics of the child, such as the age or sex of the child. It is noteworthy that the dolls and game characters presented in our study were diverse (e.g., dolls of different races, sizes, and genders; see Hashmi et al., 2020), lending support to the notion that children of varying backgrounds could identify with the toys and characters. Future research should more directly investigate whether the diversity of children and/or dolls and the match or mismatch between these alters how children play and how their brains process this play.

Although we included tablet games that were similar to doll play in the inclusion of characters, being open-ended, and allowing for creative play, there are also important differences between these ways of playing. Doll play involves physical interaction in handling the dolls and other toys that is absent when playing with tablet games, which involves interacting with a touch screen. Similarly, although the tablet games allow for open-ended play in that there are no pre-scripted narratives embedded in either game, children are somewhat restricted by what is possible given the games' programming in a way that playing with dolls may not be. Finally, although both tablet games featured characters, the theme of one of the tablet games (Hoopa City 2) was centred around building a city which may be more similar to *construction play* than doll play. Therefore, future research comparing a variety of different types of virtual and non-virtual play can help further illuminate why different types of play appear to evoke differences in children's use of ISL.

It is possible that some children may have reflected on the internal states of others without verbalizing these thoughts. If this is the case, we may not have identified some children who were engaging in this type of social processing. There is no reason to believe, however, that the tendency to verbally express these thoughts would differ between conditions, so if this is the case, the current findings would represent a conservative estimate of the propensity of children to engage in social processing during play. The fact that we found significant results despite this limitation is promising.

Finally, our study aimed to assess in vivo neural activity while children engaged in play. Therefore, we used a regions of interest approach (rather than specific channels of activation), like a number of different studies (e.g., Krishnamurthy et al., 2020; Mauri et al., 2020; Su et al., 2020), in the context of a novel design. However, this analytical approach lacks a degree of precision and precluded us from examining event-related instances of language use in these children. Although controlled experimental tasks have enabled event-related instances of language to be matched in time to brain activity (e.g., Bowman et al., 2015; Saxe et al., 2009), a fruitful avenue for future research would be to investigate the possibility of conducting event-related analysis with specific channels of activation to establish whether ISL may be the output of a longer enduring thought process, or whether it is possible to pin-point brain activation with corresponding unprompted ISL language production in time.

These findings have implications for interventions that are designed to improve children's social understanding through encouraging the use of ISL (e.g., Bianco et al., 2016). Given our findings that joint play with dolls and tablet games were similar in the extent to which they elicited ISL, either of these activities in a social context could be targeted to promote the use of ISL. More specifically, our findings that playing alone with dolls is an activity that elicits spontaneous conversations about the internal states of *others* is particularly intriguing in light of previous research indicating that encouraging this kind of ISL promotes social processing skills. Although these findings are based on an English-speaking sample, the relation between ISL and theory of mind has been found in native languages of multiple western countries (e.g., Canada, Olineck & Poulin-Dubois, 2007; Germany, Lohmann & Tomasello, 2003; Italy, Grazzani & Ornaghi, 2012; USA, Hale & Tager-Flusberg, 2003), in addition to eastern countries (e.g., China [Hong Kong], Chan et al., 2020), suggesting that the findings have broader relevance.

Children simply enjoy play, but it is also a core part of the childhood experience associated with social, emotional, and cognitive

development. Our findings highlight that playing with dolls and tablet games with others promotes the use of ISL about both other real people and fictional characters, as does playing with dolls on one's own. We have also extended our earlier findings regarding differences in pSTS activation (Hashmi et al., 2020), an area associated with social understanding, and identified relations between increases in activity in this region and the use of ISL about others. Future work building upon these novel results can further explore whether the differences seen for these varying types of play translate into long-term differences in children's performance on social understanding tasks and their everyday social interactions.

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CONFLICT OF INTEREST

Funding for this research was provided by Mattel Inc through partnership with Oxy Insight Ltd. Mattel and Oxy Insight funded the equipment and some personnel for this project and were involved in initial discussions regarding the study design. Neither Mattel or Oxy Insight had final say in the study design nor played a direct role in the collection or analysis of the data; interpretation of the results; or writing of the manuscript.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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