Received: 22 January 2021 | Revised: 27 November 2021 | Accepted: 16 December 2021

DOI: 10.1111/1460-6984.12697

International Journal of Language & Communication Disorders

RESEARCH REPORT

You may point, but do not touch: Impact of gesture-types and cognition on language in typical and atypical development

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Funding information
H2020 Marie Skłodowska-Curie Actions, Grant/Award Number: 676063.

Abstract

Background: Evidence shows that the relation with the referent (object manipulation, contact/no contact pointing) and the different hand features (index finger/open palm) when pointing indicate different levels of cognitive and linguistic attainment in typical development (TD). This evidences the close link between pointing, cognition and language in TD, but this relation is understudied in autism. Moreover, the longitudinal pathway these abilities follow remains unexplored and it is unclear what specific role (predictor or mediator) pointing and cognition have in both typical and atypical language development.

Aims: The first aim was to investigate whether pointing hand features (index finger/open palm) and relation with the referent (manipulation, contact and no contact pointing) similarly predict language in children with and without autism. The second aim was to explore whether cognition mediates the longitudinal relationship between pointing and language development.

Methods & Procedures: Sixteen children with autism, 13 children at high risk (HR) for autism and 18 TD children participated in an interactive gesture-elicitation task and were tested on standardised cognitive and expressive language batteries in a longitudinal design. A two-step analysis consisted of a stepwise linear regression and mediation analyses. First, the linear regression identified which hand features and types of relation with the referent predicted expressive language in all groups. Second, three mediation analyses (one per group) assessed the predictor/mediator role of the variables that met significance in the regression analysis.

Outcomes & Results: Both cognition and index finger pointing were direct longitudinal predictors of further expressive language skills in the autism group. In TD and HR groups this relation was mediated by age.

Conclusions & Implications: Findings highlight the role of age in communicative development, but suggest a key role of cognition and index finger use in the longitudinal relationship between pointing gestures and expressive language development in children with autism. This has important clinical implications and supports the view that index finger pointing production might be a useful tool in the intervention for communicative and language abilities in autism.

What this paper adds: What is already known on the subject: There is evidence that no contact pointing is associated with complex socio-cognitive abilities that underpin communication in TD. Similarly, studies in TD show that index finger pointing is closely linked with language acquisition. However, it is unclear whether these associations are present in autism. In addition, the mediating (or predictive) role of cognition in the pointing–language relation has not yet been explored neither in typical nor in atypical development.

What this paper adds to existing knowledge: This paper shows that index finger pointing and cognition are direct longitudinal predictors of expressive language in the autism group. In the other groups this relation is mediated by age. This suggests that there is a window of opportunity for pointing to predict expressive language whereas the predictive value of cognition expands in development. Based on this, children with autism would share the same language predictors as TD children, but with delays.

What are the potential or actual clinical implications of this work?: This study reveals that index finger, age and cognition reliably predict spoken language in autism, which may indicate that early prelinguistic intervention based on pointing production and the improvement of cognitive skills might have a positive impact on spoken language in this population.

KEYWORDS

autism, cognition, communicative interaction, index finger pointing, language development

INTRODUCTION

Pointing is a complex act which involves the understanding that a communicative partner is an independent mental agent that can be influenced, and whose attention can be directed (Camaioni, 1997; Liszkowski *et al.*, 2004; Liszkowski *et al.*, 2008). The distinctive use of hand for communicative purposes signals infants' socio-cognitive development (Tomasello *et al.*, 2007) and their readiness for spoken language acquisition (for a meta-analysis see Colonnesi *et al.*, 2010). As a matter of fact, the cognitive underpinnings of pointing are at the very base of communication development and make apparent the link between gestures, cognition and language (Kita, 2003). In contrast to other deictic gestures (i.e. showing and giving), pointing allows for reference-making without necessarily establishing contact with the referent. Pointing production thus implies the acquisition of the cognitive skills necessary to go beyond pure object manipulation and engage in social-interactive uses of objects (Wing *et al.*, 1977). Pointing is also the only gesture type that has been shown to reliably predict language in both typically developing children (TD) and children with autism (Özçalışkan *et al.*, 2016; Ramos-Cabo *et al.*, 2019 for a review).

Importantly, there are specific parameters of pointing that have been associated with language development, and which have to do with the physical features of the hand. There is evidence suggesting that, at least in TD children, taking distance from the object in the progress from touching or reaching to pointing, reflects the cognitive readiness of the child to understand the communicative value implicit in this type of gesture (Murillo & Belinchón, 2012; Salo *et al.*, 2018). Additionally, pointing with the index finger, as opposed to open palm pointing, has been shown to be strongly associated with vocalisations and declarative communicative intent in typical development (TD) from 1 to 3 years (Cochet & Vauclair, 2010; Liszkowski & Tomasello, 2011) and in children with autism from approximately 2–4 years (Dimitrova *et al.*, 2019; Manwaring *et al.*, 2019; Özçalışkan *et al.*, 2016).

However, despite recent evidence of a differential interactive–communicative pattern in autism in terms of handshape and contact with the referent (Ramos-Cabo *et al.*, 2020), no study has investigated the impact of distinct formal manual features on language development of children diagnosed with autism spectrum disorder (ASD). Previous studies with ASD samples are either comparative or correlational (Dimitrova *et al.*, 2019; Özçalışkan *et al.*,

2017) or have explored the longitudinal impact of gestures on vocabulary comprehension (Choi *et al*., 2020), but no study to date has focused on exploring the predictive role of different hand features which characterise gesture production on expressive language longitudinally. Furthermore, although cognitive abilities are inherent to gestures, no study has explored whether this relation is independent of, or mediated by, children's cognitive abilities. The aim of this study was to fill this gap in the literature with a sample of children diagnosed with autism, children at high risk (HR) for autism and TD children.

Relation between hand features, cognition and language in typical development

Children's communicative manual behaviour has provided considerable insight in early cognitive and language attainment. Seminal epidemiological studies have linked very early hand gestures with the development of complex cognitive abilities, such as symbolic abilities (Wing, 1981), or executive functions linked to behaviour regulation (Bruner 1981, Rodríguez *et al*., 2017). Studies with TD infants have observed that those who are instructed to use gestures to drive their thinking show better performance in planning and math problems than those who are not taught these gesture-strategies, revealing the potential of gestures to drive cognitive resources and high-order mental abilities (Beilock & Goldin-Meadow, 2010; Broaders *et al*., 2007; Goldin-Meadow & Beilock, 2010). Also, cross-sectional regression studies have revealed that conventional and deictic gestures produced by children aged 3–5 years during the execution of a card sorting task, are strong predictors of their executive functions above and beyond age (O'Neill and Miller 2013, Rhoads *et al*., 2018). This suggests that gestures can enhance high-order cognitive processes by invoking a referent or action in the child's mind (Novack & Goldin-Meadow, 2015). However, different types of gesture have been associated with distinct high-order abilities, suggesting that specific gestures, and hand features in particular, might be differentially related to specific aspects of cognition. For instance, while object manipulation has been linked to object perception and organisation of self-directed actions (McCarty *et al*., 2001; Rodríguez *et al*., 2017), conventional and deictic gestures have been found to underlie attention directing actions and communicative functions from 14 months up to 4 years (Rowe & Goldin-Meadow, 2009; Rohlfing *et al*., 2017).

Among communicative gestures, deictic gestures (pointing, showing, reaching or giving) have been shown to be specifically associated with the development of communicative abilities and spoken language in early childhood (Cochet & Vauclair, 2010; Özçalışkan *et al*., 2016; Romano & Windsor, 2020). When children distance themselves from the object, the opportunity to use gestures for communicative purposes increases. Furthermore, Rohlfing *et al*. (2017) point out that the deployment of deictic gestures for communicative purposes requires disengagement from the object. This is consistent with the fact that distal gestures, such as pointing, are better predictors of language with increasing age, in comparison to proximal gestures, such as reaching (Murillo & Belinchón, 2012; Salo *et al*., 2018). Ramos-Cabo *et al*. (2020) argue that pointing without contact with the referent is based on more cognitively advanced mechanisms than pointing with contact.

There are several reasons that sustain this claim. Firstly, developmental evidence suggests that pointing to distal objects emerges later than pointing within the infant's reach, which may involve touching the object (Butterworth, 2003). Secondly, pointing gestures emerge later and involve body movements to a lesser extent than reaching (Cochet *et al*., 2011, 2014). Finally, pointing handedness is associated with an improved infant word production while grasping handedness does not yield the same effect (Esseily *et al*., 2011). Supporting this claim, a recent longitudinal study revealed that specifically index finger pointing predicted language comprehension by the first year of life, language production by the fifth and grammar by 6 years of age (Lüke *et al*., 2020) revealing the underlying socio-cognitive abilities of declarative index finger pointing (Liszkowski & Tomasello, 2011). In contrast, imperative pointing is usually produced with an open palm and used as a means to obtain desired objects (Tomasello *et al*., 2007). Previous evidence accounts for the link between distinct hand features and specific communicative intentions (Camaioni *et al*., 2004; Liszkowski *et al*., 2004). For instance, imperative gesture elicitation protocols require that the child requests an object, while declarative elicitation protocols require that the child signals where an object is or to simply share their interest for a referent with a communicative partner. It is noteworthy that children between 1 and 4 years of age use open palm pointing to make requests approximately 80% of the time while index finger is used declaratively in the same proportion (Cochet & Vauclair, 2010; Cochet *et al*., 2014; Grünloh & Liszkowski, 2015).

This is consistent with evidence showing that declarative index finger pointing is the gesture primarily linked with communicative intent and spoken language acquisition (Blake *et al*., 2005; Camaioni *et al*., 2004). A meta-analysis of 25 studies has established both a concurrent and longitudinal predictive relation between declarative pointing and spoken language acquisition between 12 and 24 months in TD children (Colonnesi *et al*., 2010). In the reviewed studies, pointing onset and pointing quantity, in particular, predicted the onset of spoken language and the number of words produced by the child, respectively. These outcomes reveal that the predictive power of pointing is rooted in the child's understanding of social intentions, and in the acquisition of complex socio-cognitive abilities that allow reference-making (Liszkowski & Tomasello, 2011). Importantly, whilst declarative pointing is frequently paired with vocabulary spurt and early vocalisations (Liszkowski & Tomasello, 2011; Cochet & Vauclair, 2010), imperative pointing correlates with object manipulation (Cochet *et al.*, 2011). Interestingly, several studies have systematically reported that hand preference for object manipulation and hand preference for pointing gestures are not correlated (Bates *et al.*, 1986; Esseily *et al.*, 2011; Jacquet *et al.*, 2012), suggesting that structural differences in hand features in relation to the referent associate with distinct cognitive aims. While hand features involved in object manipulation might entail individual object exploration, hand features involved in pointing might reveal referential intent related to an object (Vauclair & Imbault, 2009). In addition, the asymmetry in favour of the right hand for pointing gestures has been linked to language production between the first and third year of life (Esseily *et al.*, 2011; Vauclair & Cochet, 2012).

Therefore, although both imperative and declarative gestures require taking distance from the referent, the fact that index finger pointing specifically predicts language in TD children suggests that this type of gesture is a proxy of the willingness of the child to interact socially. Infants' awareness of their ability to influence others when pointing declaratively indicates that they have reached a cognitive stage where they no longer use pointing as a mere instrumental tool, as it happens in open palm pointing (Tomasello *et al.*, 2007). Overall, the findings of studies of TD children illustrate that different types of hand features and distance from the object in deictic gestures might be key indicators of cognitive and communicative abilities in early development. Critically, these hand features might serve to discriminate communicative and non-communicative behaviours in an objective observable manner, and thus be reliable predictors of cognitive attainment and spoken language acquisition. In other words, differences in gesture morphology in terms of hand features (open palm, index finger use) and relation with the object proximal (e.g. involving contact) or distal (without contact) might distinguish between communicative and non-communicative intentions. This on the one hand, supports the communicative value of pointing and, on the other, suggests that the assessment of hand features in early development offers an invaluable opportunity to detect the onset of communicative skills, and identify those children at risk of specific difficulties in such skills, such as children with ASD.

Pointing, hand features and language in autism

Often the very first signs of early communicative development of infants who go on to receive an ASD diagnosis may resemble the neurotypical pathway during the first 2 years of life (Iverson *et al.*, 2017; Rogers, 2009). However, many studies have reported gesture impairments in ASD individuals later in development, and specifically, reduced gesture production in comparison to TD infants (Attwood *et al.*, 1988; LeBarton & Iverson, 2016; Mundy *et al.*, 1986; Özçalışkan *et al.*, 2016). The gestural decline coincides with the decline in cognitive and communicative abilities (Bussu *et al.*, 2018; Ozonoff *et al.*, 2010), which could explain why declarative pointing is the most impaired, while imperative pointing is spared in ASD (Baron-Cohen, 1989; Mastrogiuseppe *et al.*, 2015; Veness *et al.*, 2012; Zwaigenbaum *et al.*, 2005).

Some studies argue that rather than impairment, the reduced gesture rate in ASD children reflects a delayed development. The onset of pointing appears much later in ASD than in TD (Camaioni *et al.*, 2003), but children with autism may catch up at around 3 years of age (LeBarton & Iverson, 2016), suggesting that they might follow the same milestone patterns as TD toddlers, but with delays (Özçalışkan & Dimitrova, 2013). Consistent with this rationale, the commonly reported gesture–language relation in TD has been found also in ASD (Ingersoll & Lalonde, 2010; Özçalışkan *et al.*, 2017; Tager-Flusberg *et al.*, 1990; for a review see Ramos-Cabo *et al.*, 2019). However, only few studies address specifically the relationship between deictic gesture and language outcomes in autism (Manwaring *et al.*, 2018). Some longitudinal studies have found a relation between deictic gestures and expressive language in children with ASD from the second to the fourth year of life (Özçalışkan *et al.*, 2016, 2017) and as late as 8 years of age (Ökcün-Akçamuş *et al.*, 2019). Similarly, the right-hand bias has also been reported in ASD, but at a later age compared to TD (Dimitrova *et al.*, 2019). Even though features of the hand seem to have an important role in communication development, no study has systematically addressed the predictive relation between hand features and expressive language in the same sample longitudinally.

A recent study based on a formal taxonomy of gesture morphology provides evidence of impaired gesture production in autism, and specifically in the production of index finger pointing in ASD (Ramos-Cabo *et al.*, 2020), which is consistent with the previous evidence of impaired declarative pointing (Baron-Cohen, 1989; Goodhart & Baron-Cohen, 1993). Despite the findings of a different pointing gesture pattern in ASD, and the close relation between the index finger pointing hand feature and spoken language in TD, no study to date has investigated the specific role of different hand features in the language acquisition of ASD children.

Current study

Extant research has demonstrated the predictive value of communicative gestures in language development in TD children. There is extensive evidence supporting that: (i) the use of gestures is inherent to the development of the child's cognitive skills; and (ii) certain hand features are better predictors of language than others. However, given the vast amount of evidence showing a strong association between pointing, a cognitive and linguistic ability (Manwaring *et al*., 2017), the question remains whether index finger pointing, compared to other hand features scaffolds language, and whether this occurs via or independently of cognitive abilities. Moreover, there is still a gap in research on the relationship between deictic pointing and language outcomes in children with autism (Manwaring *et al*., 2018).

The aim of the current study was twofold: (i) to identify whether distinct hand features (index, open palm) and relation with the referent (manipulation, contact, no contact) predict expressive language in development in children diagnosed with autism, children at risk for autism (HR children, Ozonoff *et al*., 2011) and TD children; and (ii) to explore the role of cognition in the relation between pointing and expressive language. Expressive language measures were selected as outcome measure based on two sources of evidence. First, most recent studies have focused on expressive language and gesture use in order to test the relation between the two key means of productive communication in infancy (Dimitrova *et al*., 2019; Ozkaliskan *et al*., 2016, 2017). Second, some evidence suggests that receptive language assessments can lead to poorer scores than expressive language assessments in ASD (Charman *et al*., 2003). It could be that the child's lack of need to use index finger pointing in receptive tasks might be causing the observed gap between receptive and expressive measures. To this end, we used repeated measures of pointing hand features collected in a semi-structured interactive gesture-elicitation task, as well as standardised measures of cognitive abilities and expressive language collected simultaneously with the gesture elicitation task and 1 year later. The fine-grained pointing categorisation we developed for the study based on a classification of features of gesture morphology versus the traditional imperative/declarative pointing classification allows for an objective analysis of spontaneous pointing production, essential for the study of language acquisition. An additional measure of object manipulation was added to control for non-communicative manual acts, and in order to explore whether these acts differ between groups and whether they exert any influence on cognition and language. Our hypothesis was that no contact and index finger pointing, together with cognition would predict expressive language in the sample as a whole, and also in children with autism, whilst open palm and object manipulation should exert a null or negative influence on children's expressive language abilities.

METHODS

Participants

The children in the current study participated in a longitudinal study on deictic communication (as part of a larger study within the Horizon 2020 MSCA International Deictic communication research Network DCOMM). The communicative development of three groups of children (ASD, HR and TD) was assessed longitudinally in two data collection points over 1 year. Children in the three groups were Spanish monolingual children from northern regions of the country with equivalent socio-cultural environments. The ASD group consisted of 16 children diagnosed with autism (14 boys, two girls) and with a mean age of 51.81 months (age range = 35–72 months, SD = 10.45) at the first data collection point (Time 1). The ASD diagnosis was determined by an independent neuro-paediatrician or psychiatrist from the Spanish public health system. The diagnostic report was made available by parents of children with autism at the first stage of the study. The HR group consisted of 13 children (six boys, seven girls) who had an older sibling with ASD – at genetic risk but no ASD diagnosis based on clinical history – and whose mean age at Time 1 was 36 months (age range = 16–64 months, SD = 16.23). The TD group served as a control group, and consisted of 18 children (11 boys, seven girls) with no history of developmental disorders and with a mean age of 37.72 months (age range = 17–68 months, SD = 16) at the first stage of the study. The decision about the age of the sample was based on previous studies, which have mostly explored the relation between gesture and expressive language in toddlers with autism around 30 months (Dimitrova *et al*., 2019; Ozcaliskan *et al*., 2017), but also between 3 and 8 years (Ökcün-Akçamuş *et al*., 2019). Although in some studies the relation between gesture and receptive language has been explored in infants at high and low risk for ASD ranging from 12 to 24 months of age (Choi *et al*., 2020), expressive language abilities have been tested later on in development. Due to our interest in the productive dimension of gesture and language, and to avoid floor effects in children with autism, children in this sample were approximately 20 months older than those in previous studies. The inclusion of a HR group was specifically motivated by the interest in observing subtle early communicative differences in children who are genetically predisposed, but who have not received a formal diagnosis yet. This decision is consistent with extant evidence revealing that HR siblings can display atypical joint attention and language developmental patterns compared to TD and children with autism (Hundry *et al.*, 2014; Gangi *et al.*, 2016). For this reason, it was important that the HR and TD were developmentally comparable, and children in these two groups were selected, so that they would be closely matched on age. An ANOVA revealed an effect of age between groups $F(2,46) = 5.61$, $p = 0.007$, $MSE = 9158.04$. There was a significant difference between the children with ASD and the TD children, $F(1,33) = 8.97$, $p = 0.005$, $MSE = 5994.03$; and between the children with ASD and the HR children, $F(1,28) = 177.86$, $p = 0.004$, $MSE = 1793.35$. No significant difference was found between the TD and the HR children, $F(1,30) = 259.29$, $p = 0.771$, $MSE = 7519.61$. The study was conducted under the guidelines of the ethical committee of the University of the Basque Country UPV/EHU, project approval reference M10_2016_330.

Pointing elicitation task

Pointing gestures were elicited in a caregiver–child interactive context using a task designed by Liszkowski *et al.* (2012) that allows for a fine-grained formal analysis of spontaneous pointing gestures. For the task, the child and a main caregiver (the mother or the father) were walked into a room and asked to stand in front of a wall where the stimuli (colourful pictures and objects) were displayed. Adults carried their child or held their hand (for older children) while standing together in front of the set-up. The following instructions were given to all participants: ‘Please look at and comment together the images and objects on the wall. Interact as you would normally do, but please, do not remove any of the items from the wall.’ Different from the instructions provided by Liszkowski *et al.* (2012), which explicitly requested the participants to not touch the stimuli, we did allow participants to touch the stimuli. This was done to observe the possible differences in communicative and non-communicative behaviours between the groups. The researcher could observe the situation from outside through a panel, but only the main caregiver and child were in the room while the recording was taking place. All participants were given 10 min to interact and were videotaped for the entirety of that time. Five minutes were subsequently coded out of the total of 10 min of interaction.

Coding

Caregiver–child interactions were coded off-line using the software ELAN (version 5.8, 2019) (https://archive.mpi.nl/tla/elan). The first 5 min of interaction were coded per participant (participants were videotaped while interacting at Time 1). Instances where there was no relevant interaction (i.e. participants were discussing something different from the stimuli) or when the participants were off camera were excluded from the coding. This way, all coders started to code at the beginning of the video and coded until a total of 5 min of interaction (not including the excluded footage) was reached per participant. This coding system ensured comparable interactions across participants.

Pointing and object manipulation measures

Measures of pointing hand features were collected attending to two categories with two subcategories each: hand feature (index finger pointing/open palm pointing) and contact with the referent (contact pointing/no contact pointing). This way, each pointing gesture was simultaneously classified according to the shape of the hand used (extended index finger or extended palm of the hand) and whether the child touched or did not touch the object/picture referred to in the experimental set-up.

The measure object manipulation involved non-communicative acts with the hand and an object from the set-up. Some examples of behaviours categorised as object manipulation are touching, tapping, caressing and squeezing. Total raw scores were obtained for the two key pointing hand features: index finger and open palm measures. For the distal/proximal relation with the referent, the percentage of times that the child touched, did not touch or manipulated the referent was calculated. This was done as a way to assess the type of communicative engagement with the object.

Coding reliability

Two trained coders blind to children’s diagnosis coded 36% of the data (37.5% of the data of the ASD group, 46.15% HR and 33.33% of the TD group) that was randomly selected for quality assurance. The coders first observed examples of each gesture category based on a delimited set of behaviour criteria established by the researcher, and then coded a pilot video. The training was complete when both coders reached an agreement of 85% for the observations of the entire pilot video. Interrater reliability on experimental videos was calculated on gesture annotations. The percentage of agreement for a total of 425 observations (i.e. gestures) was 88.9% (Cohen's $\kappa = 0.867$). The percentage of agreement for the coding of according to handshape (index/open palm pointing), with a total of 192 observations, was 90.62% (Cohen's $\kappa = 0.856$). The percentage of agreement for a total of 259 observations categorising the relation with the referent (contact/no contact pointing and object manipulation) was 86.10% (Cohen's $\kappa = 0.836$).

Standardised expressive language and cognitive measures

The measures of expressive language and cognition were obtained by testing participants using the Spanish version of expressive language and the cognition battery of the Merrill-Palmer Revised Scales of Development (Roid & Sampers, 2011). According to the test manual, test–retest reliability estimates for the expressive language and cognition batteries are 0.85 and 0.97, respectively. Estimates for internal consistency are 0.91 and 0.93, respectively; and estimates for validity are 0.80 and 0.81, obtained from comparing values of Bayley, Battelle and Reiter-R batteries. All participants were individually tested by trained psychologists. The cognition battery consists of six short subscales (cognitive, fine motor, comprehension, memory, speed of processing and visuomotor) with items assessing inductive and deductive reasoning, categorisation, pattern identification, sequencing, and selective and divided attention tasks. This battery was run only in Time 1. In the expressive language battery, children were asked to perform tasks on naming (body parts, clothing and actions) and to provide the correct adverbs, adjectives, prepositions and pronouns when shown a series of colourful images. This battery was run twice, in the beginning of the study (Time 1) and 12 months later (Time 2).

Data analyses

The data analyses consisted of two main steps. First, and in order to identify the longitudinal predictors of expressive language at Time 2, we conducted a stepwise linear regression by entering age, group, cognition and expressive language at Time 1 as predictors in Step 1, and type of hand feature (index, palm) and relation to the referent (manipulation, contact, no contact) in Step 2. Secondly, we explored whether the variables previously identified as predictive of expressive language at Time 2 had a direct influence on language or whether it was mediated by cognition and by age. To that end, we ran three separate mediation analyses per group (ASD, HR and TD). The analyses were carried out using IBM SPSS Statistics version 22.0 and macro-program PROCESS 2.1 (Hayes, 2013), which tested the mediation model using the bootstrapping procedure (with 5000 bootstrap samples) to estimate the 95% confidence interval (CI; for more details, see Preacher & Hayes, 2008). This technique is advantageous over alternative approaches (causal steps, multivariate product of coefficients), as it does not assume that the product term of the indirect effect *ab* (or its constituent paths *a b*) is normally distributed, and outperforms the causal steps approach in terms of power to detect an indirect effect in multiple mediation (Williams & MacKinnon, 2008). Importantly, contrary to the causal steps approach, the absence of an initial 'total' effect of X on Y does not preclude examination of indirect effects, as the total effect represents the 'end-product' of numerous paths of influence (indirect or direct; present or absent in the final model). This procedure was chosen due to the suitability for small and heterogeneous samples like the current ones, since it generates a sampling distribution for the indirect effect by replicating power analyses, assuming the collected sample is a subset representing the population. We employed 5000 replications or bootstraps to calculate CI. To ensure power estimation, we calculated again with 10 000 bootstraps. Estimates converged to stable values ensuring that CI were reliable.

To identify full or partial mediation, the predictor variable and the mediators were entered together into a final regression model. In total, two multi-mediator path models were estimated per group, where the effects of X (index pointing and no contact pointing in the stepwise regression) on Y (expressive language at Time 2) through cognition (M) were examined. Figure 1 shows a visual depiction of the mediation model.

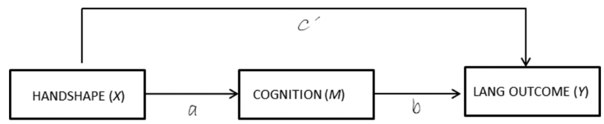

FIGURE 1 Hypothesised path model to test indirect effects of pointing hand features on expressive language outcomes via cognition. For clarity, covariance between mediators and exogenous variables is not shown.

RESULTS

Descriptive statistics and correlational analyses

Descriptive statistics for all variables at each time point are shown in Table 1. Data were screened for univariate

TABLE 1 Descriptive data of pointing hand feature measures at Time 1 and of expressive language at Time 2 per experimental group

Type of hand feature	Mean	SD	Reliability	Skew	Kurtosis
Autism spectrum disorder					
Index finger pointing	6.75	5.55	0.69	0.69	0.52
Open palm pointing	2.00	276	0.23	1.52	1.51
Contact pointing	3.56	3.48	0.26	1.29	0.91
No contact pointing	5.19	4.69	0.75	1.07	1.12
Object manipulation	7.31	6.69	0.64	−1.08	0.10
Cognition	106.7	39.8	0.37	0.36	0.56
Expressive language T1	11.56	15.7	0.28	1.7	2.9
Expressive language T2	15.08	12.5	0.29	0.03	−1.72
High risk					
Index finger pointing	18.06	13.44	0.53	0.88	−0.12
Open palm pointing	1.94	2.04	0.35	0.73	−0.86
Contact pointing	7.89	8.62	0.65	2.13	6.18
No contact pointing	12.11	10.11	0.68	1.58	2.70
Object manipulation	5.56	3.03	0.12	−0.17	−0.94
Cognition	132.1	48.1	0.30	−0.05	−1.7
Expressive language T1	13.23	12.51	0.28	0.22	−1.82
Expressive language T2	28.06	7.63	0.31	−1.84	3.93
Typical development					
Index finger pointing	10.85	8.68	0.27	0.82	−0.40
Open palm pointing	1.92	3.17	0.51	3.05	10.15
Contact pointing	6.62	8.11	0.70	1.04	−0.35
No contact pointing	7.15	3.73	0.27	0.07	−0.08
Object manipulation	8.26	7.12	0.69	0.29	−1.24
Cognition	123.1	49.3	0.35	−0.09	−1.48
Expressive language T1	16.55	14.21	0.32	−0.04	−1.89
Expressive language T2	21.69	11.45	0.29	−0.93	−0.17

outliers, which were defined as cases 2 SD above or below the mean. No children were removed from the sample; thus, the final dataset for subsequent analyses consisted of 16 ASD children, 13 HR and 18 TD children. Reliability was calculated by analysing split-half coefficients, based on mean number occurrence of pointing hand features measures (i.e. hand feature: index finger pointing/open palm pointing; and contact with the referent: contact pointing/no contact pointing) and mean percentage correct responses in cognitive and language tasks. Due to the small sample size and high variability in response outcomes, in all cases reliability was adequate to low in value, with index finger pointing and no contact pointing showing the highest reliabilities in ASD and HR children, and object

TABLE 2 Correlation coefficients among pointing hand feature measures at Time 1 and expressive language at Time 2, controlling for group

	1	2	3	4	5	6	7	8
1. Cognition 1	–							
2. Expressive language 1	0.717**	–						
3. Expressive language 2	0.789**	0.562**	–					
4. Index finger pointing	0.073	−0.007	0.327*	–				
5. Open palm pointing	−0.014	0.000	−0.005	0.081	–			
6. Contact pointing	−0.159	−0.220	0.086	0.719**	0.308*	–		
7. No contact pointing	0.249	197	0.386**	0.786**	0.161	0.195	–	
8. Object manipulation	−0.377**	−0.278	−0.391	0.099	0.204	0.279	−0.052	–

Note: Sample $n = 47$. Values represent correlations of all measures at Time 1 and expressive language at Time 2.
*$p \leq 0.05$.
**$p \leq 0.01$.

manipulation in TD. Skewness and kurtosis values for all measures indicated normal distributions of scores, with two estimates exceeding two (the values for contact pointing in HR, and open palm pointing in TD).

The correlation coefficients between pointing hand feature measures and cognition at Time 1 and expressive language at Time 2 are shown in Table 2, controlling for group and age. Pearson correlation coefficients with Bonferroni correction for multiple comparisons revealed that index finger pointing was highly associated with contact pointing, $r(44) = 0.71$; and with no contact pointing, $r(44) = 0.79$. This analysis also reflected a significant relation between cognition at Time 1 and expressive language at Time 1, $r(44) = 0.71$, and Time 2, $r(44) = 0.78$. Both index finger pointing and no contact pointing were significantly associated with expressive language at Time 2, $r(44) = 0.32$ and $r(44) = 0.38$, respectively.

P-values associated with the other correlation coefficients, except the ones mentioned, were below 0.050, and variance inflation factors in the conducted regressions were below 2. Additionally, a Durbin–Watson value was 2.4. This suggests that multicollinearity or autocorrelation were not overly problematic in this study (Tabachnick & Fidell, 1996).

Longitudinal influence of pointing hand features and cognition in children's expressive language abilities

To address our first aim, we tested the relative predictive power of pointing hand features and cognition on children's expressive language abilities at Time 2. A stepwise linear regression was conducted to explore the relative contribution of pointing hand features (i.e. index finger pointing/open palm pointing, contact pointing/no contact pointing and object manipulation) controlling for experimental group, cognition and expressive language at Time 1. The model tested is shown in Table 3. Variance as well as standardised β values and t statistics per step are listed. Group, cognition and expressive language at Time 1 were entered at the first step in the model, and hand feature (index finger pointing/open palm pointing) was entered in the next steps, followed by contact with the referent (contact pointing/no contact pointing) and object manipulation with expressive language at Time 2 as the outcome measure. Sex was not included, since preliminary analyses with the whole sample demonstrated that it did not have any predictive power on expressive language at either Time 1 or 2. We also made sure that groups did not differ on the cognition measure, $F(2,46) = 1.31$, $p = 0.28$, $MSE = 210.4$. Regarding age, the correlation between age and expressive language was not significant in ASD, but significant at Time 1 and Time 2 in both TD and HR. Similarly, when we entered age as predictor of expressive language at Time 1 or Time 2, age was significant in both TD and HR, but not in ASD. For this reason, age was entered as predictor in the main regression and as covariate in the mediation models. Age and cognition accounted for a large proportion of the variance (71%), whilst group and expressive language at Time 1 did not account for any variance. From the predictors entered in Step 2, index finger pointing accounted for additional variance in expressive language (7%). This was followed by no contact pointing (4%). Whilst these hand features were positively related to language outcome, contact pointing showed a negative relation and accounted for 2% of variance. These values show that most of the variance associated with expressive language was accounted for by cognition, although two specific pointing hand features (index finger and no contact pointing) uniquely predicted developmental increase in expressive language.

TABLE 3 Stepwise regression analysis predicting expressive language at Time 2

		R^2	ΔR^2	ΔF	β	t	p
Variables							
Step 1:	Age	0.717	0.717	30.12**	0.500**	4.17	0.000
	Group				0.140	1.48	0.247
	Cognition 1				0.761**	7.35	0.000
	Expr. Lang 1				0.035	0.31	0.757
Step 2:	Index finger	0.776	0.059	40.22**	0.188*	2.22	0.019
	Open palm				0.006	0.070	0.934
	Contact				−0.195*	−2.36	0.023
	No contact				0.198*	2.58	0.013
	Object manip.				−0.174	−1.94	0.090

Longitudinal effects of pointing hand features and cognition on language outcomes per group

To address our second aim, we explored whether the key predictive pointing hand features at Time 1 exerted a direct influence on the key variable – expressive language at Time 2 – in each experimental group, or whether this influence was actually mediated by cognition. To that aim, we examined cognition level as a mediator of the relationship between Time 1 two specific hand features (no contact and index finger), and expressive language at Time 2 in ASD, TD and HR groups. Unstandardised parameter estimates for specific direct and indirect effects per group are presented. Bootstrapped CI that do not contain zero signify that an effect is statistically significant; therefore, subsequent interpretation will be made using this criterion. However, for comparison, significance levels according to normal theory testing are also indicated with asterisks in the traditional fashion. Overall, significant models explained a modest amount of variance in language abilities.

The first mediation analysis had no contact pointing as predictor in the model. The mediation analysis with age as a covariate revealed that in the ASD group only cognition was a predictor of expressive language, $\beta = 0.25$; $p = 0.001$ (95% bcBootCI = 0.151–0.351); whereas in the TD and HR groups, no factor in the model predicted expressive language due to the predictive role of age on cognition, $\beta = 0.394$; $p = 0.005$ (95% bcBootCI = 2.56–3.33), and $\beta = 0.285$; $p = 0.001$ (95% bcBootCI = 2.30–3.41), respectively. When age was not included as covariate, cognition was the only predictor of expressive language in the three groups, in ASD $\beta = 0.274$; $p = 0.000$ (95% bcBootCI = 0.175–0.372), in TD $\beta = 0.123$; $p = 0.005$ (95% bcBootCI = 0.064–0.182) and in the HR group $\beta = 0.212$; $p = 0.001$ (95% bcBootCI = 0.136–0.288). No contact pointing had no indirect impact on expressive language. The second mediation analysis included index finger pointing as predictor in the model. Results of this mediation analysis are depicted in Figure 2. In the ASD group, the explained variance of total index finger pointing on language in the model was $R^2 = 0.78$, in the HR group was $R^2 = 0.72$, and in the TD group the variance explained in the model was $R^2 = 0.81$. In the ASD group, there was a significant direct effect of cognition ($R^2 = 0.63$), as well as of index finger pointing on expressive language at Time 2 ($R^2 = 0.14$). No significant indirect effect was found in this group, suggesting a key independent role of cognition and index finger pointing production on the development of expressive language abilities in the ASD group. This effect was only observed in the ASD group. In TD and HR groups, no factor in the model predicted expressive language due to the predictive role of age on cognition (see values in Figure 2). Specific differential effects of cognition and index finger pointing on expressive language were found in both of the control groups (HR, TD) when age was not included as covariate ($\beta = 0.26$; $p = 0.001$ (95% bcBootCI = 0.16–0.34); $\beta = 0.18$; $p = 0.001$ (95% bcBootCI = 0.097–0.26); and $\beta = 0.17$; $p = 0.002$ (95% bcBootCI = 0.004–0.065, in the ASD, HR and TD groups, respectively).

DISCUSSION

In a longitudinal design, the current study investigated the predictive role of different hand features, based on gesture morphology (i.e. index finger vs open palm) and relation with the referent (contact, no contact, object manipulation), in the language development of children with AUTISM, children at HR for autism and TD children, as well as the mediating role of cognition in this predictive relationship. Unlike previous studies, we took detailed measures of various aspects of deictic gestures and explored their predictive relation with expressive language outcomes longitudinally in children with and

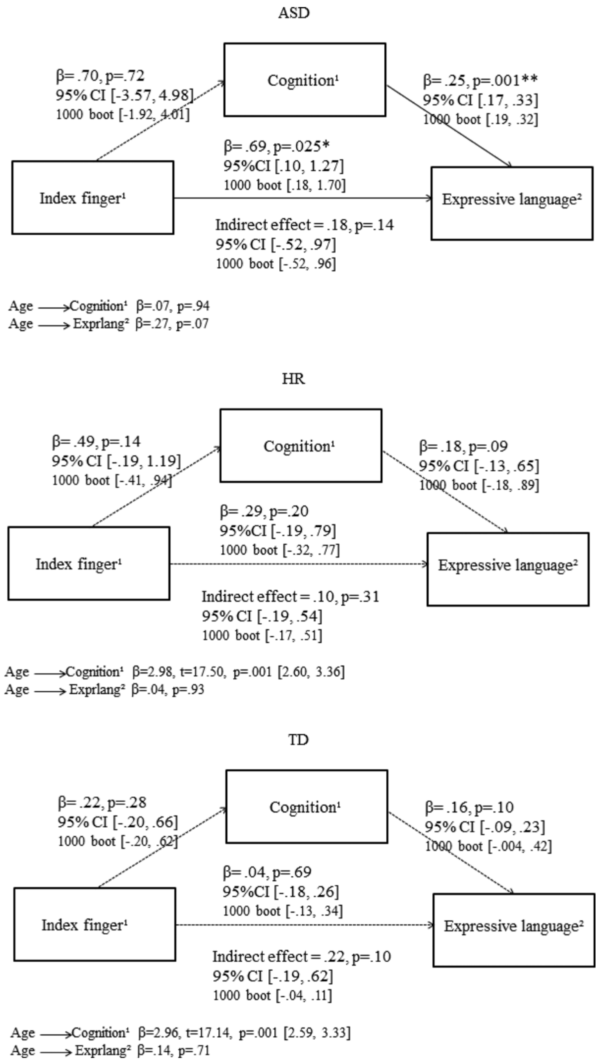

FIGURE 2 Specified models for 5000 and 1000 bootstrapped mediation analyses in each group with age as covariate (unstandardised coefficients).

without ASD. Our results argue in favour of a key role age and cognition in the development of expressive language abilities in the sample as a whole, and on the specific influence of index finger use on the development of these abilities in ASD children independently of cognition.

Building on previous evidence (Cochet *et al.*, 2011; Esseily *et al.*, 2011; Salo *et al.*, 2018), we developed a formal classification system of gesture features for the analyses in the current study (see for details Ramos-Cabo *et al.*, 2020). Two features were of specific interest: the presence/absence of contact and using the index finger while pointing. These two features can be assumed to be directly linked to the emergence of advanced gestural deictic reference, and specifically, the absence of contact and the use of index finger. Moreover, these features allow to distinguish aspects of gesture production between children with and at-risk for autism and TD children (Ramos-Cabo *et al.*, 2020). The key role of these two features was also confirmed by the first analysis in the current paper.

Given the close link between gesture and cognition reported in the literature (Rhoads *et al.*, 2018; Vauclair & Imbault, 2009), cognition was entered as control in the analysis together with age, group and expressive language at Time 1. Results revealed that most of the variance explained in the regression was due to age and cognition. This effect is consistent with the relation found in previous studies between specific aspects of cognition, such as (joint) attention, working memory and executive abilities – all of them age-dependent – and language (see de Abreu *et al.*, 2011; Gray *et al.*, 2017). Consistent with this, the cognition composite employed in our study tapped into the mentioned cognitive mechanisms, since it included working memory, associations, analogies and response planning, besides motor and visuospatial tasks. In addition, given the significant difference in age between the participants with an autism diagnosis and the two other groups in our sample, cognition was a more reliable measure of language ability than age in children with ASD. The analysis also revealed that index finger pointing total score and percentage of no contact pointing bids were key predictors of expressive language measured 1 year apart, once the effect of group, expressive language and cognition at Time 1 were controlled. Importantly, object manipulation was found to exert no effect on expressive language. This is consistent with previous studies establishing index finger pointing as closely associated with linguistic attainment (Cochet & Vauclair, 2010; Liszkowski & Tomasello, 2011), and studies that demonstrate a dissociation between object manipulation and communicative behaviours (Cochet *et al.*, 2011; Esseily *et al.*, 2011). Such findings suggest that object manipulation entails cognitive processes dissociated from communication, and also that this type of manual motor behaviour may be disadvantageous for social interaction and communicative development (Kaur *et al.*, 2015). There is also indication that object manipulation may be associated with an earlier stage in cognitive development (Charman *et al.*, 2000).

Another important finding was the negative relation between the contact hand feature and expressive language 1 year later, providing additional evidence for the cognitive implications of taking distance from the referent and using the index finger as a proxy of action control, symbolic function and socio-cognitive abilities necessary for the emergence of language both in TD and in ASD (Honey *et al.*, 2007). Supporting this view, Cochet *et al.* (2014) found that body distance towards the referent in TD children aged 3–4 was greater in imperative and declarative pointing than in reaching actions. Interestingly, this distance was greater in the declarative than in the imperative pointing. Similarly, Choi *et al.* (2020) observed that children with high and low risk of ASD tended to make more conventional gestures involving body movements than controls, who showed more deictic gestures between 12 and 18 months. These differences however disappeared at 24 months. This evidence suggests that gestures conveying socio-communicative intentions become independent from body movement as long as socio-cognitive abilities increase with age both in TD children and in children with ASD.

Our second aim was to assess whether the observed predictors of expressive language – index finger and no contact pointing – directly impacted on expressive language or whether this relation was mediated by cognitive skills (indirect relation) in each group. Our data revealed that: (i) cognition at Time 1 directly predicted expressive language at Time 2 in children with ASD, but not in TD and HR children, due to the strong predictive relation between age and cognition; (ii) only in the ASD group did index finger directly predict expressive language; and (iii) no contact with the referent does not predict language above and beyond cognition when models are tested by group. We discuss our findings in more detail below.

Given the association between gesture and language, and the evidence that children with autism not only produce less pointing (deictic) gestures (Mastrogiuseppe *et al.*, 2015; Ramos-Cabo *et al.*, 2020; Veness *et al.*, 2012; Zwaigenbaum *et al.*, 2005), but also display a delayed pointing onset (Camaioni *et al.*, 2003, LeBarton and Iverson, 2016), we hypothesised that the predictive role of specific hand features would vary across groups, suggesting different time scales for the potential of index finger pointing to predict language. In addition, based on the reported relationship between gesture and cognition (Manwaring *et al.*, 2017; Wing, 1981), we expected that cognition could serve as a mediator in the pointing hand feature–language relation in all groups (Path b-c' in Figure 1).

Regarding the mediation analyses, our findings do not confirm a model in which pointing hand features would predict expressive language outcomes through the mediation of cognition in all groups. Contrary to the hypothesis that the pointing–language relation would be indirect and partially determined by cognition, we found that cognition exerted a direct effect on language outcomes and was the main longitudinal predictor of expressive language in children with ASD. This confirmed the results in the initial regression outlined above. More interestingly, we found distinct patterns of relation between index finger and language development in the different groups, suggesting different time scales in the relationship between deictic reference, cognition and language in typical and atypical developmental pathways.

A key finding in the current analyses is the difference between children with autism, on the one hand, and TD children and children at HR, on the other. Notably, the two latter groups were matched on age, and children with autism were older. While in the autism group index finger and cognition were both direct independent influences on language development, in the HR and the TD group, only cognition was linked to expressive language outcomes when age was partialled out. These data suggest a specific developmental frame for the emergence of index finger pointing as a cognitive tool to express referential intention in ASD, and imply that, in those children who have passed the referential stage, distinct aspects of cognition and action might be linked to language attainment (Watt *et al.*, 2006; Zambrana *et al.*, 2013). The independent role of pointing gesture and cognition for expressive language in children with autism may indicate that the development of these two cognitive domains is not temporally synchronised in autism.

Our result is consistent with other studies establishing a direct relation between the broader category of pointing and language in children with autism (Charman *et al.*, 2003; Mundy *et al.*, 1990). However, children with autism have been documented to produce fewer deictic gestures, and evidence from our recent research shows that ASD children produce fewer no contact index finger pointing compared to TD children (Ramos-Cabo *et al.*, 2020). This may appear controversial on the surface, however, is entirely consistent with the idea that the emergence of advanced deictic reference by using the index finger is directly linked to expressive language development. Thus, even if deictic gestures are severely impaired in ASD, they are also the only ones which reliably predict language acquisition in ASD and TD (see Özçalışkan *et al.*, 2016 for vocabulary attainment). These results support the hypothesis that ASD children follow a similar, albeit delayed, developmental pattern to TD children, and are consistent with findings in other domains of performance in that population (Vulchanova *et al.*, 2019).

The unexpected absence of predictive power of index finger pointing in the TD and HR groups, while present in the ASD group, might point to the existence of a (limited) time window in development when pointing gestures can reliably predict language. Thus, index finger pointing may support language development during a specific period early on that the TD children and the HR children in our sample had already passed, while the ASD group is still at this stage, due to the developmental delay. Colonnesi *et al.* (2010) reported the strongest pointing–language association in TD between the ages of 15 and 20 months, coinciding with the age for the onset of sentence production. From that point on, TD children start relying more and more on spoken language for communication, and pointing production reduces as spoken language takes over. The age range of the TD group in our sample was 17–68 months, and this might explain the current results compared to other studies (Liszkowski & Tomasello, 2011). However, it is important to note that, while the strength of the current study is its longitudinal design, the relatively small size and the wide age range in our sample should be considered as limitations. It is possible that the lack of effects observed in the HR and TD groups may be also due to a lack of statistical power. Future research should shed more light on the developmental pathway of the influence of different types of gestures on language learning.

Despite the differences in predictive role of index finger pointing for language in our three groups, cognition consistently predicted language in children with ASD, and in the control groups when age was not entered in the model. Regardless of the limitation of the age variability in our control samples, this outcome suggests that unlike index finger pointing, whose language predictor role might be restricted to a specific point in time, cognitive abilities might support linguistic attainment throughout a longer period in infant development, with age also playing a critical role. Moreover, with age, the relationship between language and cognition becomes bi-directional and more complex (Kuhn *et al.*, 2014). It could be argued, for instance, that the group differences emerging in our study are in fact due to, for example, poorer cognitive skills in the ASD group. However, this seems unlikely, as gesture impairment (i.e. lower gesture rate than TD) has been reported in ASD regardless of the level of cognitive skills (Attwood *et al.*, 1988). Similarly, comparative studies have shown differences in declarative gesture production between ASD children (range = 2–3 years) and children with Down's syndrome and TD children, even when matched on IQ (Mastrogiuseppe *et al.*, 2015; Özçalışkan *et al.*, 2016, 2017).

To conclude, the direct positive influence of cognition on expressive language in the ASD group suggests that cognitive skills play a fundamental role in communicative development and may adjust the weight of pointing gestures in language acquisition. As a matter of fact, a recent study on pointing and language development in William's syndrome showed that pointing gesture production is not a prerequisite for language development, as these children produce referential language before their pointing onset (Becerra & Mervis, 2019). Pointing production scaffolds language, but pointing in turn, needs the mastery of foundational cognitive skills. The central role of cognition in language acquisition serves as a reminder of the fact that language is not acquired in isolation, but rather develops in rich situated environments, where multiple skills are acquired simultaneously, scaffolding and influencing each other. Recent research (Donnellan *et al.*, 2020) indicates that very young infants can coordinate vocalisations and gestures with gaze to their caregiver's face at above chance rates, indicating that they are plausibly intentionally communicative, and that it is such coordinated behaviours which predict expressive language outcomes later. Importantly, the regression analysis of the sample as a whole also identifies index finger pointing total score and percentage of no contact pointing bids as key predictors of expressive language measured 1 year apart. This finding highlights the importance of the features of gesture morphology selected for the current study and their relevance for disentangling different aspects of deictic gesture production.

Our data serve to highlight that general cognition and joint attention are important skills supporting language which work hand in hand in the development of expressive communicative abilities in children with autism. Therefore, both components should be targeted for early clinical intervention to enhance the processes involved in language use in this population. The age range in our sample, however, should offer a cautionary note for the generalisation of these findings. Future long-term longitudinal studies with younger samples should aid in identifying the exact developmental window in which these skills emerge and interact, in order to ensure suitable assessment and practice.

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How to cite this article: Sara, R., Joana, A., Valentin, V., Mila, V. (2022) You may point, but do not touch: Impact of gesture-types and cognition on language in typical and atypical development. *International Journal of Language & Communication Disorders*, 57:324–339. https://doi.org/10.1111/1460-6984.12697