Full title: YOU MAY POINT, BUT DO NOT TOUCH: IMPACT OF GESTURE-TYPES AND COGNITION ON LANGUAGE IN TYPICAL AND ATYPICAL DEVELOPMENT

Short title: The impact of pointing and cognition on language in TD and ASD

Sara Ramos-Cabo¹, Joana Acha², Valentin Vulchanov¹ and Mila Vulchanova¹

¹Language Acquisition and Language Processing Lab, Department of Language and Literature, Norwegian University of Science and Technology, 7491 Trondheim, Norway.

²Department of Basic Cognitive Processes and their Development, Faculty of Psychology, University of The Basque Country, 20018 Donostia, Spain.

Corresponding author:

Mila Vulchanova

e-mail: mila.vulchanova@ntnu.no

Language Acquisition and Language Processing Lab, Department of Language and Literature, Norwegian University of Science and Technology, 7491 Trondheim, Norway

Abstract

This study investigated whether two types of pointing hand features (index finger and open palm pointing) and three types of relation with the referent (manipulation, contact, no contact) similarly predict language in children with and without autism, and whether cognition mediates the longitudinal relationship between pointing and language development. Sixteen children with autism, thirteen children at high risk for autism, and eighteen typically developing children participated in an interactive gesture-elicitation task and were tested on standardized cognitive and expressive language batteries in a longitudinal design. Cognition was a significant and direct predictor of language skills in all groups. However, index finger pointing was a direct predictor of language in the autism group above and beyond cognition. In addition, *index finger* pointing total score and percentage of *no contact* pointing bids were key predictors of *expressive language* measured one year apart, once the effect of group, expressive language and cognition at Time 1 were controlled. Findings highlight the role of cognition in communicative development, but suggest a key role of index finger use in the longitudinal relationship between deictic gestures and language atypical development above and beyond cognition.

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

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 [1-3]. The distinctive use of hand for communicative purposes signals infants' socio-cognitive development [4] and their readiness for spoken language acquisition (for a meta-analysis see [5]). 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 [6]. 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 [7]. *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 [8] and [9] 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. On the one hand, it seems that, at least in typically developing 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 [10-11]. Additionally, *pointing* with the index finger, as opposed to *open palm pointing*, has been shown to be strongly associated with vocalizations and declarative communicative intent in typical development (TD) [12-13] and in children with autism [8, 14, 15].

However, despite recent evidence of a differential interactive-communicative pattern in autism in terms of handshape and contact with the referent [16], no study has investigated the impact of these formal manual features on the language development of children diagnosed with

Autism Spectrum Disorder (ASD). Furthermore, although cognitive abilities are inherent to gestures, no study has explored the specific role of different features of gesture morphology and cognitive skills in the development of communicative abilities and spoken language in childhood. The aim of the current longitudinal study was to explore this relation in a sample of children diagnosed with autism, children at high risk for autism and typically developing children and to test whether this relation is independent from children's cognitive abilities.

The relation between hand features, cognition and language in typical development

Children's manual features have 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 [17], or executive functions linked to behavior regulation [18-19]. Studies with typically developing 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 hand movements to drive cognitive resources and high order mental abilities [20-22]. Also, cross-sectional regression studies have revealed that *conventional* and *deictic gestures* produced by children aged 3 to 5 during the execution of a card sorting task, are strong predictors of their executive functions above and beyond age [23-24]. This suggests that gestures can enhance high order cognitive processes by invoking a referent or action in the child's mind [25]. However, different gestures have been related with distinct high order abilities, suggesting that specific gesture, and hand features, in particular, might be distinctly related to specific aspects of cognition. For instance, while object manipulation has been related to object

perception and organization of self-directed actions [26, 19], conventional and deictic gestures are linked to attention directing actions and communicative functions [27-28].

Among communicative gestures, deictic gestures (pointing, showing, reaching or giving) have been shown to be specifically associated with the development of communicative abilities and language [12, 8, 29]). When children distance themselves from the object, the opportunity to use gestures for communicative purposes increases. Furthermore, Rohlfing et al. [28] 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 [11, 10]). Ramos Cabo et al. [16] argue that *pointing without contact* with the referent is based on more cognitively advanced mechanisms than *pointing with contact*. Developmental evidence suggests that pointing to distal objects emerges later than pointing within the infant's reach, which may involve touching the object [30]. Furthermore, Esseily, Jacquet, & Fagard [31] reported that, while *pointing handedness* is associated with an improved infant word production, *grasping handedness* does not yield the same effect. Supporting this claim, a very recent longitudinal study revealed that specifically *index finger pointing* in the first year of life predicted language skills by 5/6 years of age [32]. This is consistent with evidence supporting that *declarative pointing*, the type of *pointing* that is typically produced with an extended index finger, is the gesture primarily linked with communicative intent and spoken language acquisition [33-34]). A meta-analysis of 25 studies has established both a concurrent and longitudinal predictive relation between *declarative pointing* and spoken language acquisition [5]. In the reviewed studies, *pointing* onset and *pointing* quantity, in particular, predicted the onset of spoken language, and the amount of words produced by the child, respectively. However, the predictive power of pointing is rooted in the child's understanding of social intentions, and on the acquisition of complex social-cognitive abilities that allow reference-making [13].

Sustaining the view of specific social-cognitive abilities underlying *index finger pointing*, evidence has shown that this hand-feature is more tightly yoked to language acquisition than *imperative pointing* [13], a distal but open palm deictic gesture that infants use as a medium to obtain desired objects and is not an intrinsically communicative instrument [4]. Whilst the former is frequently paired with vocabulary spurt and early vocalizations [13, 12]), the latter correlates with object manipulation [35]. Although both gestures require taking distance from the referent, the fact that index finger pointing specifically predicts language in TD children supports the claim of this type of gesture as 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* [4]. Overall, the findings of studies of TD children illustrate that different types of hand configurations and distance from the object in deictic gestures might be key indicators of cognitive and communicative abilities in early development. Critically, these 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.

Interestingly, several studies have systematically reported that hand preference for object manipulation and hand preference for *pointing gestures* are not correlated, suggesting that structural differences in hand features in relation to the referent associate with distinct cognitive aims [36-37, 31]. Some authors suggest that while hand features involved in object manipulation might index individual object exploration, hand features involved in pointing might reveal referential intent related to an object [38]. 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 for the detection of the onset of communicative skills, particularly to detect those children at risk of specific difficulties in such skills, such as children with ASD.

Pointing, hand features and language in autism

Although the very first signs of early communicative development of infants who go on to receive an Autism Spectrum Disorders (ASD) diagnosis resemble the neurotypical pathway during the first two years of life [39-40], many studies have reported gesture impairments in ASD individuals later in development, and specifically, reduced gesture production in comparison to TD infants [41-43, 8]. The gestural decline coincides with the deterioration of cognitive and communicative abilities [44-45], which could explain why *declarative pointing* is the most impaired while *imperative pointing* is spared in ASD [46-49].

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 [50], but children on the spectrum catch up at around 3 years of age [43], suggesting that they might follow the same milestone patterns as TD toddlers, but with delays [51]. Consistent with this rationale of a shared developmental pattern with TD children, the commonly reported gesture-language relation in TD has been found also in ASD (for a review see [9]), with gestures predicting language also in children with autism [52-54]. However, only few studies address specifically the relationship between deictic gesture and language in autism, a clear gap in research identified in the scoping review by Manwaring and colleagues [15]. These studies have shown that only *deictic gestures* predicted language in ASD as well as in TD [8, 55, 14]. Not surprisingly, ASD children produce fewer deictic gestures than TD children, and this might account for the developmental lag.

On an assumption that *deictic gestures* are closely associated with language development, and given that they are impaired in ASD, one can expect lower production of spoken language in ASD in comparison with TD [42], and poorer coordination of gestures and vocalizations in this population [56]. This is important for two reasons: 1) the fact that children tend to use open palm gestures when interacting with their mothers [50, 8] clearly suggests that there is a distinct underlying communicative pattern in ASD, and 2) hand features are relevant in the prediction of spoken language abilities also in ASD. Additionally, there is recent evidence of impairment in *index finger pointing* in ASD [16], consistent with the previous evidence of impaired *declarative pointing* typically characterized by an extended index finger [46, 57]. However, the *imperative/declarative* categorization entails the subjective assessment of *pointing*, as it requires that the researcher infers whether the child has produced a *pointing gesture* with the purpose of communicating socially or with the purpose of obtaining something. The only scenario in which the *gesture* categorization based on the child's intentionality could be applied is in highly controlled experiments that would exclusively prompt *imperative* or *declarative gestures* according to the context. This imposes a limitation in the study of the gestural predictors of language, because it does not allow for the exploration of spontaneous gesture production during play- interactions. Despite the findings of a different *pointing gesture* pattern in ASD, and the close relation between *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 of TD children. There is an extensive literature supporting i) that the use of

gestures is inherent to the development of the child's cognitive skills, and ii) that there is a preeminence of some hand-features over others to predict language. However, given the vast amount of evidence showing a strong association between *pointing*, a cognitive and linguistic ability [58], 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 in children with autism [15].

The aim of the current study is twofold: (1) 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 [44]) and TD children, and (2) to explore the role of cognition in the relation between *pointing* and language. To this end, we used repeated measures of *pointing hand features* collected in a semi-structured interactive gesture-elicitation task, as well as standardized measures of cognitive abilities and expressive language collected simultaneously with the gesture elicitation task and one year later. The fine-grained *pointing* categorization 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.

Methods

Participants

The children in the current study participated in a longitudinal study on deictic communication (as part of a large-scale study within the Horizon2020 ITN *DCOMM*). The communicative development of three groups of children (ASD, HR and TD) was assessed longitudinally in two data collections over one year. The ASD group consisted of 16 children diagnosed with autism (14 boys, 2 girls) and with a mean age of 51,81 months (age range=35-72months; SD=10,45) at the first data collection (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 the parents of the ASD children at the first stage of the study. The HR group consisted of 13 children (6 boys, 7 girls) who had an older sibling with ASD and whose mean age at Time 1 was 36 months (age range=16-64months; SD=16,23). The TD group served as a control group, and consisted of 18 children (11 boys, 7 girls) with no history of developmental disorders and with a mean age of 37,72 months (age range=17-68months; SD=16) at the first stage of the study. 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. 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, $p = .771$, $MSE = 7519.61$. Children in the three groups were Spanish monolingual children from northern regions of the country with equivalent socio-cultural environments.

Pointing elicitation task

Pointing gestures were elicited in a caregiver-child interactive context using a task designed by Liszkowski, Brown, Callaghan, Takada and de Vos [59] that allows for a fine-grained formal analysis of spontaneous *pointing gestures*. For the task, caregivers and children were asked to look at and comment together on the stimuli displayed as colourful pictures and physical objects hanging on a wall. Adults were asked to carry their child or to hold their hand (for older children) while standing together in front of the set-up. They were encouraged to interact freely, and as they would normally do, with the only condition of not removing any object/picture from the wall. An important difference in the instruction in comparison to Liszkowski et al. [59] was allowing participants to touch the stimuli. This was done to observe the possible differences in communicative and non-communicative behaviours between the groups. Interactions were videotaped for subsequent coding.

Coding

Caregiver-child interactions were coded off-line using the software ELAN (<https://archive.mpi.nl/tla/elan>) [60]. In order to make interactions comparable across participants, a total of 5-minute interactions 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.

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 categorized as *object manipulation* are touching, tapping, caressing and squeezing. For index finger and open palm measures total raw scores were calculated in the present study. Percentage scores rather than raw scores were used for contact/no contact and object manipulation.

Coding reliability

A randomly selected 36% of the data (37,5% of the data of the ASD group, 46,15% HR and 33,33% of the TD group) was coded by an independent second coder to assess inter-coder reliability. Agreement reached 88.9% (Cohen's Kappa; $\kappa = 0.867$) for a total of 425 categorized behaviours including *object manipulation and pointing gestures*.

Standardized 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 [61]. All participants were individually tested by trained psychologists. The Cognition battery consists of 6 short subscales (the cognitive, fine motor, comprehension, memory, speed of processing and the visuomotor subscale) with items assessing inductive and deductive reasoning, categorization, 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 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 one year later (Time2).

Results

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 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. 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 [62], which tested the mediation model using the bootstrapping procedure (with 5000 bootstrap samples) to estimate the 95% confidence interval (95 CI, for more details, see [63]). 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 (nor 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 [64]. 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). To identify full or partial mediation, the predictor variable and the mediators were entered together into a final regression model. In total 2 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. Hypothesized 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

Descriptive statistics and correlational analyses

Descriptive statistics for all variables at each time point are shown in Table 1. Data were screened for univariate 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 manipulation* in TD. Skewness and kurtosis values for all measures indicated normal distributions of scores, with two estimates exceeding 2 (the values for *contact pointing* in HR, and *open palm pointing* in TD).

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

<i>Type of hand movement</i>	<i>Mean</i>	<i>SD</i>	<i>Reliability</i>	<i>Skew</i>	<i>Kurtosis</i>
ASD					
Index finger pointing	6.75	5.55	0.69	.69	.52
Open palm pointing	2.00	2.76	0.23	1.52	1.51
Contact pointing	3.56	3.48	0.26	1.29	.91
No contact pointing	5.19	4.69	0.75	1.07	1.12
Object manipulation	7.31	6.69	0.64	-1.08	.10
Cognition	106.7	39.8	0.37	.36	.56
Expressive language T1	11.56	15.7	0.28	1.7	2.9
Expressive language T2	15.08	12.5	0.29	.03	-1.72

HR

Index finger pointing	18.06	13.44	0.53	.88	-.12
Open palm pointing	1.94	2.04	0.35	.73	-.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	-.17	-.94
Cognition	132.1	48.1	0.30	-.05	-1.7
Expressive language T1	13.23	12.51	0.28	.22	-1.82
Expressive language T2	28.06	7.63	0.31	-1.84	3.93

TD

Index finger pointing	10.85	8.68	0.27	.82	-.40
Open palm pointing	1.92	3.17	0.51	3.05	10.15
Contact pointing	6.62	8.11	0.70	1.04	-.35
No contact pointing	7.15	3.73	0.27	.07	-.08
Object manipulation	8.26	7.12	0.69	.29	-1.24
Cognition	123.1	49.3	0.35	-.09	-1.48
Expressive language T1	16.55	14.21	0.32	-.04	-1.89
Expressive language T2	21.69	11.45	0.29	-.93	-.17

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*, $r(44) = .71$; and with *no contact pointing*, $r(44) = .79$. This analysis also reflected a significant relation between *cognition* at Time 1 and expressive language at Time 1, $r(44) = .71$, and Time 2, $r(44) = .78$. Both index finger pointing and no contact pointing were significantly associated with expressive language at Time 2, $r(44) = .32$ and $r(44) = .38$, respectively.

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	.717**	-						
3. Expressive Language 2	.789**	.562**	-					
4. Index finger pointing	.073	-.007	.327*	-				
5. Open palm pointing	-.014	.000	-.005	.081	-			
6. Contact pointing	-.159	-.220	.086	.719**	.308*	-		
7. No contact pointing	.249	.197	.386**	.786**	.161	.195	-	
8. Object manipulation	-.377**	-.278	-.391	.099	.204	.279	-.052	-

Note. Sample $N=47$. Values represent correlations of all measures at Time 1 and expressive language at Time 2.

* $p \leq .05$; ** $p \leq .01$.

All correlation coefficients except the ones mentioned were below .050. In addition, all variance inflation factors in the conducted regressions were below 2. This suggests that multicollinearity was not overly problematic in this study [65].

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 standardized 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. Age and gender were not included since previous analyses demonstrated that they did not have any predictive power on Expressive language at either Time 1 or 2. *Cognition* accounted for a large proportion of the variance (77%), whilst group and Expressive language at Time 1 did not account for any variance. From the predictors entered in Step 2, *no contact pointing* accounted for additional variance in Expressive language (78%). This was followed by *index finger pointing* (27%). Whilst these hand features were positively related to language outcome, contact pointing showed a negative relation and accounted for 39% 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: Group	.634	.634	24.83**	.105	1.12	.267
Cognition 1				.772**	5.75	.000
Expr Lang 1				.002	0.13	.990
Step 2: Index finger	.696	.062	50.39**	.271**	3.24	.002
Open palm				.006	.070	.945
Contact				-.39**	-2.85	.009
No contact				.780**	8.58	.001
Object manip.				-.108	-1.09	.278

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 children. Unstandardized parameter estimates for specific direct and indirect effects per group are presented. Bootstrapped confidence intervals 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 included the *no contact* variable as predictor in the model. Results of this mediation analysis revealed that in the three groups only cognition was a predictor of Expressive language, in ASD $\beta = .274$; $p = .000$ (95% bcBootCI = .175 to .372); in TD $\beta = .123$; $p = .005$ (95% bcBootCI = .064 to .182), and in HR $\beta = .212$; $p = .001$ (95% bcBootCI = .136 to .288). In no group neither direct, nor indirect, effect of no contact hand-features on expressive language was found. The second mediation analysis included the index finger variable as predictor in the model. Results of this mediation analysis are depicted in Figure 2. In the ASD children group, the explained variance of total *index finger* on language in the model was $R^2=.75$, in the HR sibling group was $R^2=.71$, and in the TD group the variance explained in the model was $R^2=.80$. In the three groups, most variance in the model was explained by *cognition* at Time 1, although specific differential effects of *index pointing* on language were found in each group. In the ASD group, there was a significant direct effect of *cognition* ($R^2=.64$), as well as of *index finger pointing* on *expressive language* at Time 2 ($R^2=.14$). 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 ASD children. This effect was only observed in the ASD group.

Figure 2. Specified models for bootstrapped mediation analyses in each group (unstandardized coefficients)

Discussion

In a longitudinal design, the current study investigated the predictive role of different gesture types 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 high risk for autism and typically developing children, as well as the mediating role of cognition in this predictive relationship. Our results argue in favour of a key role of 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 that two structural gesture variables - index finger vs open palm use, and distal (with no contact) or proximal (potentially with contact) relation to the referent - might explain differences in language attainment [35, 31, 11], our first aim was to explore the extent to which these variables predicted expressive language longitudinally in a sample of ASD, TD and HR children. Extant research suggests a tight relationship between gesture production and subsequent language development in both typically developing children and children on the autism spectrum [9, 66]. There is also evidence that TD infants point more often with the index finger when they vocalize [13], and they use *no contact pointing* when they interact with their caregivers in social contexts. We therefore developed a formal classification system of gesture features for the analyses in the current study (see for details [16]). 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 use of index finger. Moreover, these features allow to distinguish aspects of gesture production between children with

and at-risk for autism, and typically developing children [16]. 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 [24, 38], this variable was entered as control in the analysis together with group and expressive language at Time 1. Results revealed that most of the variance explained in the regression was due to cognition. This effect is not surprising given the link found in previous studies between specific aspects of cognition, such as (joint) attention, working memory and executive abilities and language (see [67-68]). Not surprisingly, the cognition composite employed in our study included the basic cognitive mechanisms that support language. However, our analysis also revealed that *index finger* pointing total score and percentage of *no contact* pointing bids were key predictors of *expressive language* measured one 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 supporting *index finger pointing* as closely associated with linguistic attainment [12-13], and studies that demonstrate a dissociation between *object manipulation* and communicative behaviours [35, 31]. 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 communicative development, specifically in situations that require social interaction. There is also indication that object manipulation may be associated with an earlier stage in cognitive development [69]. Another important finding was the negative relation between the *contact* hand feature and expressive language one 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 [70].

Our second aim was to assess whether the observed predictors of expressive language - *index finger* and *no contact* pointing- directly impacted on linguistic attainment or whether this relation was mediated by cognitive skills (indirect relation) in each group. Our data revealed that: a) in all groups cognition at Time 1 directly predicted expressive language at Time 2, b) only in ASD children *index finger* was a direct predictor of expressive language and c) *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 [47-49, 16], but also display a delayed pointing onset [50, 43], we hypothesized 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 [17, 58], we expected that *cognition* could serve as a mediator in the *pointing hand feature*-language relation in all groups (Path b-c' in Fig. 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 all groups. 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 first important finding in the current analyses is the difference between children with autism, on the one hand, and typically developing children and children at high risk, on the other. Notably, the two latter groups were matched on age, and the 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. 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 [71-72]. The independent role of pointing gesture and cognition for expressive language in the children with autism may indicate that the development of these two cognitive domains is not temporally synchronized 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 [73-74]. However, children on the autism spectrum 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 [16]. 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 [8]. 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 [75].

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 typically developing children and the HR children in our sample had already passed, while the ASD group are still at this stage, due to the developmental delay. Colonna et al. [5] 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 drastically, 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 [13]. However, it is important to note that, while the strength of the current study is its longitudinal design, the relatively small sample size should be considered as a limitation. It is possible that the lack of effect observed in the HR and TD groups may be 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 ASD and HR and TD, *cognition* consistently predicted language in all groups. This might suggest that unlike *index finger pointing*, whose language predictor role might be restricted to an specific point in time, cognitive abilities might support linguistic attainment throughout a longer period in infant development. Moreover, with age, the relationship between language and cognition becomes bi-directional and more complex [76]. It could be argued, for instance, that the group differences emerging in our study are in fact due to e.g., 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 [42]. 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 [8, 54, 47].

To conclude, the direct positive influence of *cognition* on *expressive language* in all groups 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 [77]. *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 an isolation, but rather develops in rich situated environments, where multiple skills are acquired simultaneously, scaffolding and influencing each other. Recent research [78] indicates that very young infants can coordinate vocalizations 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 one year apart, once the effect of group, expressive language and cognition at Time 1 are controlled. 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.

Acknowledgements

The authors gratefully acknowledge funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No. 676063 (DCOMM, "Deictic Communication", <http://www.dcomm.eu>). SR-C is grateful to Alba Perez, for her help with data collection. Special thanks go to the personnel of Escuela Infantil

Anduva (Miranda de Ebro), Asociación APTACAN (Santander), Colegio Altamira (Revilla de Camargo), Asociación ARPA (Logroño), Autismo Valladolid, and to the families that participated in this research.

References

1. Camaioni, L. The emergence of intentional communication in ontogeny, phylogeny and pathology. *European Psychologist*. 1997; 2, 216–225.
2. Liszkowski U, Carpenter M, Henning A, Striano T, Tomasello M. Twelve-month-olds point to share attention and interest. *Developmental Science*. 2004; 7: 297–307.
3. Liszkowski U, Carpenter M, Tomasello M. Twelve-month-olds communicate helpfully and appropriately for knowledgeable and ignorant partners. *Cognition*. 2008; 108: 732–739.
4. Tomasello M, Carpenter M, Liszkowski U. A new look at infant pointing. *Child Development*. 2007; 78: 705– 22. DOI:10.1111/j.1467-8624.2007.01025.x
5. Colonnese C, Stams GJJM, Koster I, Noom MJ. The relation between pointing and language development: a meta-analysis. *Dev. Rev.* 2010; 30: 352–366. doi: 10.1016/j.dr.2010.10.001.
6. Kita S. *Pointing. Where language, culture, and cognition meet*. 2003; Mahwah, NJ: Lawrence Erlbaum.
7. Wing L, Gould J, Yeates SR, Brierly LM. Symbolic play in severely mentally retarded and in autistic children. *Journal of Child Psychology and psychiatry*. 1977; 18(2): 167-178.
8. Özçaliskan S, Adamson LB, Dimitrova N. Early deictic but not other gestures predict later vocabulary in both typical development and autism. *Autism*. 2016; 20: 754–763. doi: 10.1177/1362361315605921
9. Ramos-Cabo S, Vulchanov V, Vulchanova M. Gesture and language trajectories in early development: An overview from the autism spectrum disorder perspective. *Frontiers in Psychology*. 2019; 10, 1211. <https://doi.org/10.3389/fpsyg.2019.01211>

10. Murillo E, Belinchón M. Gestural-vocal coordination: Longitudinal changes and predictive value on early lexical development. *Gesture*. 2012; 12(1): 16-39. Doi: 10.1075/gest.12.1.02mur
11. Sado VC, Rowe ML, Reeb-Sutherland BC. Exploring infant gesture and joint attention as related constructs and as predictors of later language. *Infancy*. 2018; 23(3): 432-452. Doi: 10.1111/infa.12229
12. Cochet H, Vauclair J. Pointing gestures produced by toddlers from 15 to 30 months: Different functions, hand shapes and laterality patterns. *Infant Behaviour and Development* 2010; 33: 431–441. doi:10.1016/j.infbeh.2010.04.009.
13. Liszkowski U, Tomasello M. Individual differences in social, cognitive, and morphological aspects of infant pointing. *Cognitive Development*. 2011; 26: 16–29. doi: 10.1016/j.cogdev.2010.10.001
14. Dimitrova N, Mohr C, Özçalışkan S, Adamson LB. (2020). Early Lateralization of Gestures in Autism: Right-Handed Points Predict Expressive Language. *Journal of Autism and Developmental Disorders*. 2020; 50(4): 1147-1158. doi: 10.1007/s10803-019-04347-9.
15. Manwaring SS, Swineford L, Mead DL, Yeh CC, Zhang Y, Thurm A. The gesture–language association over time in toddlers with and without language delays. *Autism & Developmental Language Impairments*. 2019; 4: 1-15. doi: 10.1177/2396941519845545
16. Ramos-Cabo S, Vulchanov V, Vulchanova M. Different Ways of Making a Point: A Study of Gestural Communication in Typical and Atypical Early Development. (under revision).
17. Wing L. Language, social, and cognitive impairments in autism and severe mental retardation. *Journal of autism and developmental disorders*. 1981; 11(1): 31-44.
18. Bruner J. The social context of language acquisition. *Language & Communication*, 1981; 1 (2–3) : 155-178. [https://doi.org/10.1016/0271-5309\(81\)90010-0](https://doi.org/10.1016/0271-5309(81)90010-0).
19. Rodríguez C, Estrada L, Moreno-Llanos I, de los Reyes J L. (2017). Executive Functions and educational actions in an infant school: private uses and gestures at the end of the first year. *Studies in Psychology*. 2017; 38(2): 385-423. Doi: 10.1080/02109395.2017.1305061
20. Beilock SL, Goldin-Meadow S. (2010). Gesture changes thought by grounding it in action. *Psychological science*. 2010; 21(11): 1605-1610.

21. Broaders SC, Cook SW, Mitchell Z, Goldin-Meadow S. (2007). Making children gesture brings out implicit knowledge and leads to learning. 2017; *Journal of Experimental Psychology: General*, 136(4): 539.
22. Goldin-Meadow S, Beilock SL. Action's influence on thought: The case of gesture. *Perspectives on psychological science*. 2010; 5(6): 664-674.
23. O'Neill G, Miller PH. A show of hands: Relations between young children's gesturing and executive function. *Developmental Psychology*. 2013; 49(8): 1517.
24. Rhoads CL, Miller PH, Jaeger GO. Put your hands up! Gesturing improves preschoolers' executive function. *Journal of experimental child psychology*. 2018; 173: 41-58.
25. Novack M, Goldin-Meadow S. Learning from gesture: How our hands change our minds. *Educ Psychol Rev*. 2015; 27(3): 405–412. doi:10.1007/s10648-015-9325-3.
26. McCarty, M. E., Clifton, R. K., & Collard, R. R. The beginnings of tool use by infants and toddlers. *Infancy*. 2001; 2(2): 233-256.
27. Rowe ML, Goldin-Meadow S. Early gesture selectively predicts later language learning. *Developmental science*. 2009; 12(1): 182-187. Doi: 10.1111/j.1467-7687.2008.00764.x
28. Rohlfing KJ, Grimminger A, Lüke C. An interactive view on the development of deictic pointing in infancy. *Frontiers in Psychology*. 2017; 8: 1319. Doi: 10.3389/fpsyg.2017.01319
29. Romano MK, Windsor KS. (2020). Increasing deictic gesture use to support the language development of toddlers from high poverty backgrounds. *Early Childhood Research Quarterly*. 2020; 50: 129-139. Doi: 10.1016/j.ecresq.2018.12.004
30. Butterworth G. "Pointing is the royal road to language for babies" in *Pointing: Where language, culture, and cognition meet*. ed. S. Kita (Mahwah, NJ: Lawrence Earlbaum Associates). 2003; 9–33.
31. Esseily R, Jacquet AY, Fagard J. Handedness for grasping objects and pointing and the development of language in 14-month-old infants. *Laterality*. 2011; 16(5): 565–585. doi:10.1080/1357650X.2010.499911

32. Lüke C, Ritterfeld U, Grimminger A, Rohlfsing KJ, Liszkowski U. Integrated Communication System: Gesture and Language Acquisition in Typically Developing Children and Children with LD and DLD. *Frontiers in Psychology*. 2020 11: 118. DOI=10.3389/fpsyg.2020.00118
33. Blake J, Vitale G, Osborne P, Olshansky E. A cross-cultural comparison of communicative gestures in human infants during the transition to language. *Gesture*. 2005; 5: 201–217.
34. Camaioni L, Perucchini P, Bellagamba F, Colonnese C. (2004). The role of declarative pointing in developing a theory of mind. *Infancy*. 2004; 5: 291–308.
35. Cochet H, Jover M, Vauclair J. (2011). Hand preference for pointing gestures and bimanual manipulation around the vocabulary spurt period. *Journal of Experimental Child Psychology*. 2011; 110: 393– 407. <https://doi.org/10.1016/j.jecp.2011.04.009>
36. Bates E, O'Connell B, Vaid J, Sledge P, Oakes L. (1986). Language and hand preference in early development. *Developmental Neuropsychology*. 1986; 2(1): 1-15.
37. Jacquet AY, Esseily R, Rider D, Fagard J. Handedness for grasping objects and declarative pointing: a longitudinal study. *Dev Psychobiol*. 2012; 54(1): 36–46. doi:10.1002/dev.20572
38. Vauclair J, Imbault J. Relationship between manual preferences for object manipulation and pointing gestures in infants and toddlers. *Developmental Science*. 2009; 12(6): 1060-1069.
39. Rogers SJ. What are infant siblings teaching us about autism in infancy? *Autism Res*. 2009; 2: 125-137. doi:10.1002/aur.81.
40. Iverson JM, Northrup JB, Leezenbaum NB, Paradé MV, Koterba EA, West KL. Early gesture and vocabulary development in infant siblings of children with autism spectrum disorder. *J. Autism Dev. Disord*. 2017; 48: 55–71. doi: 10.1007/s10803-017-3297-8
41. Mundy P, Sigman M, Ungerer J, Sherman T. Defining the social deficits of autism: the contribution of non-verbal communication measures. *J. Child Psychol. Psychiatry*. 1986; 27: 657–669. doi: 10.1111/j.1469-7610.1986.tb00190.x
42. Attwood A, Frith U, Hermelin B. (1988). The understanding and use of interpersonal gestures by autistic and Down's syndrome children. *J. Autism Dev. Disord*. 1988; 18: 241–257. doi: 10.1007/BF02211950
43. LeBarton ES, Iverson JM. Gesture development in toddlers with an older sibling with autism. *Int. J. Lang. Commun. Disord*. 2016; 51: 18–30. doi: 10.1111/1460-6984.12180

44. Ozonoff S, Iosif AM, Baguio F, Cook IC, Hill MM, Hutman T, et al. A prospective study of the emergence of early behavioral signs of autism. *J. Am. Acad. Child Adolesc. Psychiatry*. Retrieved from PMC2923050. 2010; 49: 256–266.e1-2. doi: 10.1097/00004583-201003000-00009
45. Bussu G, Jones EJH, Charman T, Johnson MH, Buitelaar JK, Baron- Cohen S. et al. (2018). Prediction of autism at 3 years from behavioural and developmental measures in high-risk infants: a longitudinal cross-domain classifier analysis. *J. Autism Dev. Disord.* 2018; 48: 2418–2433. doi: 10.1007/s10803-018-3509-x
46. Baron-Cohen S. (1989). Perceptual role taking and protodeclarative pointing in autism. *Br. J. Dev. Psychol.* 1989 ; 7: 113–127. doi: 10.1111/j.2044-835X.1989.tb00793.x
47. Mastrogiuseppe M, Capirci O, Cuva S, Venuti P. Gestural communication in children with autism spectrum disorders during mother-child interaction. *Autism*. 2015; 19: 469–481. doi: 10.1177/1362361314528390
48. Veness C, Prior M, Bavin E, Eadie P, Cini E, Reilly S. Early indicators of autism spectrum disorders at 12 and 24 months of age: a prospective, longitudinal comparative study. *Autism: the international journal of research and practice*. 2012; 16(2): 163–177. <https://doi.org/10.1177/1362361311399936>
49. Zwaigenbaum L, Bryson S, Rogers T, Roberts W, Brian J, Szatmari P. (2005). Behavioral manifestations of autism in the first year of life. *International Journal of Developmental Neuroscience*. 2005; 23(2-3): 143–152. DOI: 10.1016/j.ijdevneu.2004.05.001
50. Camaioni L, Perucchini P, Muratori F, Parrini B, Cesari A. (2003). The communicative use of pointing in autism: developmental profile and factors related to change. *European Psychiatry*. 2003; 18(1): 6-12. doi: 10.1016/s0924-9338(02)00013-5.
51. Özçalışkan, Ş., & Dimitrova, N. How gesture input provides a helping hand to language development. *Semin. Speech Lang.* 2013; 34: 227–236. doi: 10.1055/s-0033-1353447
52. Tager-Flusberg H, Calkins S, Nolin T, Baumberger T, Anderson M, Chadwick-Dias A. (1990). A longitudinal study of language acquisition in autistic and Down syndrome children. *J. Autism Dev. Disord.* 1990; 20: 1–21. doi: 10.1007/BF02206853

53. Ingersoll B, Lalonde K. (2010). The impact of object and gesture imitation training on language use in children with autism spectrum disorder. *J. Speech Lang. Hear. Res.* 2010; 53: 1040–1051. doi: 10.1044/1092-4388(2009/09-0043)
54. Özçalışkan Ş, Adamson LB, Dimitrova N, Baumann S. Early gesture provides a helping hand to spoken vocabulary development for children with autism, down syndrome, and typical development. *J. Cogn. Dev.* 2017; 18: 325–337. doi: 10.1080/15248372.2017.1329735
55. Ökcün-Akçamuş MÇ, Acarlar F, Keçeli Kaysili B, Alak G. Examination of the relationship between gestures and vocabulary in children with autism spectrum disorder at different language stages. *Early Child Dev. Care.* 2017; 4430: 1–15. doi: 10.1080/03004430.2017.1344233
56. Paradé MV, Iverson JM. The Development of Coordinated Communication in Infants at Heightened Risk for Autism Spectrum Disorder. *J Autism Dev Disord.* 2015; 45: 2218–2234. <https://doi.org/10.1007/s10803-015-2391-z>
57. Goodhart F, Baron-Cohen S. (1993). How many ways can the point be made? Evidence from children with and without autism. *First Lang.* 1993; 13: 225–233. doi: 10.1177/014272379301303804
58. Manwaring SS, Mead DL, Swineford L, Thurm A. Modelling gesture use and early language development in autism spectrum disorder. *International Journal of Language and Communication Disorders.* 2017; 52 637-651. <https://doi.org/10.1111/1460-6984.12308>
59. Liszkowski U, Brown P, Callaghan T, Takada A, de Vos C. (2012). A Prelinguistic Gestural Universal of Human Communication. *Cognitive Science.* 2012; 36(4): 698-713. doi: 10.1111/j.1551-6709.2011.01228.x
60. ELAN (Version 5.8) [Computer software]. (2019). Nijmegen: Max Planck Institute for Psycholinguistics, The Language Archive. Retrieved from <https://archive.mpi.nl/tla/elan>
61. Roid G, Sampers J. MP-R Escalas de desarrollo Merrill-Palmer revisadas. 2011; Madrid: TEA Ediciones.
62. Hayes AF. Methodology in the social sciences. Introduction to mediation, moderation, and conditional process analysis: A regression-based approach. 2013; Guilford Press.

63. Preacher KJ, Hayes AF. Asymptotic and resampling strategies for assessing and comparing indirect effects in multiple mediator models. *Behavior Research Methods*. 2008; 40: 879–891. <https://doi.org/10.3758/BRM.40.3.879>
64. Williams J, MacKinnon DP. Resampling and Distribution of the Product Methods for Testing Indirect Effects in Complex Models. *Structural Equation Modeling: A Multidisciplinary Journal*. 2008; 15(1): 23-51. DOI: 10.1080/10705510701758166
65. Tabachnick BG, Fidell LS. *Using Multivariate Statistics* (3rd ed.). 1996; New York: Harper Collins.
66. Gulsrud, A. C., Hellemann, G. S., Freeman, S. F., & Kasari, C. (2014). Two to ten years: Developmental trajectories of joint attention in children with ASD who received targeted social communication interventions. *Autism Research*, 7(2), 207-215.
67. de Abreu PMJE, Gathercole SE, Martin R. (2011). Disentangling the relationship between working memory and language: The roles of short-term storage and cognitive control. *Learning and Individual Differences*. 2011; 21(5): 569-574. Doi: 10.1016/j.lindif.2011.06.002
68. Gray S, Green S, Alt M, Hogan T, Kuo T, Brinkley S, Cowan N. The structure of working memory in young children and its relation to intelligence. *Journal of Memory and Language*. 2017; 92: 183-201. Doi: 10.1016/j.jml.2016.06.004
69. Charman T, Baron-Cohen S, Swettenham J, Baird G, Cox A, Drew A. (2000). Testing joint attention, imitation, and play as infancy precursors to language and theory of mind. *Cognitive development*. 2000; 15(4): 481-498.
70. Honey E, Leekam S, Turner M, McConachie H. Repetitive behaviour and play in typically developing children and children with autism spectrum disorders. *Journal of autism and developmental disorders*. 2007; 37(6): 1107-1115. Doi: 10.1007/s10803-006-0253-4
71. Zambrana I.M, Ystrom E, Schjølberg S, Pons F. Action imitation at 1½ years is better than pointing gesture in predicting late development of language production at 3 years of age. *Child development*. 2013; 84(2): 560-573. Doi: 10.1111/j.1467-8624.2012.01872.x
72. Watt N, Wetherby A, Shumway S. (2006). Prelinguistic predictors of language outcome at 3 years of age. *Journal of Speech, Language, and Hearing Research*. 2006; 49(6): 1224-37. Doi: 10.1044/1092-4388(2006/088)

73. Charman T, Baron-Cohen S, Swettenham J, Baird G, Drew A, Cox, A. Predicting language outcome in infants with autism and pervasive developmental disorder. *Int J Lang Commun Disord.* 2003; 38(3): 265–285. doi:10.1080/136820310000104830
74. Mundy P, Sigman M, Kasari C. A longitudinal study of joint attention and language development in autistic children. *J Autism Dev Disord.* 1990; 20(1): 115–128. doi:10.1007/bf02206861
75. Vulchanova M, Chahboun S, Galindo-Prieto B, Vulchanov V. Gaze and Motor Traces of Language Processing: Evidence from Autism Spectrum Disorders in Comparison to Typical Controls. *Cognitive Neuropsychology.* 2019; 36: 7-8, 383-409. DOI: 10.1080/02643294.2019.1652155
76. Kuhn LJ, Willoughby MT, Wilbourn MP, Vernon-Feagans L, Blair CB, Family Life Project Key Investigators. (2014). Early communicative gestures prospectively predict language development and executive function in early childhood. *Child Development.* 2014; 85: 1898–1914.
77. Becerra AM, Mervis CB. (2019). Age at Onset of Declarative Gestures and 24-Month Expressive Vocabulary Predict Later Language and Intellectual Abilities in Young Children With Williams Syndrome. *Frontiers in Psychology.* 2019; 10: 2648 <https://doi.org/10.3389/fpsyg.2019.02648>
78. Donnellan E, Bannard C, McGillion ML, Slocombe KE, Matthews D. (2019). Infants' intentionally communicative vocalizations elicit responses from caregivers and are the best predictors of the transition to language: a longitudinal investigation of infants' vocalizations, gestures and word production. *Developmental Science.* 2019; e12843. doi:10.1111/desc.12843