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Unpacking the Ontogeny of Gesture Understanding: How Movement Becomes Meaningful Across Development

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Gestures, hand movements that accompany speech, affect children's learning, memory, and thinking (e.g., Goldin-Meadow, 2003). However, it remains unknown how children distinguish gestures from other kinds of actions. In this study, 4- to 9-year-olds (n = 339) and adults (n = 50) described one of three scenes: (a) an actor moving objects, (b) an actor moving her hands in the presence of objects (but not touching them), or (c) an actor moving her hands in the absence of objects. Participants across all ages were equally able to identify actions on objects as goal directed, but the ability to identify empty-handed movements as representational actions (i.e., as gestures) increased with age and was influenced by the presence of objects, especially in older children.

In our daily lives, we are surrounded by people and objects. We see people act on objects, and we make inferences about a person's goals and intentions from those acts. For example, if we see a woman reach toward a ball, we infer that the ball is the goal of the woman's action. Infants as young as 5 months make these same inferences when observing a person act on an object (Woodward, 1998)—if a woman reaches out to grab a ball, infants focus on the target of her reach (the object) rather than the spatiotemporal properties of the reach.

But the spatiotemporal properties of a movement are relevant at times, particularly when the purpose of the movement is not to achieve an external goal (like obtaining a ball) but rather just to move. Some movements are produced for the sake of movement—and these movements have internal or movement-based goals (Novack, Wakefield, & Goldin-Meadow, 2016; Schachner & Carey, 2013). Just as we make inferences about actions on objects from the context in which the action occurred (e.g., we use movement of a hand toward an object, as well as cues like hand shape and eye gaze, to interpret the movement as goal directed), we also use context (or its lack) to make inferences about movements when the goal is simply to move. For example, if we see someone wiggling her fingers in the air and there is no obvious context that offers a reason for the movements, we are likely to focus on the movement itself and interpret it as a movement produced for its own sake, (e.g., "oh, she probably just wanted to wiggle her fingers").

Finally, in addition to object-directed actions (which have external goals) and movements for their own sake (which have internal goals), there are also movements that have *representational goals*—these movements are called *gestures*. Visually, gestures are similar to movements that we interpret as having internal, movement-based goals: they typically occur in the air (i.e., off objects) and therefore cannot be used to achieve external goals. However, when we interpret an empty-handed

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movement as a gesture, we use the spatiotemporal properties of the movement, along with features of the context in which the movement is produced, to imbue the movement with meaning, that is, to see it as a representation of an idea (Novack et al., 2016). For example, if we see someone wiggling her fingers in the air while saying, "the bugs were creeping all around," the context provided by speech makes it likely that we will interpret the movement as having a representational goal (e.g., representing the movements of the bugs), rather than a movement-based goal (e.g., "just wiggling her fingers for no reason").

Recognizing the difference between gesture and other forms of movement is important from a psychological perspective, as gesture has been shown to have unique impacts on cognitive processes (Novack & Goldin-Meadow, 2016). Gesture's effect on cognition has been documented in adults (Alibali, Spencer, Knox, & Kita, 2011; Beilock & Goldin-Meadow, 2010). But the bulk of the literature has focused on children who are given instruction that includes gesture (see Goldin-Meadow, 2015 for review). For example, children are more likely to learn about the function of a novel toy (Novack, Goldin-Meadow, & Woodward, 2015), early language concepts (Wakefield & James, 2015), bilateral symmetry (Valenzeno, Alibali, & Klatzky, 2003), Piagetian conservation (Ping & Goldin-Meadow, 2008), and mathematical equivalence (Goldin-Meadow, Cook, & Mitchell, 2009) if they are given instruction with gesture than instruction without gesture (i.e., spoken instruction by itself). These positive learning outcomes appear to be unique to gesture. Other types of movements, such as meaningless movements (Brooks & Goldin-Meadow, 2015) or actions on objects (Novack, Congdon, Hemani-Lopez, & Goldin-Meadow, 2014; Wakefield, Hall, James, & Goldin-Meadow, 2017), do not show the same effects on cognition, encouraging researchers to explore what makes gesture a particularly good teaching tool (Goldin-Meadow, 2011).

Here, we focus not on whether children can *learn* from gesture—this point has been well established. Rather, we ask how children interpret and categorize different forms of movement, particularly the movements that adults interpret as representational (i.e., gesture; Novack et al., 2016). This issue has received relatively little attention and may play an important role in determining whether a child will learn from gestures used as teaching tools—learners who interpret a movement as a gesture may be more likely to be influenced by that movement during instruction than learners who do not interpret the movement as a gesture.

To determine when children categorize movement as gesture, we take advantage of a paradigm, developed by Schachner and Carey (2013) and adapted by Novack et al. (2016), to probe how participants classify movements. In this paradigm, participants describe simple scenes in which an agent moves and perceptual/contextual cues are varied. The original studies demonstrated that when adults see an actor moving objects (moving colored balls into boxes), they uniformly interpret the movements in terms of external goals—they recognize that the purpose of the movements is to affect objects in the external world (Novack et al., 2016; Schachner & Carey, 2013). In contrast, when adults see the actor move her hands in the air, either with objects present or absent, they are less uniform in how they interpret these empty-handed movements (Novack et al., 2016). They sometimes describe the empty-handed movements as having movement-based goals, (e.g., "she waved her hands back and forth in the air") and sometimes describe them as having representational goals (e.g., "she was showing how to move objects"). In addition, the presence of objects, as well as the presence of speech (even unintelligible speech) and a hand shaped as though it had performed the movement, all influence whether adults interpret the movement as having a movement-based goal or a representational goal. In general, the more contextual information adults have, the less likely they are to focus on the spatiotemporal properties of the movements, and the more likely they are to attribute *representational* meaning to the movements. The question we ask is whether children process object-directed movements and empty-handed movements differently from adults.

Previous literature suggests that children should be able to understand actions on objects as goal directed from an early age. Young infants possess a number of the cognitive skills needed to read intent off of another's actions—for example, the ability to follow body direction and gaze (e.g., Butterworth & Jarrett, 1991; Phillips, Wellman, & Spelke, 2002; Woodward, 2003), the ability to identify the animacy of an agent (e.g., Biro & Leslie, 2007; Johnson, Shimizu, & Ok, 2007), and the ability to perform intentional actions oneself (e.g., Sommerville, Woodward, & Needham, 2005; See Woodward, Sommerville, Gerson, Henderson, & Buresh, 2009; for more on this topic). Indeed, infants as young as 5 months systematically interpret actions on objects as goal directed (e.g., Trabasso, Stein, Rodkin, Munger, & Baughn, 1992; Woodward, 1998). At the neural level, infants display neural responses that are similar to the responses adults display when viewing object-directed actions (Rotem-Kohavi et al., 2014; Virji-Babul, Rose, Moiseeva, & Makan, 2012), suggesting that there is continuity in the way humans process object-directed actions across the life span.

In contrast, we expect a more protracted period for children to develop an understanding of empty-handed movements as representational. Although some gestures such as points, are viewed as intentional and communicative before 2 years (Krehm, Onishi, & Vouloumanos, 2014; Woodward & Guajardo, 2002), being able to interpret the content of representational gestures appears to develop gradually between the ages of 2 and 5 years (Goodrich & Hudson Kam, 2009; Novack et al., 2015; Sekine, Sowden, & Kita, 2015; Stanfield, Williamson, & Ozcaliskan, 2014). For example, it is not until 26 months that children recognize the transparency of iconic gestures and find iconic representations easier to learn from than arbitrary representations (e.g., they find it easier to link a hammering motion with a hammer than to link an arbitrary motion with the hammer—before 26 months, the two representations for hammer are equally easy to learn; Namy, Campbell, & Tomasello, 2004). Neuroimaging data suggest that these developmental changes continue until at least age 11, particularly with respect to integrating gesture with contextual cues like speech (Demir-Lira et al., under review; Dick, Goldin-Meadow, Solodkin, & Small, 2012; Wakefield, James, & James, 2013). Taken together, these findings suggest that children's ability to distinguish gestures from actions on objects as well as from meaningless movements may not be as developed as adults' ability to make these distinctions.

Following Novack et al. (2016), in this study, we use participants' explicit descriptions of movement to provide insight into how they have interpreted that movement. We expect that, like adults, children will interpret movement performed on objects as directed toward external goals. If we find no age-related differences in children's interpretation of movement performed on objects, we can be confident that our paradigm is appropriate for children of all ages. In contrast, we expect that age will influence children's likelihood of interpreting an empty-handed movement as representational. We have two additional predictions. First, we expect the presence of objects to play a role in children's ability to interpret empty-handed movement as representational. We know that adults use object cues when interpreting empty-handed movement (Novack et al., 2016), that objects are a salient part of children's early learning environment (e.g., Pereira, Smith, & Yu, 2014; Yoshida & Smith, 2008), and that children's early gestures often refer to objects (Gullberg, de Bot, & Volterra, 2008). As a result, children may exploit this type of concrete cue when searching for meaning in movement. Second, given previous work suggesting that children display protracted development in their ability to integrate gesture with one particular contextual cue (speech), we predict that this other important contextual cue (object presence) may have a greater effect in later childhood than in the early years.

Method

Participants

Usable data were collected from 339 children between the ages of 4 and 9 years (142 female, 197 male) at a large, science museum in Chicago, IL in the summer of 2015. Although we did not collect demographic information from individuals, our sample was representative of the general profile of museum visitors. According to museum reports based on short surveys with museum visitors, visitors to the museum represent a number of different racial and ethnic backgrounds (70% White, 10% Hispanic, 6% African American, 6% Asian, 5% Other, < 1% Native American, Native Hawaiian), and are also diverse in socioeconomic status, based on self-report measures of perceived socioeconomic status (13% lower or lower-middle class, 54% middle class, 33% upper middle or upper class) and parent or guardian's highest level of formal education (1% < high school diploma, 18% high school diploma, 16% associates degree, 35% bachelors degree, 21% master's degree, 7% PhD, or other terminal professional degree, 3% not reporting). Parents provided informed consent, and children provided verbal assent. Children were recruited to be as evenly distributed across the age range as possible (4 years: $n = 70$; 5 years: $n = 58$; 6 years: $n = 50$; 7 years: $n = 59$; 8 years: $n = 56$; 9 years: $n = 46$); nevertheless, birth dates were collected and exact age in years (e.g., 7.76) was calculated (difference between birth date and date of experiment) and used as a continuous variable in all analyses except when specified. Children were randomly assigned to one of three conditions, with a target of ~ 20 children of each age group in both the *empty-handed movement with objects present* and the *empty-handed movement with objects absent* conditions, and a target of ~ 10 children per age group in the *movement performed on objects* condition. Pilot testing showed almost no variability in responses for the *movement performed on objects* condition; as a result, we decreased the sample size for this condition. An additional 64 children were recruited for the study but excluded from analyses for refusing to respond to the initial prompt (n = 51), providing a response to the initial prompt that was completely irrelevant (e.g., mentioning events from popular children's movies; mentioning things happening nearby in the museum; n = 10), saying they could not remember or did not understand what the prompt was about (n = 2), or providing a response that was inaudible during coding (n = 1). The task took 2–3 min for children to complete, and they were given a small prize for participating.

Data were also collected from 50 adults (M = 42.2 years, SD = 12.1 years; 26 female, 24 male) on the same task in the museum. Adult participants were not the parents of child participants. Like children, adults were randomly assigned to one of three conditions, with 20 adults in both the *empty-handed movement with objects present* condition and the *empty-handed movement with objects absent* condition, and 10 adults in the *movement performed on objects* condition. Data were collected on adults to: (a) serve as a comparison to the child responses and (b) replicate the adult findings from Novack et al. (2016) in the identical testing environment as the children.

Stimuli

Figure 1 displays still frames from three movie stimuli. Movies showed the torso of a woman in front of a table. Her chest, arms, and hands were visible, but her face was not. In each 10-s video, the woman produced movements with her hands. In two conditions (*movement performed on objects; empty-handed movement with objects present*), four balls (two orange and two blue) and two boxes (one orange and one blue) sat on the table in front of the woman. In the third condition (*empty-handed movement with objects absent*), no objects were present on the table. The movies were identical to those used by Novack et al. (2016).

Movement Performed on Objects

A woman picks up each of the four balls on the table and places them one at a time in the color-matched boxes (see Figure 1a). First, she picks up the inner blue ball with her left hand and places it in the blue box on her left; then she picks up the inner orange ball with her right hand and places it in the orange box on her right. These actions are repeated with the outer balls.

Empty-Handed Movement With Objects Present

A woman produces the same movements in the *movement performed on objects* condition but over the

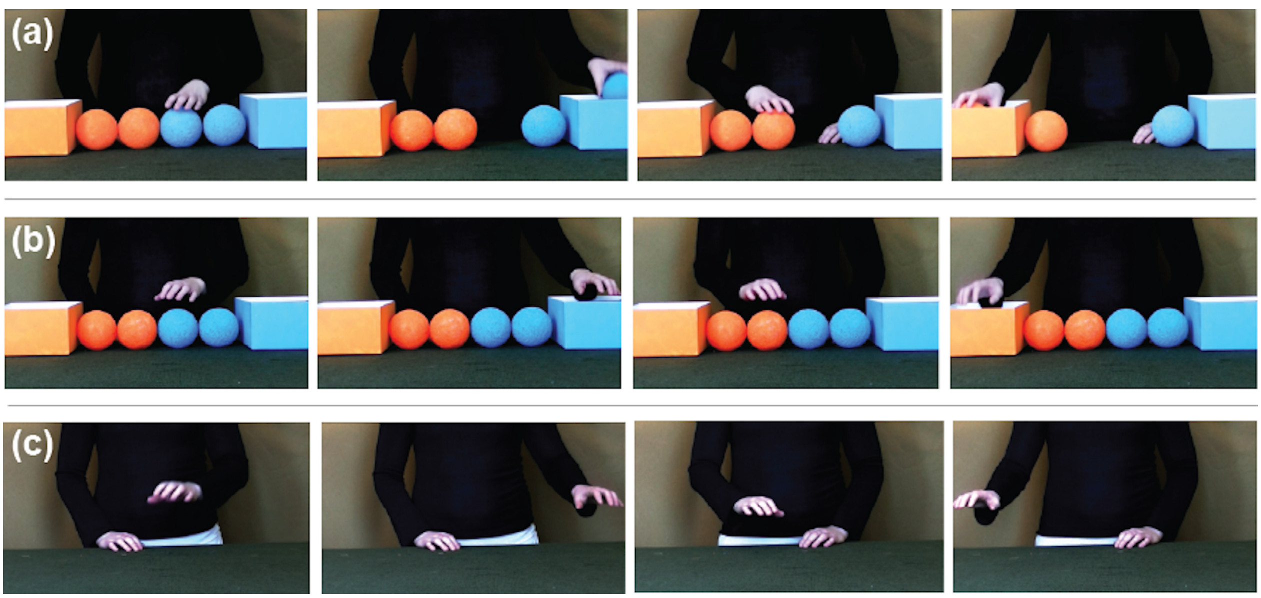

Figure 1. Stills from movie stimuli in the three conditions: (a) movement performed on objects, (b) empty-handed movement with objects present, (c) empty-handed movement with objects absent.

objects, maintaining the hand shape necessary to grasp the balls (i.e., a palm down C-shape) and the trajectory of movement used in the *movement performed on objects* condition but not touching the balls (see Figure 1b). In contrast to the *movement performed objects* condition, there is no change in the location of the balls during the movie.

Empty-Handed Movement With Objects Absent

A woman produces the same movements as in the other two conditions, but without any of the objects present (see Figure 1c). The woman maintains the same hand shape and trajectory as in the first two conditions.

Timing of movements across videos was carefully controlled by having the woman in the movies synchronize her movements to an audio track, which was removed from the final versions of the stimuli. For additional details, see Novack et al. (2016).

Procedure

Children and adults were invited to participate in the study while they were visiting a science museum. The study was conducted at a small table located in a relatively quiet part of the museum, and children sat next to the experimenter facing a wall to decrease distractions. At the beginning of the study, all participants were told they would watch a very short movie and then be asked what had happened in the movie. They were also told that the movie had no sound so they had to pay very close attention. Participants then watched one of three 10-s movies on a 9.7-inch display iPad, depending on the condition to which they had been randomly assigned. When the movie ended, the experimenter asked, "What happened in the movie?" followed by additional prompts that were designed to further probe participants' interpretation of the movie. All participants received the additional prompts, which were as follows. For participants in the *movement performed on objects* or *empty-handed movement with objects present* conditions, the experimenter asked, "So at the end of the movie, were the balls in the boxes or out of the boxes." This question was asked to determine whether children could correctly remember the end state of the movie that they watched. The correct answer in the *movement performed on objects* condition was that the balls were inside the boxes; the correct answer in the *empty-handed movement with objects present* condition was that the balls were out of the boxes on the table. For consistency, a similarly structured prompt was asked in the *empty-handed movement with objects absent* condition: "So at the end of the movie, were her hands on the table or off of the table?" After focusing on the end state of the movie, the experimenter again probed participants' interpretation of the scene by asking, "So tell me one more time, what happened in the scene?" Finally, after children responded, the experimenter asked, "Did she do it for a reason?" For children who answered "yes," the experimenter asked "What reason?" Participants' responses were audio recorded for later coding.

Coding and Reliability

Participants' responses to the prompt, "What happened in the movie?" were classified into categories based on an adapted version of a coding scheme used by Novack et al. (2016). Although the prompt does not specifically probe the intentions of the woman in the stimuli, the pragmatics of the question, combined with the fact that the woman's movements appeared to be produced voluntarily, should invite descriptions of goals and intentions (see Schachner & Carey, 2013 for discussion of assumptions about intentionality). The codes are described below:

1. *External goal:* The movie is described in terms of actions completed on objects, with the description focusing on movement of objects, rather than movement of hands (e.g., "she took balls and put them in boxes"; "the blue balls goed in the blue container and the orange balls goed in the orange container"; "balls were placed in boxes"). In rare cases, this category also included attempted actions on objects ("it looked like he was trying to put the balls in the box").
2. *Movement-based goal:* The movie is described in terms of low-level spatiotemporal movements without mentioning a higher-level goal—the description is focused on the movement of the hands themselves (e.g., "a guy had his hands going back and forth"; "she was like, moving her arms"; "someone moved their hand from a ball to the block and back to the ball").
3. *Representational goal:* The movie is described in terms of movements representing (but not

actually carrying out) external goals (e.g., "the person was imitating putting the balls in the boxes"; "he was pretending to put balls in the container"; "she looked like she was playing a piano in the air").

4. *Other:* The movie is described: (a) without mentioning movement at all (e.g., "there was a hand," "It showed a rectangle that was orange and two orange balls two blue balls and a blue rectangle"), or (b) mentioning movement, but the response was too ambiguous to assign a goal-oriented code (e.g., "it did um some marbles and um I saw some box"; "he was doing one by one").

Two researchers independently assigned a single code to all responses, which had been transcribed from the original audio files. Coders were blind to the condition and age of each participant. Coders agreed on 731 of 778 trials (94.0%), $\kappa = 0.92$. Any disagreements were discussed between the coders and resolved.

A separate coding system was used for the final set of prompts, "Did she do it for a reason? What reason?" As we were particularly interested in children's ability to interpret empty-handed movement as representational, we coded whether responses to these questions for children in the *empty-handed movement with objects present* and *empty-handed movement with objects absent* conditions suggested that they interpreted the movement as representational. Responses were coded as *representational* if participants described the woman as having a goal to *represent* information through her actions (e.g., "to show us what he was gonna do with the balls into the blue boxes"; "To show little kids how to match colors"). Responses were coded as *nonrepresentational* if participants said they were not sure or thought the woman did not have a reason for her movements (e.g., "No, I have no idea why she did it"), or if their response suggested the woman had a movement-based goal (e.g., "To like practice for something she was going to get tested for"), or was ambiguous in terms of whether the goal of described actions was to *represent* information (e.g., "She was doing one by one").

As in coding the main prompts, two researchers assigned a single code to all responses and were blind to the condition of each participant. Coders agreed 307 of 317 trials (96.8%, $\kappa = 0.92$). Any disagreements were discussed between the coders and resolved.

Results

As detailed earlier, children and adult participants were asked to describe one of three movies depicting a woman moving her hands and to answer additional prompts about the movie. Descriptions were coded as having an external goal, a movement-based goal, or a representational goal; if a description did not mention a goal, it was assigned the code of "Other."

We first calculated the proportion of participants who gave the four types of response to the initial prompt in the *movement performed on objects* condition (note that each participant gave only one response). Second, we calculated the proportion of participants who gave the four types of responses to the initial prompt in the two empty-handed movement conditions, *empty-handed movement with objects present* and *empty-handed movement with objects absent.* We also calculated whether participants gave a representational goal response in these two conditions at any time across the entire study, taking into account responses across all prompts; here, our dependent variable was a binomial response—either providing, or not providing, a representational goal response at any point during the study. To assess the effect of age on responses in this section, we used age as a continuous variable, although we collapsed into age groups for data visualization and for post hoc analyses. As a preview, we found almost no variability in participants' responses in the *movement performed on objects* condition and much more variability when participants described the empty-handed movement movies in the *empty-handed movement with objects present* condition and the *empty-handed movement with objects absent* condition.

Movement Performed on Objects

An established body of literature shows that the ability to interpret actions on objects in relation to external goals develops in infancy (e.g., Woodward, 1998). Thus, it was not surprising that we saw essentially no variability in responses elicited to the *movement performed on objects* movie, regardless of age. Almost all responses children gave to the *movement performed on objects* condition were coded as external goal responses (97.2%). A binomial logistic regression predicting the likelihood of an external goal response by child age confirmed that there was no effect of age ($\beta = .39$, $SE = .46$, $z = 0.84$, $p = .40$). We analyzed the adults separately and found, in line with previous work (Novack et al., 2016; Schachner & Carey, 2013), that 100% of adults provided external goal responses.

Empty-Handed Movement

In contrast to the uniform responses elicited by the *movement performed on objects* movie, there was considerable variability in responses from both children and adults to the empty-handed movement conditions, although participants did display distinct patterns to the two conditions overall (see Figure 2). Adults were most likely to produce movement-based goal responses in the *empty-handed movement with objects absent* condition; 70% of adults gave this response, with 25% giving representational responses. Children, too, gave movement-based goal responses in this condition, although a little more often than adults; 83.7% of children gave this response, with 12.6% providing representational responses. The opposite pattern was found for adults in the *empty-handed movement with objects present* condition; 60% of adults gave representational responses, with 20% providing movement-based responses, thus replicating previous findings (Novack et al., 2016). More children provided representational responses in this condition than in the *empty-handed movement with objects absent* condition (22.0% vs. 12.6%), but movement-based goals were still children's dominant response in this condition; 42.4% of children gave this response, with 20.5% describing external goals, and 15.2% giving responses coded as "Other."

Log-linear poisson models, which allow for comparison of nonindependent response codes, confirmed that both children and adults showed distinct patterns of responses in the two empty-handed movement conditions. For children, we ran a log-linear poisson model on a 2 (condition) × 4 (response code) contingency table, which revealed that responses in the *empty-handed movement with objects present* condition were significantly different from responses in the *empty-handed movement with objects absent* condition (χ^2, 3 = 64.57, $p < .001$). The same was true for adults, using a 2 (condition) × 3 (response code) contingency table (χ^2, 2 = 10.78, $p < .005$). Please note, three response codes were used in the contingency table as no adult responses were coded in the "Other" category.

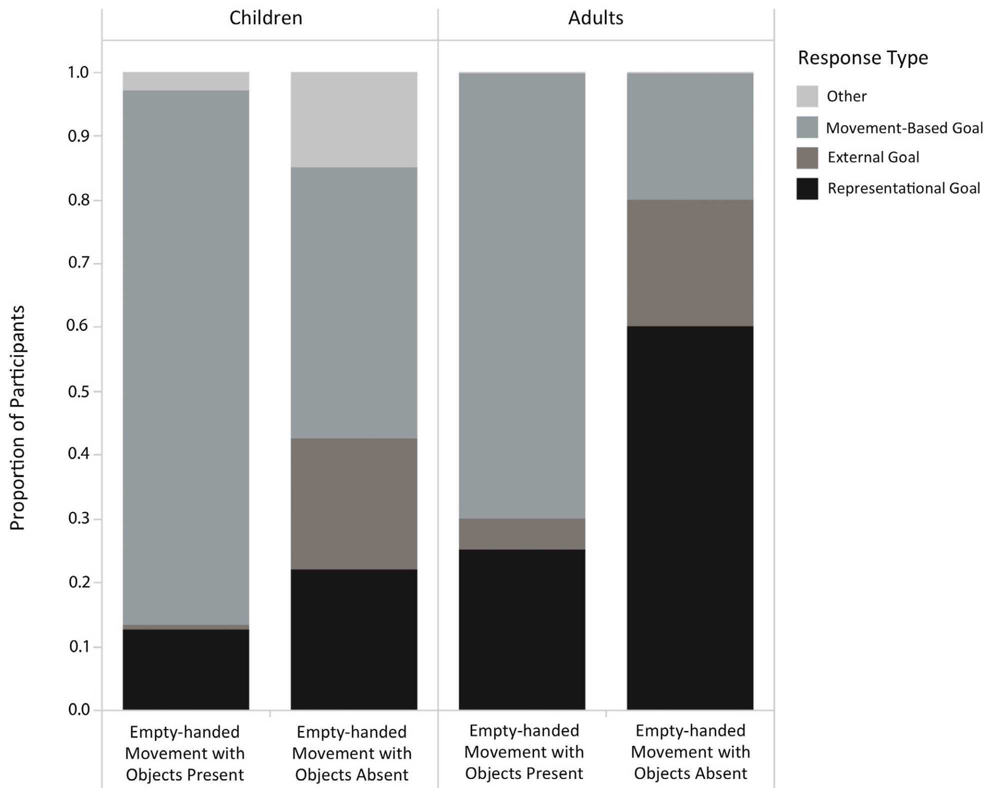

Figure 2. Proportion of adults and children who gave external goals, representational goals, movement-based goals, or "other" responses in the two empty-handed movement conditions.

Finally, we compared representational goals given by children and adults across both empty-handed conditions and found significantly higher rates of representational goal responses in adults (45.0%) than in children (17.2%), χ^2, 1 = 12.12, $p < .001$. There thus appears to be a developmental change in the ability to ascribe representational goals to empty-handed movements.

Exploring the Language of Responses

Comparing representational goals in children versus adults indicates that there is a developmental change in how empty-handed movement is interpreted: notably, children are less likely to describe movement as representational than adults. However, as our dependent measure was based on participants' verbal responses, it is possible that the difference we see in representational goals between children and adults can be traced to differences in language abilities between the groups. In other words, describing representational goals may be more difficult than describing external goals or movement-based goals; if so, adults' better verbal skills may underlie the developmental difference in representational goal responses. We address this possibility by examining features of the language used for each type of response.

Response Length

First, we considered the length of responses. We ask whether representational goal responses tended to be longer than other types of goal responses and also whether response length differed with age. If more words are necessary to describe a representational goal than other types of goals, children may be limited by their language. We found that this was not the case. Overall, an analysis of variance predicting response length (number of words) by age binned into groups (e.g., 4-year-olds, adults) and response code (external goal, representational goal, movement-based goal) showed an overall effect of age, $F(5, 363) = 6.91$, $p < .001$, where older participants gave longer responses than younger participants (see Figure 3). However, there was no significant effect of response code, $F(2, 363) = 1.97$, $p = .14$, suggesting that a lower rate of representational responses in younger age groups is not due to a limitation in language ability. We find further support for this idea using a qualitative approach: We see a range of response lengths for representational goal descriptions. Typical examples of short responses included "She was pretending to put balls in the container" (4-year-old) and "Imaginarily moving objects" (adult). Examples of longer responses included "Well she, it looked like she

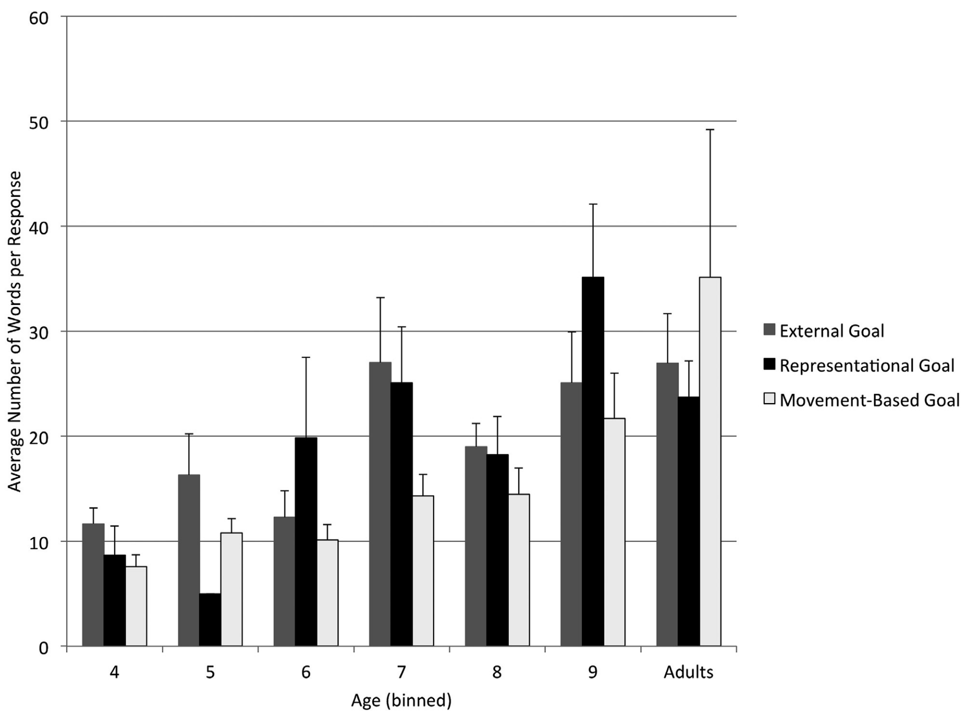

Figure 3. Average length of response in each age group as a function of response code.

was pretending to pick the balls to there but she wasn't really moving them." (8-year-old) and "In the video, the gentleman, or lady, whichever it was, was simulating picking up a ball with each hand and putting it in the crate on the sides" (Adult).

Types of Constructions Used to Convey Representational Goals

As can be seen from the examples provided, certain constructions (e.g., *pretend to put, simulate picking up*) lend themselves to describing representational goals. We coded the types of constructions participants used to convey representational goals and asked (a) what types of constructions adults used in their representational responses and (b) whether these devices were also used by children. If so, we have evidence that the children's linguistic skills do not prevent them from expressing representational goals.

We identified seven types of constructions used by the 17 adults who provided representational goal responses. Three of the constructions were each used by 4 of 17 adults (23.5% each): (a) using the verb *pretend* (e.g., *pretend to put, pretending to take*), (b) using a more sophisticated verb that signaled pretense (e.g., *simulate picking up, mime putting*), and (c) using a construction that indicated the actor was attempting to communicate information or demonstrate something (e.g., *trying to say; signaled to go*). The fourth construction was used by three of 17 adults (17.6%), (d) using the word *like* (e.g., *looked like moving*). The fifth, sixth, and seventh types were each used by one of the 17 adults (5.9% each), (e) modifying the noun to make it clear that the action was not actually taking place (e.g., *moving imaginary cups*), (f) describing an action on an object not present in the scene (e.g., *playing the piano*; the woman in the video was seen by some participants as pretending to play a keyboard instrument), and (g) indicating an action that would take place in the future (e.g., *going to put*).

Having established the types of constructions that adults use to convey representational goals, we then asked whether children were able to use these same devices. We found that our youngest children—4- and 5-year-olds (of which there were only six)—used three of the adults' construction types: type (a), two of the six children who produced representational responses used the verb *pretend*; type (e), one child modified the noun so that it was clear that the action was not actually taking place (e.g., *pretend balls*); type (f), three children described an action on an object that was not present (e.g., *playing the piano*). The remaining four construction types that adults used were seen only in the older children. The 6- and 7-year-olds used two types not found in the responses of the 4- and 5-year-olds: types (c), for example, *showing*, and type (g), for example, *going to put*. The 8- and 9-year-olds added two more types to their repertoires: type (b), for example, *fakely took*, and type (d), for example, *looked like stacking*.

Although there are many ways to express a representational goal, the point we stress here is that there are simple devices that even the 4- and 5-year-olds in our sample were able to use. The difference in rates of representational goal responses that we have found across development is thus not likely to be due to developmental changes in language skills, but rather to changes in the ability to think about movements as representational actions.

Representational Responses by Age

Given that age-related language differences are not a concern, we next explored the effect of age on representational goal responses within our child sample, focusing on age-related differences in representational goal responses between the ages of 4 and 9. We had two hypotheses: (a) The propensity to interpret empty-handed movement as representational would increase with age, and (b) given findings that children show protracted acquisition of the ability to integrate gesture and contextual cues (Demir-Lira et al., under review; Dick et al., 2012; Wakefield et al., 2013), object presence (which is a contextual cue) may have a bigger effect on the likelihood of interpreting empty-handed movement as representational later (rather than earlier) in childhood. Based on these hypotheses, we built a binomial model to test whether children's likelihood of providing a representational response was predicted by age as a main effect term and Age × Condition (*empty-handed movement with objects present; empty-handed movement with objects absent*) as an interaction term. The model supported our hypotheses, revealing a positive effect of age ($\beta = .40$, $SE = .11$, $z = 3.79$, $p < .001$)—children became more likely to give a representational response with age—as well as an interaction between age and condition ($\beta = .10$, $SE = .04$, $z = 2.18$, $p < .05$). Likelihood ratio tests confirmed that this model (a main effect of age, and an interaction between age and condition) was a better fit than a simpler model without the interaction term, $\chi^2(1) = 4.89$, $p < .05$. A more complex model with both main effects (age and condition) and the interaction term (Age × Condition), did not improve the fit, $\chi^2(1) = 0.02$, $p = .88$.

The interaction between age and condition suggests that the older a child is, the more influence object presence has on her ability to see empty-handed movement as meaningful. To explore this interaction more fully, we separated children into age groups by year (e.g., 4-year-olds, 5-year-olds, etc.) and asked whether the presence of objects was a predictor of representational goal response within each group. There were no groups in which object presence was a significant predictor, probably because, when partitioned in this way, the age groups were too small to detect an effect. However, exploratory post hoc analyses do point to differences with age: Condition (*empty-handed movement with objects present; empty-handed movement with objects absent*) predicted the likelihood of a representational response after age 6 ($\beta = .82$, $SE = .38$, $z = 2.19$, $p < .05$) but not before age 6 ($\beta = .04$, $SE = .84$, $z = 0.052$, $p = .96$). With the current data set, we cannot make a strong claim about the exact age at which object presence becomes an important cue to interpreting movement as representational. Nevertheless, our data do allow us to state with some certainty that this process unfolds across childhood.

Our findings are thus in line with our two predictions: (a) Children's ability to understand empty-handed movement as representational develops with age, and (b) a rich context (objects present) supports representational goal responses better than a less rich context (objects absent), particularly in older children. However, we were surprised at the overall low rates of representational goal responses across the children (17.2%). Even 9-year-olds, the oldest children in our sample, gave representational goal responses at half the rate as the adults in our sample (9-year-olds: 20.5%; adults: 42.5%). These low rates may suggest that children between the ages of 4 and 9 rarely interpret empty-handed movement as representational. Alternatively, children may simply need more opportunity and encouragement to express their competence. We explored this possibility using data from the additional prompts.

Recall that after children gave their initial response to the prompt, "What happened in the scene?" they were asked about the ending state of the movie. They were then asked a second time, "What happened in the scene?" as well as, "Did she do it for a reason? What reason?". We calculated whether a child gave a representational goal response to any of these three prompts. A child

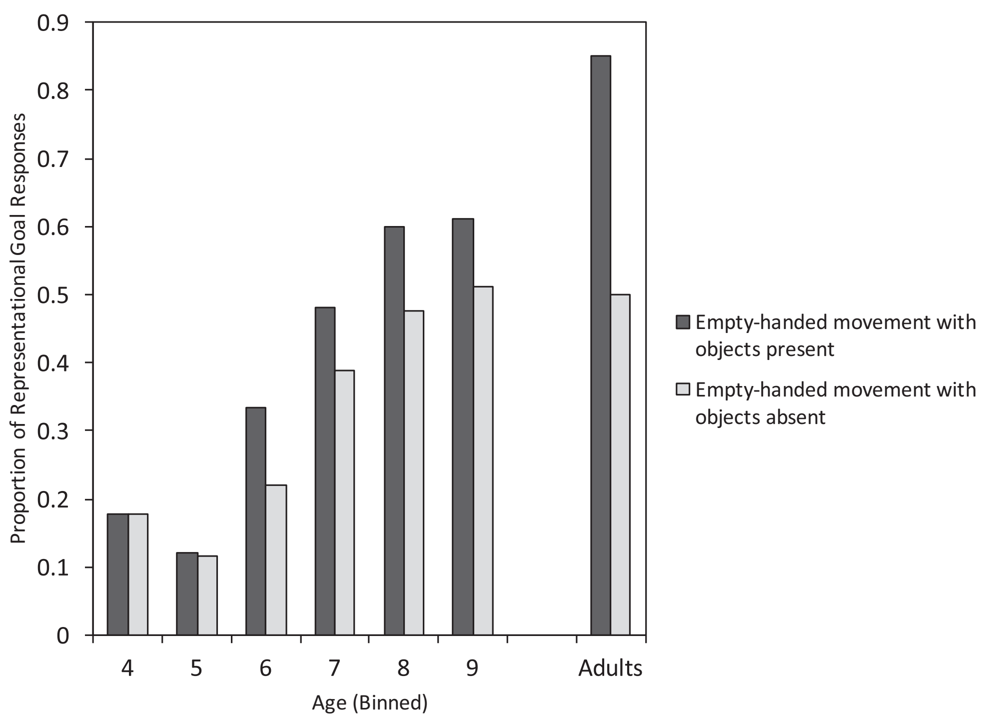

Figure 4. Proportion of children in each age group giving at least one representational goal response during the experimental session in each of the two empty-handed movement conditions.

was classified as having given a representational goal response if she provided a representational goal (as opposed to an external goal, movement-based goal, or "other" response) to at least one of the first two prompts, and/or if she provided a representational response (as opposed to a nonrepresentational response) to the final prompt.

Based on data from these three prompts, we found that 31.1% of our child sample provided at least one representational response, which almost doubles the proportion of children describing empty-handed movements as representational after the first prompt (17.2%). As in the model based on responses following the first prompt, we found a significant effect of age ($\beta = .46$, $SE = .09$, $z = 5.15$, $p < .001$) and an interaction between condition and age ($\beta = .11$, $SE = .04$, $z = 2.75$, $p < .01$; see Figure 4). In addition, using the same exploratory post hoc analysis, we found that children below the age of 6 were not influenced by the presence of objects ($\beta = .05$, $SE = .55$, $z = 0.09$, $p = .93$), whereas 6- to 9-year-olds were influenced by the presence of objects ($\beta = .88$, $SE = .32$, $z = 2.71$, $p < .01$). Again, this result is exploratory—the solid conclusion from our data is that, over childhood, the presence of objects becomes increasingly influential in how empty-handed movements are interpreted; at issue is the precise age at which children begin to display this effect.

We performed the same analysis on adults and found that they too were significantly more likely to provide representational responses after further prompting, raising their overall rate of representational responses from 42.5% to 67.5%, (χ^2, 1 = 5.05, $p < .05$). Prompting thus increased representational goal responses in all participants, which means that children gave representational responses to empty-handed movement significantly less often than adults (31.1% vs. 67.5%) even after continued prompting (χ^2, 1 = 18.51, $p < .001$).

Empty-Handed Movement as Action

Both children and adults, at times, gave external goal responses to the initial prompt in the *empty-handed movement with objects present* condition. This response was unexpected, as Novack et al. (2016) found no external goal responses to empty-handed movement in adults who typed their responses online. The external goal responses that the participants in our study gave were structured as if the actress in the movies had actually completed an action (e.g., "She moved balls into boxes") despite the fact that no completed actions occurred (i.e., the woman never physically touched or moved the objects). These responses raise two possibilities: (a) participants actually encoded movement *off* objects as movement *on* objects, or (b) given the pragmatics of the task, participants may have described the stimuli in terms of the actor's intended goal (e.g., to move or try to move balls into boxes) on the assumption that the experimenter would know that the goal was not actually completed. In other words, these participants may have described the *meaning* of the actor's movement, rather than providing a factual account of the video.

To test these possibilities in adults, we first considered whether adults correctly answered the second prompt, "So, at the end of the movie, were the balls in the boxes or out of the boxes." Of the four adults who provided external goal responses, three correctly stated that, at the end of the movie, the balls were outside of the boxes. All three adults then changed their response to the third prompt, "Can you tell me again what happened in the movie?" from external goal responses to representational goal responses. For example, after providing an external goal response initially, one participant said, "The person was reaching for the balls and putting—pretending to put them in the box, is, I guess what they were doing." The one adult who incorrectly said that the balls were inside the boxes at the end of the movie persisted in giving an external goal the second time she was asked. For the most part, adults who described empty-handed movements in terms of external goals did not actually think the balls had been moved. Rather, the pragmatics of the experimental context seemed to draw them to interpret the empty-handed movement within an external goal framework.

Like adults, children's external goal responses describing empty-handed movement seemed not to be driven by an incorrect encoding of the event but rather by the pragmatics of the experimental context. Of the 27 children who provided an external goal response to the initial prompt, 24 (88.9%) correctly identified the balls as being outside of the boxes at the end of the movie, which was comparable to the number of children who gave the correct answer across the other response types (82 of 93, 88.2%). But, unlike adults, of those 24 children, 17 persisted in giving external goal responses on the third prompt. The remaining seven children gave a variety of responses, with only three changing their response to a representational goal. Although both adults and children were affected by the pragmatics of the situation, children were still more limited than adults in their ability to describe empty-handed movements in terms of representational goals.

Discussion

We investigated whether the ability to interpret empty-handed movement as gesture—as movements that *represent*—changes across development. Specifically, we asked children (4- to 9-year-olds) and adults to describe empty-handed movements performed in the presence or absence of objects, and explored whether age and context affected their ability to imbue these movements with meaning. We found an overall increase across childhood in the ability to interpret empty-handed movement as representational actions and some suggestion that, before age 6, children are not affected by the presence of objects. The influence of objects as a cue for seeing meaning in movement strengthens across childhood.

We also found that the ability to describe movement as gesture follows a protracted period of development, particularly compared to the ability to attribute external goals to movement performed on objects. Children as young as 4 consistently described an event in which an actor physically moved balls into boxes in terms of external goals, as did adults. However, when shown empty-handed movements, children's descriptions were not completely adult like. For example, although both adults and children sometimes described empty-handed movement in terms of external goals, adults corrected their responses when prompted, changing them to representational goals, whereas children did not. Most importantly, even by age 9, the oldest age tested in our child sample, children were not yet describing empty-handed movements as having representational goals as often as the adults in our sample, and our analysis of children's language suggests that these effects were not a by product of developing language skills. Together, these results suggest that even though a few children are able to attribute a representational goal to empty-handed movement at age 4, overall, children's ability to describe empty-handed movement as representational is underdeveloped at this age. Our results thus build on the previous literature, broadening our understanding of humans' abilities to interpret different types of movement across the life span.

The ability of children to use the presence of objects as a cue to interpret an empty-handed movement as representational strengthened across development, and an exploratory analysis suggested that this contextual cue may not affect 4- and 5-year-old children's interpretation of empty-handed movement. This finding has implications for the framework developed by Novack et al. (2016), which suggests that adults use contextual cues from a variety of sources to increase their likelihood of seeing empty-handed movement as meaningful. Novack et al. identified three potential contextual sources: (a) cues *internal to the movement*, such as hand shape: (b) cues *external to the movement*, such as the presence of objects: and (c) *communicative* cues, such as speech accompanying the movement. Here, we asked whether children could make use of cues *external to the movement* when interpreting empty-handed movement and found that this is an ability that strengthens across childhood. Thus, although adults reliably use a basic process—attending to and integrating contextual cues—to differentiate between meaningful and meaningless movement, children do not, at least with respect to one type of cue—cues that are external to the movement. Further work is needed to determine whether children use the other two types of cues identified by Novack et al. (2016)—cues internal to the movement and communicative cues—and to understand how the general ability to integrate context into decisions about what counts as a gesture develops over childhood.

This study shows that even with limited context, children are inclined to see empty-handed movement as having representational goals. Yet it is, in some sense, surprising that we observed such low rates of representational goal responses, particularly in our youngest participants (even after giving them additional chances to rethink and revise their interpretations). After all, previous work has found that children as young as 2 and 3 years can infer meaning from iconic gestures (e.g., Goodrich & Hudson Kam, 2009; Marentette & Nicoladis, 2011; Novack et al., 2015). Why then did fewer than 25% of our 4- to 6-year-olds offer representational goal responses to describe empty-handed movements?

One possibility is that our study provided few cues that the empty-handed movement in our video should be interpreted as representational, which would highlight and exaggerate the observed developmental changes. The hand movements in our study were brief and were presented with minimal contextual support (i.e., no speech, no face to provide eye gaze or emotional expression). Young children may require a richer context than adults to infer meaning from hand movements. For example, it may be particularly interesting to consider communicative cues, such as the presence of a face or directed gaze, as these cues might be important for interpreting gesture. In fact, eye-tracking studies have found that when watching a gesturing speaker, adults predominately focus on the speaker's face but shift their attention to the speaker's hands when the speaker looks to his own hands, suggesting that gaze can cue the importance of gesture (Beattie, Webster, & Ross, 2010; Gullberg & Holmqvist, 2006; Gullberg & Kita, 2009). In this study, we intentionally eliminated the influence of social cues by only showing the actor's torso, but future work should consider how the presence of social cues, such as the face and gaze, may influence an observer's interpretation of a movement. In addition, the stimuli in this study showed familiar objects and actions. Even when objects were not present, the hand shape and trajectory could provide clues that called to mind common actions on objects—we saw representational goal responses about moving invisible cups or playing a piano that suggest this is true. In future work, it may be interesting to ask how very novel actions on unknown objects would be interpreted. Finally, one might imagine a condition with *more* contextual support than our *empty-handed movement with objects absent* condition but *less* contextual support than our *empty-handed movement with objects present* condition. Instead of eliminating both the objects on which an actor might act (e.g., balls) and the objects involved in completing an external goal (e.g., the boxes into which balls could be placed), the empty-handed movements could be performed in the presence of just the goal-related objects (e.g., the boxes). Based on the framework put forth by Novack et al. (2016), we would expect the number of representational responses to increase in this condition, compared to the current objects absent condition. Comparing the representational responses elicited in this condition and the current *empty-handed movement with objects present* condition would help to elucidate how context affects movement interpretation—that is, it would allow us to determine whether each additional contextual cue incrementally boosts the number of representational responses found in the empty-handed movement condition.

Although it would be interesting to consider other forms of context, the finding that children are not as good as adults at integrating the meaning of gesture with other contextual information is supported by existing research. For example, Kelly and Church (1998) showed that, unlike adults whose recollection of a spoken message was influenced by information conveyed in both gesture and speech, children's recollections did not reflect an integration of these two streams of information. Along the same lines, Demir-Lira et al. (under review) found that only half of the 8- to 10-year-old children they tested on a task requiring gesture–speech integration solved the task like adults and integrated information across the two modalities. Thus, it may not be just the lack of context that caused low rates of representational responses in the children in our study. Rather, the sparseness of our context may have highlighted a developmental difference between children's and adults' ability to process empty-handed movement as meaningful.

We suggest that the developmental change we find in the ability to interpret empty-handed movement as representational may be driven by developmental changes in domain general representational processing capacities (e.g., the ability to understand analogies, representations, and abstractions more broadly). This skill is known to show a protracted period of development in early childhood (e.g., DeLoache, 1995; Richland, Morrison, & Holyoak, 2006) and could contribute to a child's ability to interpret a movement as representational. For example, Richland et al. (2006) show that children's ability to reason analogically increases between the ages of 3 and 10, as they gain the ability to process relational complexity and ignore featural distractions. This is close to the age range in this study, where we see a similar, protracted increase. Being able to describe our videos in terms of representational goals may be a signal that a child has reached a developmental milestone and is able to interpret not just empty-handed gestures, but other kinds of movements and objects as well, as representations. Note that some children at each age do offer representational goals for empty-handed movement. Perhaps children who produce more gesture themselves are particularly likely to see empty-hand movements produced by others as representational. Alternatively, children who have better representational processing capacities (e.g., are better at seeing analogies more broadly) may be likely to view gesture as representational actions. Testing this second possibility would require a separate measure of representational processing capacities to correlate with the ability to attribute representational meaning to empty-handed movement in our task.

In addition to demonstrating a developmental shift in children's ability to interpret empty-handed movement as representational, our study can inform research on the benefits of using gesture in instruction. Previous work has shown that children learn better from instruction that contains gesture than from instruction that does not contain gesture (see Novack & Goldin-Meadow, 2015; for review). Often these gestures are produced in the presence of objects that are referenced through the gestures (e.g., a gesture near two numbers indicating that a student should add the two together or pointing gestures highlighting analogous sides of rectangles in an algebra problem). Of course, not every child given instruction containing gesture benefits from that instruction. We suggest that a child's ability to learn from gesture in an instructional setting might be related to that child's ability to describe gesture in terms of representational action. For example, children who describe the empty-handed movements in our study as representational might be more able to learn a ball-moving routine from gesture than children who do not attribute representational meaning to the empty-handed movements. Alternatively, if learning from gesture is an implicit process, then children may not have to be aware that gestures are representational to learn from those gestures in a lesson. Indeed, some research has shown that, at least when children produce gestures, they do not need to be aware of the meaning of the movements to benefit from their content (Brooks & Goldin-Meadow, 2015). Even if it turns out that recognizing a hand movement as meaningful gesture is not essential to being able to learn from that movement, it could make learning more likely. If a child thinks that a hand movement is meaningless, the child may be less inclined to pay attention to it, which is likely to diminish its benefit.

In conclusion, our work shows that, by age 4, children have the capacity to recognize some kinds of hand movements as gestures—movements that are produced to *represent* information rather than to effect actual change in the world (e.g., object-directed actions) or to merely move (i.e., movement for its own sake). We also found that, particularly after the age of 6, children are able to use contextual cues (in this case, the presence of objects relevant to the form of the moving hands) to increase the likelihood that they will interpret an empty-handed movement as representational. Taken together, our results suggest that, even to children, empty-handed movements are not necessarily seen as meaningless hand movements through space but rather as rich representational forms that have the capacity to carry meaning and convey information—that is, as gesture. Our study represents an important first step in determining how children identify empty-handed movements as meaningful and raises intriguing questions about whether the ability to identify a movement as gesture is related to the efficacy of that gesture in communicative contexts, educational contexts, and cognitive processes more broadly.

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