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Do verbal children with autism comprehend gesture as readily as typically developing children?

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Abstract

Gesture comprehension remains understudied, particularly in children with autism spectrum disorder (ASD) who have difficulties in gesture production. Using a novel gesture comprehension task, study 1 examined how 2- to 4-year-old typically-developing (TD) children comprehend types of gestures and gesture-speech combinations, and showed better comprehension of deictic gestures and reinforcing gesture-speech combinations than iconic/conventional gestures and supplementary gesture-speech combinations at each age. Study 2 compared verbal children with ASD to TD children, comparable in receptive language ability, and showed similar patterns of comprehension in each group. Our results suggest that children comprehend deictic gestures and reinforcing gesture-speech combinations better than iconic/conventional gestures and supplementary combinations—a pattern that remains robust across different ages within TD children and children with ASD.

Keywords: gesture, gesture comprehension, gesture production, autism, iconicity, gesture-speech combination

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Gesture comprehension remains understudied, particularly in children with autism spectrum disorder (ASD) who have difficulties in gesture production. Using a novel gesture comprehension task, study 1 examined how 2- to 4-year-old typically-developing (TD) children comprehend types of gestures and gesture-speech combinations, and showed better comprehension of deictic gestures and reinforcing gesture-speech combinations than iconic/conventional gestures and supplementary gesture-speech combinations at each age. Study 2 compared verbal children with ASD to TD children, comparable in receptive language ability, and showed similar patterns of comprehension in each group. Our results suggest that children comprehend deictic gestures and reinforcing gesture-speech combinations better than iconic/conventional gestures and supplementary combinations—a pattern that remains robust across different ages within TD children and children with ASD.

Gesture is pervasive in human communication (McNeill, 1992). Adults, including parents and teachers, frequently gesture when they talk to children, providing substantive information not found in their speech (Iverson, Capirci, Longobardi, & Caselli, 1999; Özçalışkan & Goldin-Meadow, 2005a, 2006). The use of such gestures, in turn, leads to more positive developmental outcomes—from enhancing gesture use at the early ages (LeBarton, Raudenbush, & Goldin-Meadow, 2015) to mastering new math concepts at the later ages (Singer & Goldin-Meadow, 2005)— rendering comprehension of gesture as a key component of learning throughout development. While gesture production has been the focus of much research over the last few decades, comprehension of gesture, particularly in children with autism spectrum disorder (ASD) who have difficulties in learning to produce gestures (Mundy, Sigman, Ungerer, & Sherman, 1986), remains largely unexamined. In this study, we aim to fill this gap by providing a comprehensive account of gesture comprehension in two groups of children—typically developing (TD) children and children with ASD, using a novel gesture comprehension task in two studies.

In study 1, we first ask whether 2,- , 3-, and 4-year-old TD children's comprehension of different types of gestures and gesture-speech combinations follows the same developmental pattern that has been documented for gesture production (e.g., Özçalıskan & Goldin-Meadow, 2005a) such that deictic gestures (e.g., point at cup) and reinforcing gesture-speech combinations (e.g., "bike"+ point at bike) are easier to comprehend than iconic gestures (e.g., flap arms for bird flying) and supplementary gesture-speech combinations (e.g., "ride"+point at bike). We next ask in study 2 whether the pattern of comprehension observed in TD children is also found for verbal children with ASD with comparable receptive language skills.

I.1. STUDY 1

Gesture Comprehension in Young Typically Developing Children

Gesture comprehension typically emerges early in development (Morford & Goldin-Meadow, 1992). However, research on comprehension of different types of gestures and gesture-speech combinations remains relatively scarce compared to the large literature that documents developmental changes in gesture production. In this study, we use a novel gesture comprehension task to probe how 2- to 4-year-old TD children comprehend different gesture types and gesture-speech combinations. Our primary hypothesis is that well-documented patterns found for gesture production would also be evident for gesture comprehension.

First, looking at production of *gesture types*, it has been well established that the majority of 1- to 2-year-old TD children rely primarily on deictic gestures (e.g., point at doll) to either indicate or request objects in their immediate environment (Bates, 1976; Bates, Benigni, Bretherton, Camaioni, & Volterra, 1979; Özçalışkan & Goldin-Meadow, 2005a). Shortly after, between ages two to three, children start producing iconic gestures more frequently to depict characteristic actions or attributes associated with objects (e.g., flapping arms to convey *flying*; Özçalıskan & Goldin-Meadow, 2011) and conventional gestures to convey culturally shared meanings with prescribed gesture forms (e.g., waving hand to mean *bye*; Iverson, Capirci, & Caselli, 1994). In terms of *communicative modality*, there is considerable evidence that TD children initially rely on gesture alone to communicate before they produce speech. However, beginning around age 1, they start to produce words—one at a time—and combine these words with gestures to first express the same information as speech (i.e., reinforcing combinations such as pointing at doll while saying "doll") and, later on, to add new information not found in speech (supplementary combinations, such as point at a doll while saying "play"; Butcher & Goldin-Meadow, 2000; Greenfield & Smith, 1976; Özçalıskan & Goldin-Meadow, 2005a, 2005b). The co-speech gestures in both of these gesture-speech combinations consist primarily of deictic gestures at the younger ages, but begin to include conventional and iconic gestures more frequently in the second to third year of life (Özçalıskan & Goldin-Meadow, 2005a, 2009).

There is mounting evidence that the development changes associated with comprehension of different gesture types and communicative modalities remain similar to the ones documented for gesture production and that the two processes are temporally associated. For example, in terms of *gesture types*, one-year–old children can successfully follow an adult's pointing gesture to an object (Carpenter, Nagell, Tomasello, Butterworth, & Moore, 1998; Scaife & Bruner, 1975) and can even understand the intent behind the pointing gesture as identifying the location of a hidden object (Behne, Liszkowski, Carpenter, & Tomasello, 2012). There is also evidence that children who themselves produce deictic gestures are also more likely to comprehend such deictic gestures (Behne et al. 2012; Woodward & Guajardo, 2002), suggesting a tight link between developmental trajectories for comprehension and production of deictic gestures. The comprehension of iconic gestures emerges slightly later than deictic gestures. Children increase their comprehension of iconic gestures between ages 2 to 3 (Namy, 2008; Namy, Campbell, & Tomasello, 2004; Stanfield, Williamson, & Özçalışkan, 2014)—roughly around the time they also increase their production (Özçalışkan, Gentner & Goldin-Meadow, 2014). One-and-half-year-old children do *not* show sensitivity to iconicity as evidenced by their equally likely tendency to associate either an iconic gesture (e.g., hopping V-shaped fingers up and down to represent a rabbit) or an arbitrary gesture (e.g., moving palm sideways to represent a rabbit) with an object. In contrast, 2-year-old children are reliably more likely to associate an iconic gesture than an arbitrary gesture with an object, showing increased sensitivity to iconicity in comprehension (Namy et al., 2004). Similar findings have been reported in studies where children were asked to identify the object associated with a novel iconic gesture not previously observed by the child. After seeing a simple action performed on a novel object, 2-year-olds—but *not* 1-year-olds, were able to identify the referent of an iconic gesture that symbolically depicted the same action (Namy, 2008).

Turning next to *communicative modalities*, we also find evidence that comprehension may follow a development pattern similar to that observed for gesture production. Children understand gesture-only utterances and reinforcing gesture-speech combinations—where gesture and speech convey the same information—earlier than supplementary combinations in which gesture and speech convey different information (Morford & Goldin-Meadow, 1992), following the pattern found in their production of such communicative modalities (Butcher & Goldin-Meadow, 2000; Greenfield & Smith, 1976). Moreover, the type of gesture embedded in a gesture-speech combination influences its comprehension. While 15-month-olds can successfully act on an object that was uniquely identified in a deictic gesture-speech combination (e.g., "open"+point at bag), 20-month-olds can do so even when presented with a conventional gesture that requests a referent ("ball"+give gesture; Morford & Goldin-Meadow, 1992). At a later age, when given an iconic co-speech gesture that expresses object information not found in speech (e.g., "I am eating"+move empty cupped hands in parallel as if holding a sandwich), 3-year-olds can correctly choose the picture of the referent expressed uniquely in an iconic gesture-speech combination (e.g., sandwich; Stanfield et al., 2014).

In summary, typically developing children produce *deictic* (e.g., point at cup) gestures earlier than c*onventional* gestures (e.g., flip palms outward to convey don't know) and *iconic* gestures (e.g., flap arms to convey bird; Özçalışkan et al., 2014). Similarly, children produce gesture-speech combinations in which gesture conveys the same information as speech (i.e., *reinforcing*, "cup"+point at cup) earlier than combinations in which gesture conveys additional information not found in speech (i.e., *supplementary*, “drink”+point at cup; Butcher & Goldin-Meadow, 2000).

There is considerable evidence that gesture comprehension might follow a similar developmental pattern but to date studies have focused either on a particular type of gesture (e.g., iconics; Namy et al., 2004; Stanfield et al., 2014) or gesture-speech combination (e.g., supplementary combinations; Hodges, Özçalışkan, & Williamson, 2015, 2017; Morford & Goldin-Meadow, 1992). Different from earlier work, this study aims to document comprehension of different gesture types across different communicative modalities over a broader age range (ages 1-to-4)—a period during which children show significant changes in their production and comprehension of gesture. We predict that children’s comprehension of gesture will follow a developmental pattern similar to its production, with better comprehension of deictic gestures and reinforcing gesture-speech combinations than iconic/conventional gestures and supplementary gesture-speech combinations at the earlier ages, followed by steady gains in gesture comprehension at the later ages.

I.2. Methods

Participants

The sample consisted of 41 children, including 13 two-year-olds (M_{age}=2;7[1], range= 2;2-2;11; 4 males), 15 three-year-olds (M_{age}=3;5, range= 3;00-3;11; 8 males), and 13 four-year-olds (M_{age}=4;6, range= 4;1-5;0; 5 males)—all learning English as their native language. The children had no known cognitive or linguistic impairments and scored within the typical range in the Social Responsiveness Scale (SRS; Constantino & Gruber, 2005; M=43.66; SD=4.75, range=34-56; cutoff for autism: 59). The majority of the children were Caucasian (58%) or African-American (32%); the remaining had mixed racial backgrounds (10%). The majority of the parents had either a college degree (49%), or a postgraduate degree (34%); all remaining parents had some college education (17%). Families received small monetary compensation for their child's participation. The sample of 41 children came from an original sample of 49 children; 8 children were excluded due to developmental concerns (e.g., scoring above cutoff on SRS, premature birth or stay in a neonatal intensive care unit; n=6) or due to experimental error (n=2).

Procedure

Each child was tested individually by an experimenter who was blind to the study's hypotheses. The experimenter first administered two standardized tests, one for receptive and one for expressive vocabulary, followed by the gesture comprehension task. Sessions took place either in a comfortable room in a university-based laboratory or in the child's home and lasted approximately 20 minutes.

Vocabulary assessment.

Each child was administered the Peabody Picture Vocabulary Test (PPVT-4; Dunn & Dunn, 2007) and the Expressive Language Test (EVT-2; Williams, 2007), which provide standardized assessments of children's receptive and expressive vocabulary, respectively.

Gesture comprehension.

The gesture comprehension task consisted of 36 items, assessing children's comprehension of 3 different gesture types (*deictic, conventional, iconic*) across 3 different communicative modalities with gesture (i.e., *gesture only, reinforcing gesture-speech combination, supplementary gesture-speech combination*) and one without gesture (i.e., *speech only*). The 12 items (3 gesture types x 4 communicative modalities) were presented in three sets (see Table 1 for a sample set of 12 items), resulting in 36 items in total. Within each set, the presentation order was counterbalanced for correct choice (e.g., bench *vs.* sofa), location of correct choice (left *vs.* right of child) and for gesture type (deictic, iconic, conventional) across participants. We kept the presentation order of the communicative modality type constant, with gesture-only and supplementary gesture-speech combinations always preceding speech-only and reinforcing gesture-speech combinations, to avoid giving the child the label for the object. The gestures we included in the comprehension task were similar to the types of gestures and gesture-speech combinations children produced in their spontaneous interactions with their parents, reported in earlier work (Özçalışkan & Goldin-Meadow, 2005a; Özçalışkan, Adamson, Dimitrova, & Baumann, 2017a).

In order to avoid floor effects for younger participants, we only included objects with moderately difficult labels in our study. The labels for the stimulus objects used in the study were understood and produced by less than 50% (range=41-49%) of children at age 2;6, based on the lexical norms established by the MacArthur-Bates Communication Development Inventories (MCDI; Dale & Fenson, 1996). The 36 test items were initially administered to a group of 24 adults (16 females; M_{age}=24;0; range=18-66 years), all native English-speakers. The adults performed almost at ceiling, with mean overall comprehension score of 35.8 (SD=.77) out of 36, ensuring that the gesture comprehension task items can be easily understood by adults.

The experimenter began the gesture comprehension task by asking the child to play a game using their hands and words: "I have a lot of pictures. I will use my hands or my words to tell you which one I have. Then you can tell me which one I have". Following initial instruction, each child completed two practice trials. In the first trial, the experimenter said "cat" (speech only trial) twice, with a brief pause in between. She then placed a laminated page with two pictures, a dog (incorrect choice) and a cat (correct choice) and asked the child to make a choice (i.e., "Which one is it?"). The same procedure was repeated for the second trial but in a gesture-speech combination ("bottle" + hand with cupped fingers brought to mouth); the child was asked to make a choice between two pictures (bottle, the correct choice *vs.* book, the incorrect choice). If the child failed to make a correct choice on one or both practice trials, the experimenter repeated the trials once more to make sure that the child understood the demands of the gesture comprehension task. Upon completion of the practice trials, the experimenter continued with the 36 test trials, using the same instructions and the same question-answer format as in the practice trials (see Figure 1 for progression of a sample test trial).

(Insert Figure 1 about here)

(Insert Table 1 about here)

Scoring and analysis

For each of the 36 test trials in the gesture comprehension task, the child's response to the choice question received a score of '0' (incorrect) or '1' (correct), resulting in a maximum possible score of 9 for each gesture type (thus 9 for deictic, 9 for iconic, 9 for conventional) and a maximum possible score of 9 for each communicative modality (thus 9 for gesture only, 9 for reinforcing gesture-speech combinations, 9 for supplementary gesture-speech combinations, 9 for speech-only). One coder scored all responses using video records. A second coder, blind to study hypotheses and child age, scored a randomly selected 20% of the responses in each age group. The two coders agreed on 98% of the trials.

We assessed differences in gesture comprehension with mixed ANOVAs with *age* (2, 3, 4 years) as a between-subjects factor and either *gesture type* (deictic, conventional, iconic) or *communicative modality* (gesture only, reinforcing gesture-speech combinations, supplementary gesture-speech combinations, speech only) as within-subject factors. Children's responses to the speech-only items were not included in the gesture type analysis, because they did not include any gesture. We also determined how early children begin to show gesture comprehension across the different types of gestures and communicative modalities at levels reliably above chance, comparing children's comprehension score against chance performance, with a set of independent t-tests, separately by age.

I.3. Results

First, examining the comprehension of different *gestures types*, we found an effect of age ($F(2, 38)=14.75$, $p\leq.001$, $\eta^2_p=.44$), an effect of gesture type ($F(2, 76)=23.04$, $p\leq.001$, $\eta^2_p=.38$), but no interaction between age and gesture type ($F(4, 76)=.82$, $p=.52$). As can be seen in Figure 2A, children steadily improved their performance, with significant increases in comprehension at each age (Bonferroni, $p_s<.05$). Across ages, children showed better comprehension of deictic gestures (M=7.32, SD=1.60) than both iconic (M=6.19, SD=1.89) and conventional gestures (M=5.63, SD=1.68; Bonferroni, $p_s\leq.001$), and better comprehension of iconic gestures than conventional gestures (Bonferroni, $p=.027$).

Turning next to the comprehension of different communicative modalities, we observed a similar pattern—with an effect of age ($F(2, 38)=13.65$, $p\leq.001$, $\eta^2_p=.42$), an effect of communicative modality ($F(3,114)=12.15$, $p\leq.001$, $\eta^2_p=.24$), but no interaction between age and communicative modality ($F(6, 114)=1.10$, $p=.369$). As can be seen in Figure 2B, across ages, children's comprehension was significantly lower for supplementary gesture-speech combinations (M=5.67, SD=.22), compared to the other three communicative modality types (i.e., reinforcing gesture-speech combinations, gesture-only, speech only; Bonferroni, $p_s<.001$-.05).

Children's overall comprehension—across different types of gestures and communicative modalities—was no different than chance at age 2 (M=21.77, SD=4.51, $t(12)=3.012$, $p=.011$), but was significantly above chance both at age 3 (M=26.20, SD=4.33; $t(14)=7.34$, $p\leq.001$) and age 4 (M=30.38, SD=3.71; $t(12)=12.04$, $p\leq.001$), marking the beginning of gesture comprehension at age 3. However, when we examined children's performance separately for each gesture type and each communicative modality, we found that 2-year-olds comprehended deictic—but not iconic or conventional—gesture types ($t(12)=3.81$, $p=.002$; see Figure 2A) and reinforcing—but not supplementary gesture-speech combinations—significantly above chance ($t(12)=2.38$, $p=.034$; see Figure 2B), further suggesting earlier comprehension of deictic gestures and reinforcing gesture-speech combinations[2].

(Insert Figure 2 about here)

I.4. Discussion

In this study, we used a novel gesture comprehension task to provide a comprehensive account of 2- to 4-year-old children's comprehension of different gesture types across different communicative modalities. Not surprisingly, comprehension improved over time, with steady gains from ages 2 to 4. At age 2, children's comprehension was above chance only for deictic gestures and reinforcing gesture-speech combination; and, by age 3, children showed above chance performance for all gesture types and communicative modalities. Importantly, regardless of age, children displayed better comprehension of deictic gestures and reinforcing gesture-speech combinations than iconic and conventional gestures and supplementary gesture-speech combinations.

Why do children show better comprehension of deictic gestures and reinforcing gesture-speech combinations, compared to iconic/conventional gestures and supplementary gesture-speech combinations? One possible explanation is that children's emerging abilities in comprehension of gesture is linked to developmental changes in gesture production, which also show earlier production of deictic gestures and reinforcing gesture-speech combinations than iconic gestures and supplementary gesture-speech combinations (e.g., Butcher & Goldin-

Meadow, 2000; Iverson et al., 1994; Özçalıskan & Goldin-Meadow, 2005a, 2011). Our findings on gesture comprehension between ages 2 to 4 revealed a similar pattern, raising the possibility that the acquisition of different gesture types and their use in different communicative modalities may proceed hand-in-hand in both production and comprehension. Future research is needed to extend this interesting possibility further by probing how even younger children perform on our novel gesture comprehension task and by supplementing these data with systematic description of both the gesture type and communicative modality of their gesture production.

Another possible explanation for the pattern we observed for gesture types—particularly for the better comprehension of deictic gestures—focuses on the relative complexity of the mapping between different gestures and their referents and the complexity of the semantic meaning conveyed in different types of gesture-speech combinations. Deictic gestures indicate perceptually cohesive entities in the world, thereby mapping onto the world in a more direct way than iconic and conventional gestures, which select their referents from a set of relational concepts (e.g., associated iconic actions or features or socially-prescribed meanings) in ways that might impose additional cognitive challenges for young children. These differences in mapping have also been used to explain the developmental progression from deictic to iconic gestures in children's production of gesture in earlier work (Özçalışkan et al., 2014). Similarly, in reinforcing combinations, the semantic content expressed in gesture is the same as the one expressed in speech; while in supplementary gesture-speech combinations, the child needs to be able to combine two different meanings from the two different modalities—one in speech and one in gesture— in order to generate a unified and integrated meaning. These differences are reflected in children's *production* of these two types gesture-speech combinations, with earlier emergence of reinforcing than supplementary combinations (Butcher & Goldin-Meadow, 2000). As such, supplementary combinations might impose a heavier cognitive demand on the child—not only for production, as shown in earlier work, but also for comprehension, leading to their lower comprehension among younger children, particularly 2-year-olds.

Children's better comprehension of deictic gestures and reinforcing gesture-speech combinations at the early ages could also be an outcome of the differences in parental gesture input. Parents of young children (ages 1-3) produce primarily gestures that are conceptually simpler (i.e., deictic) and, only later on, increase their production of conceptually more complex gestures (i.e., iconic and conventional; Iverson et al., 1999; O'Neill, Bard, Linnell, & Fluck, 2005; Özçalıskan & Goldin-Meadow, 2005a, 2011; Shatz, 1982). Similarly, at the earlier ages, parents use predominantly reinforcing gesture-speech combinations when interacting with their young children (O'Neill et al., 2005; Özçalıskan & Goldin-Meadow, 2005a). As such, the frequency with which children are exposed to different types of gestures and gesture-speech combinations might in turn influence their ability to comprehend them.

Interestingly, the children in our study, at each age, showed similar levels of comprehension when asked to identify the referent with speech-only ("bench") or with a reinforcing gesture+speech combination ("bench"+point at bench). These findings thus raise the possibility that speech, but *not* gesture might be the driving force in the comprehension of multi-modal communications where gesture and speech convey the same information. One possible reason for the lack of a difference could be the relative difficulty of the labels for the items used in our study. To avoid floor effects on comprehension, we selected labels of moderate difficulty for the 2-year-olds (i.e., understood and produced by roughly 40-to-50% of children at this age). Thus, about half of the 2-year olds, and most of the 3- and 4-year-olds might have already had the spoken labels for these referents in their repertoires and no longer needed redundant information in gesture to help with comprehension. Future research that examine children's comprehension of referents for which the labels are more difficult could help further tease apart the relative contribution of gesture and speech in children's comprehension of reinforcing gesture-speech combinations.

Children in our study also showed better comprehension of iconic gestures than conventional gestures across different ages—even though we did not predict any differences in children's comprehension of these two gesture types. What might underline this difference we observed? Unlike conventional gestures, which had culture-specific but arbitrary relations to their referents (e.g., thumbs up to indicate good job), all iconic gestures in our study conveyed characteristic actions associated with the referents (e.g., bent elbows flapping like a bird flying) as this was the dominant type of iconic gesture observed in children's early productive repertoires (e.g., Özçalışkan & Goldin-Meadow, 2011). As such, the difference in the comprehension of these two gesture types could be an outcome of the relative complexity of the two gesture types—with greater demands imposed by arbitrary mappings (i.e., conventional gestures) than iconic mappings. The difference could also be an outcome of the ease of accessibility of action meanings to young children, as they present a more embodied representation of the referent (Hodges et al., 2017).

Our study, as the first comprehensive study of its kind, used a cross-sectional design, examining differences children at different ages show in comprehension over a broader age span. However, the question still remains whether each individual child follows a developmental trajectory from better comprehension of deictic gestures and reinforcing gesture-speech combinations to iconic gestures and supplementary gesture-speech combinations—one that has been documented for gesture production in earlier work. Future studies that examine changes in gesture comprehension within the same group of children over time using a longitudinal design can shed further light on the developmental trajectories associated with each type of gesture and communicative modality in comprehension.

One especially interesting finding of our study is that the pattern of better comprehension of deictic gestures and reinforcing gesture-speech combinations than iconic/conventional gestures and supplementary gesture-speech combinations was not moderated by age. Thus the pattern we observed appears to be a remarkably robust aspect of the language-learning process. However, it is not clear if it would also be evident in verbal young children with ASD, who often experience early difficulties and delays in both gesture and speech production (Wetherby, 1986). Thus, in study 2, we asked whether the patterns of comprehension of the different types of gestures and communicative modalities that we observed in young TD children would also be found to characterize the gesture comprehension of verbal children with ASD.

II.1. STUDY 2

Gesture Comprehension in Young Children with ASD

Young children with ASD gesture less than TD children with similar language ability—a difference that is particularly pronounced for deictic gestures and supplementary gesture-speech combinations (e.g., Özçalıskan, Adamson, Dimitrova, & Baumann 2017a, 2017b). Here we ask whether the patterns of differences children with ASD show in production of gesture also extend to its comprehension. One possibility is that children with ASD would show similar types of weaknesses in the comprehension of gesture as they do in production, suggesting a close coupling between production and comprehension of gesture. Alternatively, children with ASD would *not* show the kinds of difficulties that they show in production, but would instead show similar levels of comprehension as TD children, suggesting a possible dissociation between production and comprehension of gesture in autism.

First looking at production, young children with ASD gesture less than TD children (e.g., Mundy et al., 1986; Rapin, 1996), a difference that remains unchanged even after controlling for the amount of speech that they produce (Özçalıskan, Adamson, & Dimitrova, 2016). In fact, one of the key findings in previous work on children with ASD is a much lower frequency of deictic gestures, namely points at objects or events to share information about them (e.g., Camaioni, Perucchini, Muratori, & Milone, 1997; Stone, Ousley, Yoder, Hogan, & Hepburn, 1997; Özçalıskan et al., 2016). The markedly lower rate of pointing at the very early ages has been recognized as one of the primary indicators of autism in toddlers (Mundy, Sigman, & Kasari, 1990). At the same time, and despite lower rates of gesture production, children with ASD produce the same types of gestures (deictic, conventional, iconic) in similar distributional frequencies (higher production for deictic than for conventional and iconic gestures) as TD children, comparable in productive vocabulary but not in chronological age. In addition, the differences children with ASD show in production become particularly evident for deictic gestures, but not for conventional or iconic gestures (Özçalıskan et al., 2016, 2017a). Children with ASD also show similar patterns to TD children in their use of different communicative modalities, relying on gesture to both reinforce and supplement the information conveyed in speech. However, compared to their TD peers, children with ASD tend to produce fewer supplementary combinations—a difference that has not been found for reinforcing gesture-speech combinations (Özçalıskan et al., 2017b). The existing research thus far suggests close similarities between young children with ASD and with TD in their use of different types of gestures and communicative modalities; it also highlights some unique differences in the gesture production profiles of children with ASD.

Compared to production, comprehension of gesture in children with ASD remains an understudied research domain, with the notable exception of comprehension of deictic gestures, particularly points at objects. The focus on comprehension of pointing in children with ASD stems largely from the central role pointing plays in building joint attention with a caregiver—a capacity considered crucial for subsequent language development (e.g., Adamson, Bakeman, & Deckner, 2004; Smith, Adamson, & Bakeman, 1988; Tomasello & Farrar, 1986). In fact, the close link between comprehension of pointing and language development has identified early pointing comprehension as a key factor in autism diagnostic tools, including the Early Social Communication Scales (ESCS; Mundy, Delgado, Block, Venezia, Hogan, & Seibert, 2003), the Autism Diagnostic Observation Schedule (ADOS; Lord, Rutter, DiLavore, Risi, Gotham, & Bishop, 2012) and the Autism Diagnostic Interview (ADI; Rutter, Le Couteur, & Lord, 2003). Except for studies on the comprehension of pointing gestures by both younger (M_{age}=3;9; e.g., Camaioni, Perucchini, Muratori, Parrini, & Cesari, 2003) and older children with ASD (M_{age}=12;0; e.g., Hobson, Garcia-Perez, & Lee, 2010), the literature on gesture comprehension by children with ASD remains sparse.

Of the few existing studies—all with relatively older children with ASD—one compared comprehension of gestures in 15-year-old adolescents with ASD to a sample of TD adolescents, comparable in age, gender, verbal IQ, expressive and receptive vocabulary, using eye-tracking measures (Silverman, Bennetto, Campana, & Tanenhaus, 2010). Silverman and colleagues found that individuals with ASD differed from their TD peers in their comprehension of verbal utterances with gestures (e.g., “A dotted line that makes the shape of a hill”+ right hand traces the shape of a hill) and verbal utterances without gesture (e.g., “A dotted line that makes the shape of a hill”). Unlike TD adolescents, who identified the referent of the verbal utterance more quickly when it was accompanied by gesture, adolescents with ASD processed the referent more quickly when it was *not* accompanied by gesture. A more recent study, with slightly younger children (TD=12;0; SD=1.6, ASD=13;0; SD=2.1), extended this finding to verbal utterances with beat gestures, namely gestures that do not carry semantic meaning but only mark prosodic boundaries (Hubbard, McNealy, Scott-Van Zeeland, Callan, Bookheimer, & Dapretto, 2012), further suggesting that individuals with ASD might experience greater difficulties in decoding multi-modal communications involving gesture and speech.

In summary, young children with ASD show lower performance both in their production and comprehension of gesture, particularly for deictic gestures. However, to date, there is no study that examined gesture comprehension systematically across different gesture types (deictic, conventional, and iconic) and different modalities of expression (gesture only, reinforcing gesture-speech combinations, supplementary gesture-speech combinations, speech-only) in children with ASD. In study 2, we compare a sample of children with ASD to our sample of TD children from Study 1. We ask whether verbal children with ASD comprehend gesture as readily as their TD peers. Based on earlier work showing lower rates of gesture production in children with ASD (e.g., Mundy et al., 1986; Özçalıskan et al., 2016), we predict that children with ASD will show lower performance in their overall comprehension of gesture compared to their TD peers. Given the lower performance young children with ASD show in production of deictic gestures and supplementary gesture-speech combinations (e.g., Camaioni et al., 1997; Özçalıskan et al., 2017a, 2017b), we also predict that children with ASD will show greater difficulties comprehending deictic gestures and supplementary gesture-speech combinations, where gesture and speech convey semantically different information, compared to conventional and iconic gestures and reinforcing gesture-speech combinations.

II.2. Method

Participants

The sample included 30 newly recruited children[3] with ASD (M_{age}=6;1, range=1;9-12;2, 21 boys), along with the 41 TD children (M_{age}=3;6, range=1;2-5;0, 17 boys) who formed the sample of study 1. We selected the children with ASD so that they would be comparable to the TD sample in receptive language ability (PPVT-4; Dunn & Dunn, 2007; M_{TD}=49.27, SD=14.01, range=23-83 vs. M_{ASD}=51.07, SD=21.60, range=24-105; $F(1, 68)=.177$, $p=.676$). Given our study's focus on *comprehension* of gesture with or without speech, we wanted to ensure that the children did not differ in their overall speech comprehension abilities. We used PPVT standardized age equivalent scores instead of PPVT raw scores in making the two groups comparable because of the considerable age range, particularly within the ASD group, following earlier work on children with Williams syndrome (Mervis & Klein-Tasman, 2004). We also collapsed the three age groups in Study 1 into one TD group for Study 2, based on our finding in Study 1 that the pattern of comprehension for gesture types and communicative modalities did not vary by age.

All children with ASD had a formal diagnosis for autistic disorder or pervasive developmental disorder not otherwise specified (PDD-NOS) according to the DSM-IV-R criteria (American Psychiatric Association, 2000). For all but two of the children, diagnoses reported by the parents were confirmed by written documentation of a comprehensive clinical evaluation by a licensed clinical psychologist who used as part of the evaluation the Autism Diagnostic Interview-Revised (ADI-R; Rutter et al., 2003), a parent interview that assesses child behavior in three core domains of social interaction, communication, and restricted or repetitive behaviors. To further confirm the autism diagnosis in the ASD group and its lack in the TD group, all parents completed the Social Responsiveness Scale (SRS; Constantino & Gruber, 2005), a questionnaire that measures autistic traits in children. All children in the ASD group met the cutoff for autism (cutoff=59+; M_{ASD}=75.04, SD=11.66), including the two children for whom we did not have access to a formal documentation to confirm the parent's report of ASD; both of these children received a standard score of 76 or higher, indicating severe autism[4]. None of the children in the TD group scored above the cutoff for ASD (M_{TD}=43.66, SD=4.75).

The racial and socio-economic backgrounds were similar in the ASD and TD groups. The majority of the children with ASD were either African-American (40%) or Caucasian (37%), along with a few children with Asian or mixed backgrounds (23%). The majority of the parents of children with ASD had college (40%) or postgraduate degrees (34%); while the remaining parents had either high school or some college education (23%). All families received small monetary compensation for their participation.

Procedure

We followed the same data collection procedure as outlined in study 1.

Scoring and Analysis

Using the same scoring procedures used in study 1, responses to each of the 36 forced-choice questions received a score of ‘0’ (incorrect) or ‘1’ (correct). One coder scored all responses produced by children with ASD from videos. A second coder, blind to study hypotheses and child age, scored a randomly selected 20% of the responses, revealing 98% agreement between coders for the ASD group. We used the scores from study 1 for the TD group.

We first probed for gender differences in gesture comprehension, using one-way ANOVAs, separately for the TD children and children with ASD, because of the differences in the relative distribution of boys vs. girls in the two groups. Participant responses showed no effect of gender for the comprehension of either different types of gestures (TD: $F(1, 39)=1.45$, $p=.236$; ASD: $F(1, 26)=.035$, $p=.854$) or communicative modalities (TD: $F(1, 39)=1.73$, $p=.196$; ASD: $F(1, 26)=.026$, $p=.873$) in either group; therefore all subsequent analyses combined the scores across boys and girls within each group. We then assessed differences in comprehension, using mixed ANOVAs—with *group* (ASD, TD) as a between- and either *gesture type* (deictic, conventional, iconic) or *communicative modality* (gesture only, reinforcing gesture-speech combinations, supplementary gesture-speech combinations, speech only) as within-subject factors. We also determined how early children in each group begin to show gesture comprehension across the different types of gestures and communicative modalities at levels reliably above chance, comparing children's comprehension score against chance performance, with a set of independent t-tests, separately by group.

II.3. Results

We first asked whether children with ASD differed from TD children in their comprehension of different gesture types, and found an effect of gesture type ($F(2,138)=22.94$, $p \leq .001$, $\eta^2_p=.25$) but no effect of group ($F(1, 69)=.505$, $p=.48$, $\eta^2_p=.007$), or interaction between group and gesture type ($F(2, 138)=.704$, $p=.496$). As can be seen in Figure 3A, across groups, children understood deictic gestures better than iconic and conventional gestures (Bonferroni $p_s<.001$) and iconic gestures better than conventional gestures (Bonferroni, $p=.029$).

We next asked whether children with ASD differed from TD children in their comprehension of the different communicative modalities, and found an effect of communicative modality ($F(2.66, 183.52)=17.15$, $p \leq .001$, $\eta^2_p=.20$) but no effect of group ($F(1, 69)=.546$, $p=.462$, $\eta^2_p=.008$) and no interaction between group and modality ($F(2.66, 183.52)=.016$, $p=.995$, $\eta^2_p=.000$). Children—across groups—showed lower comprehension of supplementary gesture-speech combinations compared to other communicative modalities (Bonferroni, $p_s<.01$); they also showed lower comprehension of gesture-only items compared to reinforcing gesture-speech combinations (Bonferroni, $p=.04$; See Figure 3B).

(Insert Figure 3 about here)

Children with TD, as a group, performed at levels significantly above chance in their comprehension of different gesture types (deictic: $t(40)=11.25$, $p \leq .001$, conventional: $t(40)=4.31$,

$p \leq .001$, iconic: $t(40)=5.75$, $p \leq .001$) and communicative modalities (speech: $t(40)=10.40$, $p \leq .001$, gesture-only: $t(40)=7.37$, $p \leq .001$, reinforcing gesture+speech: $t(40)=8.22$, $p \leq .001$, supplementary gesture+speech: $t(40)=4.87$, $p \leq .001$). This pattern also occurred for children with ASD for both gesture types (deictic: $t(29)=5.36$, $p \leq .001$, conventional: $t(29)=3.72$, $p=.001$, iconic: $t(29)=4.18$, $p \leq .001$) and communicative modalities (speech: $t(29)=5.36$, $p \leq .001$, gesture-only: $t(29)=4.20$, $p \leq .001$, reinforcing gesture+speech: $t(29)=5.92$, $p \leq .001$, supplementary gesture+speech: $t(29)=3.42$, $p=.002$)

II.4. Discussion

In study 2 we asked whether children with ASD follow a pattern similar to TD children—who are comparable in receptive language ability—in their comprehension of different gestures and communicative modalities, and found evidence for it. Children in both groups had comparable overall scores on our gesture comprehension assessment. Moreover, they showed similar patterns of better comprehension of deictic than conventional or iconic gestures and of better comprehension of reinforcing than supplementary gesture-speech combinations.

Why do children with ASD show similar patterns of comprehension as TD children, particularly given the relative difficulties that are reported in gesture production, mainly for 2-to-3-year-old children with ASD (e.g., Mundy et al., 1986; Özçalıskan et al., 2016)? One possible explanation could be tied to the relative communicative demands of production and comprehension for children with ASD. Gesture production requires that the child initiates the expression of an explicit communicative act (e.g., pointing at a book to share information about the book; saying “read” while pointing at a book to request book reading). In contrast, comprehension of a gesture or a gesture-speech combination may place fewer communicative (and possibly cognitive) demands on the child, thereby improving performance, particularly among children with ASD who have difficulty initiating and sustaining coordinated joint engagement with social partners (Adamson, Bakeman, Deckner, & Romski, 2009).

The composition of our sample may also help explain why we found comparable gesture comprehension abilities in our two groups. Our sample included older children with ASD (M_{age}=6;1 years, range 2;9-12;2) with relatively strong verbal abilities (PPVT age equivalent age of 4;2 years). In fact, most of the previous work that found lower rates of gesture production in children with ASD sampled younger children with ASD (ages 1-3) who were either non-verbal or were at the early stages of language learning (e.g., Mundy et al., 1986; Özçalıskan et al., 2016), raising the possibility that either age or verbal ability might help explain our findings. Interestingly, gesture comprehension was strongly correlated with receptive language abilities (r=.520, p=.003) in our ASD sample but not with chronological age (r=.107, p=.574), suggesting that verbal ability but *not* age might be a key contributor to gesture comprehension.

It is noteworthy that our prediction, which stated that children with ASD would show lower comprehension of deictic gestures than other gesture types, was not supported. Indeed, we found the reverse: comprehension of deictic gestures was significantly better than comprehension of both iconic and conventional gestures, indicating that the children in the ASD group were performing much like those in the TD group. Most of the earlier work assessed gesture comprehension in children with ASD indirectly, typically in naturalistic (i.e., home videotapes; e.g., Baranek, 1999; Werner & Dawson, 2005) or semi-naturalistic elicitation contexts (i.e., responding to an experimenter pointing at objects in the room; see ESCS: Mundy et al., 2003; ADOS: Lord et al., 2012). Unlike these earlier studies, the current study provided a more stripped down and relatively less demanding elicitation context in which the child was simply asked to rely on a gesture produced by an adult to make a choice between two possible answers, possibly leading to improved performance.

Following recent work on difficulties in gesture-speech integration in ASD (Hubbard et al., 2012; Silverman et al., 2010; Özçalıskan et al., 2017b), we also predicted that children with ASD would show lower comprehension of items that combine gesture and speech, particularly items in which gesture and speech convey different pieces of semantic information (i.e., supplementary gesture-speech combinations). Our findings supported this prediction; children—both with or without ASD—showed lower comprehension of items presented in supplementary gesture-speech combinations, compared to the ones presented in one modality—be it gesture-only or speech-only. Moreover, children in both groups showed lower comprehension of items in supplementary gesture-speech combinations than the ones in reinforcing gesture-speech combinations, suggesting that the greater cognitive load imposed by processing two different pieces of information in a gesture-speech combination, but not multimodality per se, might account for the lower performance in the comprehension of gesture-speech combinations in both groups. Overall, our results show similar patterns of gesture comprehension in children with ASD and TD children—comparable in receptive language—thus suggesting a largely preserved gesture comprehension system in verbal children with ASD, compared to gesture production.

III. General discussion

In this study, we provided a comprehensive account of gesture comprehension in two groups of children—namely TD children and children with ASD, using a novel gesture comprehension task, across two studies. In study 1, we asked whether gesture comprehension improves with age and whether the pattern found for gesture type and communicative modality in gesture production extends to gesture comprehension in TD children. We found that comprehension of gesture improved significantly between ages 2 and 4, with above chance gesture comprehension abilities at age 3. Importantly, across the studied ages, the pattern of gesture comprehension was identical to the one found in gesture production reported in earlier work, with better comprehension of deictic gestures compared to iconic and conventional ones, and of reinforcing gesture-speech combinations compared to supplementary ones. In study 2, we asked whether the pattern of gesture comprehension that we observed in TD children would extend to children with ASD, who have been reported to produce fewer words and gestures than TD children early in development. We found evidence for the robustness of the pattern found in TD children: contrary to our predictions, verbal children with ASD mirrored the pattern we observed in TD children, showing better comprehension of deictic than iconic and conventional gestures and better comprehension of reinforcing than supplementary gesture-speech combinations.

One key contribution of our study is the close similarity our results on gesture comprehension show to gesture production in earlier work—with better comprehension of deictic gestures and reinforcing gesture-speech combinations. More specifically, TD children in our study were able to comprehend various types of gestures and gesture-speech combinations at about the same age they were able to produce them (Carpenter et al., 1998; Özçalışkan & Goldin-Meadow, 2005a; Özçalışkan et al., 2014; Namy et al., 2004)—a pattern that differs from speech where comprehension is often reported to precede production. One explanation for this difference is that unlike production of speech, which requires the recall and articulation of conventionalized symbols, production of gesture might place fewer cognitive and articulatory demands on the child. The child can indicate different objects by simply extending an index finger towards an object—a task that is cognitively much easier than having to recall and produce the label for each of these objects separately with words. As such, children's underlying knowledge of referents or relations can be as readily available around the same time both in their production and comprehension of gesture.

However, it is important to note here that, unlike TD children, who show better comprehension than production abilities in speech, children with ASD have been found to have more preserved production abilities in speech compared to comprehension, particularly at the early ages (Hudry et al., 2010). The attenuated receptive-expressive split in speech seems to present a stark contrast to our finding of highly preserved comprehension abilities in gesture, particularly compared to gesture production as documented in previous work in children with ASD (Özçalışkan et al., 2016). One possible explanation is that, unlike the production of gesture, which is highly context-bound, speech offers a more decontextualized symbolic medium that could help alleviate some of the difficulties children with ASD might experience in sustaining joint attention. This difference between gesture and speech may also help explain why young children with ASD produce markedly fewer gestures than TD children even when producing comparable amounts of speech (Özçalışkan et al., 2016). Another explanation is that the children with ASD in our sample were all verbal and had receptive language abilities that highly correlated with their expressive language abilities ($M_{\text{EVT st. score}}$=86.25 [SD=28.48] vs. $M_{\text{PPVT st. score}}$=81.33 [SD=27.39], r=.944, $p \leq .001$). Future studies examining comprehension and production of gesture by the same children, and particularly in relation to their expressive and receptive language abilities, can shed further light on the link between processes of comprehension and production within and across modalities.

Our study also examined comprehension of gesture using a formal task in a laboratory setting that intentionally minimized children's use of other communicative cues that might be available in a more naturalistic real-world setting. Thus, it remains a distinct possibility that the availability of additional cues in naturalistic settings might improve children's performance, revealing better gesture comprehension abilities in both groups. We know from previous work that parents of both TD children and children with ASD gesture frequently in their one-on-one interactions with their children, using different types of gestures and gesture-speech combinations (e.g., Iverson et al., 1999; Özçalıskan & Goldin-Meadow, 2005a, 2016; Özçalıskan et al., 2017a; Talbott, Nelson, & Tager-Flusberg, 2015). However, we know relatively little about children's uptake of these gestures in such everyday contexts. Future work that investigates whether children understand the different types of gestures and gesture-speech combinations as readily in such real-world contexts as they do in the laboratory can shed further light on the role communicative context may play in aiding comprehension. Furthermore, given that most of the earlier work on production of gesture relied on naturalistic observations, examination of gesture comprehension in similar naturalistic contexts might even reveal earlier comprehension abilities in gesture, compared to production, raising the possibility of a progression from comprehension to production for gesture similar to speech—a possibility that can be addressed in future studies.

Another key contribution of our studies was the close similarities TD children and children with ASD showed in their patterns of gesture comprehension. Our further analysis suggested that verbal ability might play a role in driving some of these similarities—with children who have higher receptive language abilities also showing better gesture comprehension. However, the question still remains whether language plays a causal role in children's comprehension of gesture. One possible way to approach this question in future studies would be to examine gesture comprehension in a broader sample of children with ASD, showing language abilities from nonverbal or minimally verbal to highly verbal—and ask whether they continue to show similarities to TD children in their patterns of gesture comprehension, independent of their language ability.

A third contribution of our study was its design. Our study introduced an easy-to-use tool for a comprehensive assessment of gesture comprehension in both TD children and children with ASD. Unlike existing tasks that focused mostly on comprehension of a single gesture type or communicative modality type (Hodges et al., 2017; Namy et al., 2004; Stanfield et al., 2014), our task assesses comprehension across a broader range of gesture types (deictic, iconic, and conventional) and communicative modalities (speech only, reinforcing gesture-speech combinations, supplementary gesture-speech combinations, speech only). As such, our task provides an important tool for future research to assess gesture comprehension across different learners that show unique profiles of gesture and speech production abilities. The extension of our comprehension paradigm to more diverse groups of children with or without developmental disorders, in turn, has the potential to provide a more complete account of gesture comprehension abilities at the younger ages.

In summary, our study showed a distinctive pattern of comprehension for different gesture types and communicative modalities—with better comprehension of deictic gestures and reinforcing gesture-speech combinations than iconic gestures and supplementary combinations—a pattern that remains preserved across different ages (2-to-4 years) within typical development and across different language learners with distinct developmental profiles (i.e., ASD). Overall, our results suggest that comprehension of gesture follows a pattern similar to its production, which is likely driven by the cognitive demands different gestures and gesture-speech combinations place on children.

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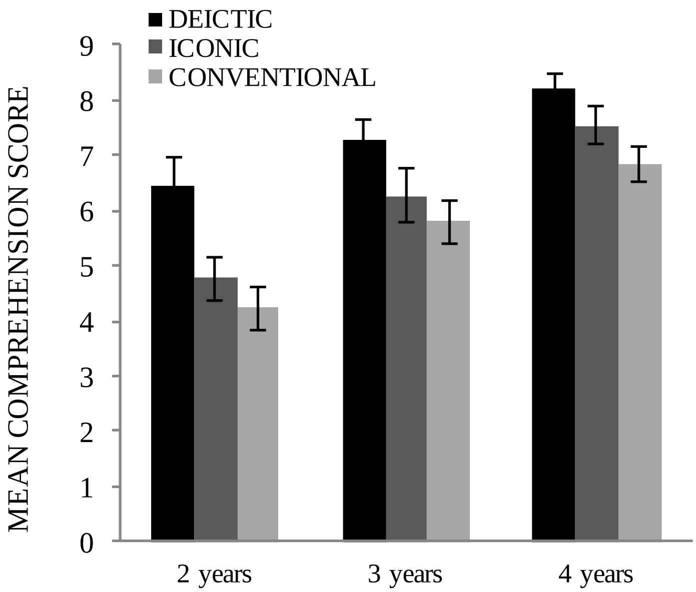
A. “Sitting” + point at sofa

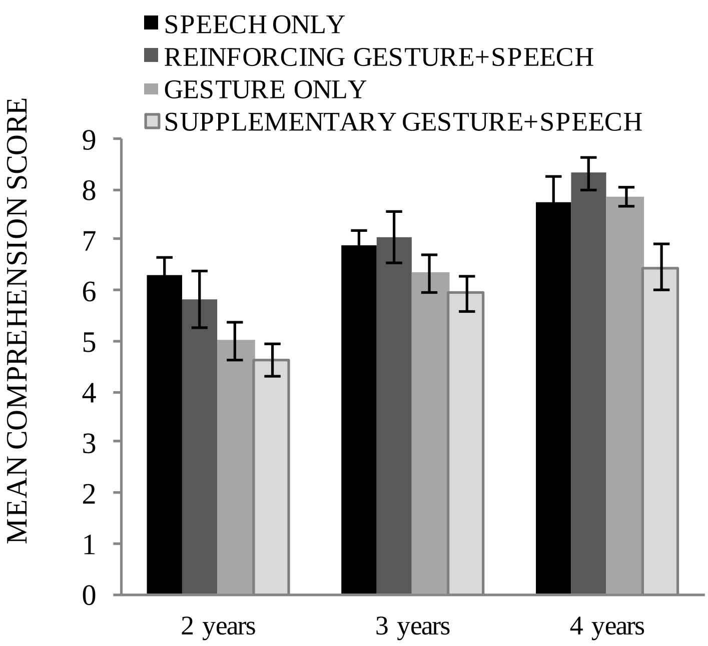
B. “Which one?”

C. Child points at sofa picture (correct choice)

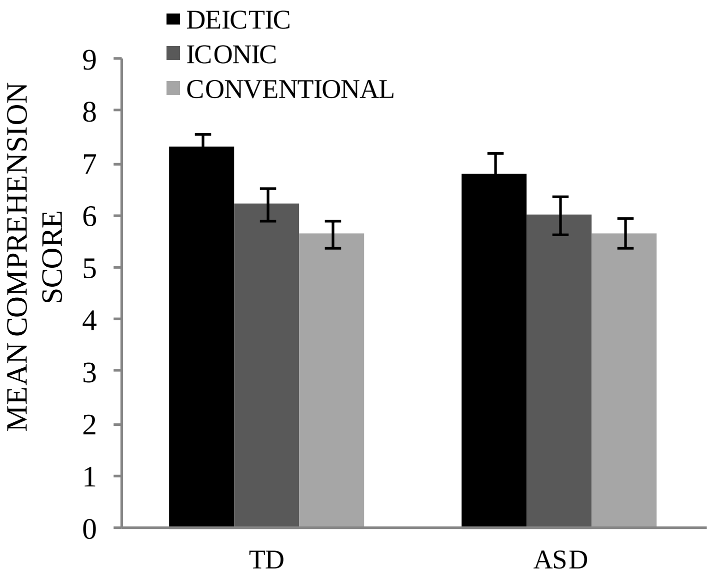
A. GESTURE TYPES



B. COMMUNICATIVE MODALITIES



A. GESTURE TYPES



B. COMMUNICATIVE MODALITIES

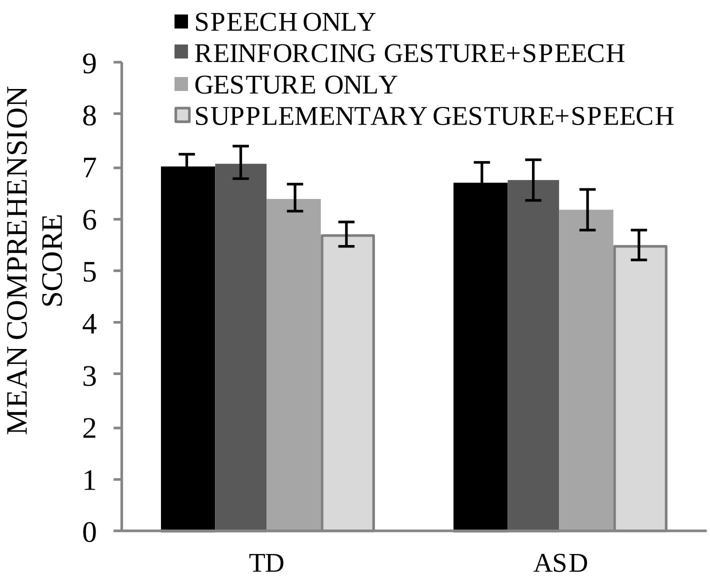
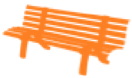


Figure 1. Sample presentation of a supplementary gesture-speech combination (A: "sitting"+POINT at sofa toy), followed by a forced-choice question by the experimenter (B: "which one?"), and a response by the child (C: POINT at sofa picture).

Table 1. Example test set consisting of 12 items with 3 types of gestures and 4 types of communicative modalities, and the forced-choice picture pair for each test item

Figure 2. Mean comprehension score of 2-, 3- and 4-year-old children by gesture type (Panel A; max score=9) and by communicative modality (Panel B, max score=9). Error bars represent standard errors.

Figure 3. Mean comprehension scores by gesture type (Panel A; max score=9) and by communicative modality (Panel B, max score=9) in TD children (left panels) and children with ASD (right panels). Error bars represent standard error.

GESTURE TYPE	**COMMUNICATIVE MODALITY TYPE**				**PICTURE CHOICES**	
	Gesture only	**Reinforcing Gesture+Speech**	**Supplementary Gesture+Speech**	**Speech only**	**Correct**	**Incorrect**
Deictic	Point at sofa	"Sofa" + point at sofa	"Sitting" + point at sofa	"Sofa"		
Iconic	Bent elbows flapping as if hen	"Hen" + bent elbows flapping as if hen	"Looking"+ bent elbows flapping as if hen	"Hen"		
Conventional	Index finger placed on mouth meaning 'quiet'	"Quiet" + index finger placed on mouth meaning 'quiet'	"Girl"+ index finger placed on mouth meaning 'quiet'	"Quiet"		

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Ethical approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent

All parents provided informed consent for their and their child's participation prior to their inclusion in the study.

Conflict of interest

The authors declare that they have no conflict of interest.