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Get to the point: Preschoolers' spontaneous gesture use during a cardinality task

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ABSTRACT

Gesture is a powerful learning tool for language, mathematics, and general problem solving, although the specific function of gesture is subject to debate. To address this question, we characterized predictors of preschoolers' spontaneous gestures while completing a cardinality task. We analyzed video data from 343 preschoolers (158 male, M_{age} = 4.07y) who participated in the Give-N task (Wynn, 1992), which is used to assess children's number knowledge and understanding of cardinality. Analyses revealed that children's number knowledge positively predicted gesture use, even when controlling for age, suggesting that as children gain better understanding of the skills necessary to complete the task, they are more likely to use gesture to solve numerical tasks. Moreover, those who had not yet acquired an understanding of cardinality (subset knowers, who are said to not use pointing gestures) were shown to use an effective gestural strategy (pointing and counting). Spontaneous gesture use across all knower-levels was also found to increase as a function of trial difficulty (trials involving larger set sizes), such that children were most likely to gesture on trials that challenged their abilities. Overall, findings indicate that children rely upon gestures as a scaffold during cognitively difficult tasks, and it is their relevant knowledge, not their age, that predicts their likelihood of engaging in gesture.

1. Introduction

Gestures are primitive forms of linguistic expression that are typically categorized as body movements that express or emphasize concepts, beliefs, or feelings (Cartmill, Beilock, & Goldin-Meadow, 2012; Lyn, Greenfield, Savage-Rumbaugh, Gillespie-Lynch, & Hopkins, 2011; Pika, 2008; Tomasello, 2007). A wealth of prior work finds that these primitive expressions are beneficial for learning and communication: speakers' use of gesture has been found to aid in listeners' comprehension (Kendon, 1994), reduce listeners' cognitive load (Goldin-Meadow, 2005) and promote learning and concept generalization (Novack, Congdon, Hemani-Lopez, & Goldin-Meadow, 2014; Valenzeno, Alibali, & Klatzky, 2003). Though much work has focused on how *speakers'* (i.e., teachers' and parents') use of gesture may aid the comprehension of the intended learner, considerably less work has focused on how *learners* themselves use gesture to scaffold their own learning. Here we investigate how preschool-aged children spontaneously employ gesture during a numerical task by exploring how individual and contextual differences predict children's gesture use.

Our investigation is informed by work showing that learners' use of gesture confers many positive benefits. For example, using gestures lightens cognitive load during learning (Alibali & DiRusso, 1999; Goldin-Meadow, 2001; Iverson & Goldin-Meadow, 1998;

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Novack et al., 2014; Ping & Goldin-Meadow, 2010) and conveys implicit conceptual knowledge and a "readiness to learn novel information" (Broaders & Goldin-Meadow, 2010; Goldin-Meadow, Wein, & Chang, 1992; Iverson & Goldin-Meadow, 2005; McNeill, 1992). These benefits may be due in part to the fact that gesture conveys information in a visuospatial representational format as opposed to a verbal one, as it represents the information contained in speech in a second modality and is more dynamic than speech alone. Gestures also highlight attention during conversations (Rowe, 2000; Rowe & Goldin-Meadow, 2009). Thus, both viewing and using gesture is linked to concept acquisition during development.

How and when learners use gestures spontaneously is relatively understudied. Infants begin to use gesture by 10–13 months of age (Bates, Camaioni, & Volterra, 1975; Bates, Benigni, Bretherton, Camaioni, & Volterra, 1979); by 24–42 months of age, children's gesture use during speech is comparable to that of adults (Nicoladis, Mayberry, & Genesee, 1999). However, during this time of rapid development, the types of gestures children use changes. For example, once infants reach toddlerhood, their use of representational gestures (gestures that use perceptual form to symbolically represent a referent; e.g., holding the empty fist to the ear for "telephone") decrease, but deictic gestures (gestures used to reference or convey intent; e.g., pointing) increase (Iverson, Capirci, & Caselli, 1994). Other similar patterns of gesture type changing has been shown in the literature (e.g. showing, giving, and pointing gestures increase as reaching and emotive gestures decrease; Blake & Dolgoy, 1993), which suggests that children spontaneously use gesture at similar rates, though their gestures may serve a different purpose depending on their age and the situational context.

A large portion of prior work regarding children's use of gesture focuses on contexts examining language development. By 16 months of age, infants' gesture use begins to predict subsequent language milestones. For example, the use of single gestures and gesture word combinations at 16 month of age is correlated with total vocal production at 20 months (Capirci, Iverson, Pizzuto, & Volterra, 1996). Indeed, gesture and language have been shown to act as an integrated system, with gesture bootstrapping verbal production and comprehension (Morford & Goldin-Meadow, 1992). Considerably less work has been devoted to studying the potential benefit of gesture outside of language learning, specifically in relation to understanding gesture's role in math learning and numerical development. Mathematical contexts serve as prime candidates for studying the role of gesture in conceptual change in early development for several reasons: First, the preschool period is marked by rapid changes in the learning of numerical concepts and math-related vocabulary (Gelman & Gallistel, 1986; Wynn, 1992). Second, math learning also involves processing visuo-temporal information that cannot be otherwise conveyed (i.e., using a pointing gesture while verbally counting highlights the conceptual knowledge that the verbal count list is tied to objects in a sequential manner). For example, Gather, Alibali, and Goldin-Meadow (1998) had children complete math equivalence tasks, explain their answer, and subsequently rate possible solutions to these problems. Children's answers were coded for both verbal and gestural responses. Some children produced gestures during their explanations that were representative of their procedural knowledge (e.g., pointing to numbers on each side of the equation and making sweeping or grabbing motions to indicate "combining", or addition). While there was overlap between what children expressed verbally and gesturally, many spontaneous gestures contained visuo-spatial information that displayed their problem-solving strategy but was not otherwise verbally conveyed, suggesting that encouraging gesture use during mathematical tasks may facilitate problem solving. Goldin-Meadow, Cook, and Mitchell (2009) also found gestures to convey implicit knowledge during a mathematical task. Children were presented with mathematical equivalence problems, such as $6 + 3 + 4 = \_ + 4$. During instruction children either viewed "correct" grouping gestures (i.e., using two fingers to group the 6 and the 3, then pointing to the blank on the right to indicate adding the $6 + 3$ will equal the number that should go in the blank), "partially-correct" grouping gestures (i.e. using two fingers to group the $3 + 4$, then pointing to the blank on the right, which is a mathematically incorrect grouping strategy since it involves referencing the two numbers on the left side which do not equal the blank on the right, but still involves a potentially helpful grouping gesture), or only the verbal instructions. Children who received the "correct" gestures showed the most learning at posttest, followed by the "partially-correct" group, with the verbal-only children showing the least learning. Additionally, children used gestural grouping strategies during their mathematical problem solving, even though the conceptual knowledge behind this correct strategy did not appear in their verbal explanations; that is, their gestures conveyed implicit knowledge of the correct strategy to use during problem-solving. Taken together, these findings suggest that examining the gestures used by children during math contexts may provide a window into implicit knowledge and conceptual understanding that young children may not be able to formally verbalize. These studies point to the importance of encouraging gesture use during math, though little is known about how gestures are used spontaneously by children during these tasks.

In this work, we explored gesture use during a cardinality task. Our focus was specifically on gestures that were *spontaneous* and *unprompted* – that is, gestures that were produced despite the fact that the experimenter did not ask for them nor model them during the task. We reasoned that children's spontaneous gestures may be particularly beneficial during counting, a crucial precursor to math learning and understanding. Previous research with preschoolers has shown that using gesture, particularly pointing, promotes counting accuracy by allowing children to individuate objects while counting, keep track of counted objects while simultaneously tagging the item during the verbal recitation of the count list (Alibali & DiRusso, 1999). Gesture is useful in this context as it highlights the one-to-one relationship between the gesture and its referent, helping children attend to the relevant information while counting. Additionally, the acquisition of counting is a long and extended process (Le Corre & Carey, 2007), which is dependent on working memory and other cognitive capacities (Carey, 2002). Thus, gesture may help to alleviate some of these constraints by making their implicit knowledge (i.e., one-to-one correspondence between the count word and the counted object) explicitly available. Therefore, children may be more likely to implement gesture when their cognitive resources are taxed. In other words, children who have learned some but not all concepts necessary to count correctly may use gesture in response to increased task demands to help them succeed in the task.

In this cardinality task (the Give-N task; Wynn, 1990, 1992), children are asked to give the researcher varying sets of toys from a pile (of approximately 10–15 toys). Children are first asked to provide one toy and if successful, they are then asked for three toys.

This task then follows a titration method in which if the child creates the requested set size (N) successfully, then s/he is asked to provide the next set size (N + 1). If, however, the child fails to provide the requested set (N), s/he is asked to provide the previously-numbered set size (N-1). The procedure continues until the child successfully produces a set of 6 items twice, or until the child fails to produce the same set size twice while successfully creating the set size below twice (i.e., correctly creating set size of 3 twice, while failing to create a set size of 4 two times). Children are then classified according to the largest numbered set they can consistently produce, referred to as their "Knower Level." For example, a child who succeeds in producing 3 items, but fails on to successfully produce a set of 4, is classified as a "3-knower". Children who successfully produce a set of the 6 items twice (the largest set size requested) are classified as a "Cardinal Principle Knowers" (CP knowers), as it is believed that these children have acquired an understanding of the purpose of counting. Children whose last two successes occurred on trials less than 6 were subsequently deemed "Subset Knowers", as they are thought to have acquired some, but not all, knowledge related to cardinality (Carey, 2004; Le Corre & Carey, 2007; Wynn, 1990). Importantly, this task is an assessment of the child's number knowledge, not necessarily of their counting ability. Although counting is an effective strategy to employ in this task, children were never explicitly asked to count the objects nor to gesture to the objects. Therefore, the gestures children made during this task were entirely spontaneous (i.e., unprompted). We were interested in not only whether children spontaneously pointed and counted during the task, but *when* they chose to do so and how children's numerical knowledge related to their spontaneous gesture use.

We sought to accomplish two goals. First, by sampling children across a wide range of number knowledge levels, we investigated how *individual differences* (i.e., differences in number proficiency) determine the use of spontaneous gesture within a learning context. Since gestures have been shown to convey implicit knowledge, we predicted that children's current number knowledge would be related to their use of gestures during the task, even after controlling for Age (i.e., another proxy for development). Our predictions followed the currently held theory that gesture use tracks with conceptual knowledge.

Second, we looked at which *contextual features* are associated with gesture use by studying the timepoints during the task that promoted the most frequent use of gesture. To address this, we explored how the set size requested during the task corresponded to children's gesture use. Specifically, all children were asked to produce set sizes that were both within their Knower Level (referred to as N and N-1 trials), as well as outside of it (e.g., N + 1, N + 2 trials) and we expected children to employ gesture more frequently on the trials that were of optimal difficulty for that individual child. In other words, a child who is proficient at producing sets of 2 may use gesture more frequently when being requested 3 items since 3 represents a number that is outside of what she is currently capable of producing. Subsequently, that same child may not use gesture when producing sets of 4, as that set size is too far beyond their current implicit number knowledge. This prediction is based in part on Vygotsky's concept of a "proximal zone" (Vygotsky, 1978), which stipulates that there is an optimal zone in which children are able to learn concepts because they possess the requisite skills and conceptual understanding. Our work similarly investigated a potential optimal period during which children may signify they are "ready to learn" by using gesture as a proxy for implicit knowledge during a singular time point.

In this study, we coded videos from 343 preschoolers that had previously participated in the Give-N task to explore how gesture use may be related to individual differences in number knowledge and individual trial difficulty. Although our primary interests lie in understanding *when* children employ gesture and *how* this may scaffold their learning, the current study is correlational in nature and can only address the question of *when* children engage in spontaneous gestures.

2. Method

2.1. Participants

Videos of children participating in the Give-N task from three previous studies (Chernyak, Sandham, Harris, Cordes, 2016; Chernyak, Harris, & Cordes, 2019; Chernyak, Harris, & Cordes, in prep), all using the same Give-N protocol, were coded for spontaneous gestures. In total, videos from 343 preschoolers (158 male, M_{age} = 4.07 years; Range 2.47–6.38 years) were included. Data from an additional seventeen participants were excluded because the child either did not complete the required number of Give-N trials to determine Knower Level (N = 8), had missing videos (N = 3), their hands were not visible on video (N = 2). Children were recruited from different testing locations including laboratory visits, museums, parks, schools, and daycare/after school programs.

2.2. Materials

Ten small yellow plastic toy ducks, and a small colored basket (the "pond") were used in the Give-N task.

2.3. Procedure

All children first participated in resource distribution tasks (Chernyak, Sandham, Harris, Cordes, 2016; Chernyak, Harris, & Cordes, 2019; Chernyak, Harris, & Cordes, in prep)), which are outlined procedurally in the Supplemental materials, prior to participation in the Give-N task. These resource distribution tasks did not involve any mention of number, counting, nor did the experimenter promote gesture during the task.

Immediately after, children participated in the Give-N task. The experimenter presented the materials, and explained the rules ("In this game, you're going to put ducks into this pond."). Next, the experimenter modeled how to place one duck in the pond ("If I wanted to put one duck in the pond, I would go like *this*"). The child was then asked to put one duck into the basket themselves and once they had done so successfully, the experimenter asked for verification that it was one duck ("Is that one duck?"). If the child confirmed that it was one duck, they moved onto the next trial. If the child did not affirm that the numerosity was correct, the experimenter asked the child if they could fix it so that it was the correct number before moving forward with the task. From there, the child was asked to place 3 ducks in the pond ("Can you put three ducks in the pond?"), and so on. Using a titration method, the experimenter asked for N + 1 ducks if the child placed the correct amount in the basket, or N-1 ducks if the child had put in the incorrect amount. The task ended once the child succeeded twice on placing N ducks in the pond and failed twice in placing N + 1 ducks in, or if the child succeeded twice on N = 6 ducks. Although the experimenter skipped asking the child to produce a set of two ducks initially, if a child failed to produce three ducks correctly, the child was then asked to produce a set of two. Importantly, the experimenter gave no specific gestural instruction, nor any indication of problem-solving methods that the children could use during the task.

Children are further classified according to the largest numbered set they can consistently produce (N), referred to as their "Knower Level." For example, a child who succeeds in producing 3 items, but fails on items larger than 3, is classified as a "3-knower". Children who successfully produce a set of the 6 items twice (the largest set size requested) are classified as a "Cardinal Principle Knowers" (CP knowers), as it is believed that these children have acquired an understanding of the purpose of counting. Children whose last two successes occurred on trials less than 6 were subsequently deemed "Subset Knowers", as they are thought to have acquired some but not all knowledge related to cardinality (Carey, 2004; Le Corre & Carey, 2007; Wynn, 1990).

2.4. Coding and analyses

Children's gestures were defined as communicative movements of the fingers, hands, and/or arms that were not a direct action on any object or individual (i.e., the movement could not co-occur with a manipulation of an object; Petitto & Bellugi, 1988). All videos were coded by a first coder and then a second coder coded approximately 25% of the data, distributed across each of the different studies. Interrater reliability using intraclass correlations showed strong agreement for both the total number of gestures for each child, ICC = 0.927 as well as total number of trials that child was given, ICC = 0.964.

Gestural types were categorized into one of two groups: (1) *Pointing and counting gestures*, which were gestures that involved pointing to, and individuating a subset of the ducks that were presented to the child; and (2) *Other gestures,* which involved either task-specific gestures that displayed the child's numerical competencies (i.e., holding up fingers to indicate a number) or task-irrelevant gestures (e.g., pointing to self, etc.). These "other" gestures occurred at a lower frequency (less than a quarter of all gestures were categorized as "other") and were thus collapsed into one group. We also coded the trial type during which each instance of gesture occurred.

Each continuous instance of hand movement was coded as one single gesture. For example, if a child pointed to 4 individual ducks in sequence, this was coded as a single instance of gesture. Importantly, this coding decision ensured that we did not treat children who dealt with larger set sizes (i.e., those with higher Knower Levels) as necessarily gesturing more than children who dealt with smaller set sizes simply because they pointed to more items in a single count sequence. Additionally, because the Give-N task involves a titration procedure which results in children of higher-Knower Levels also receiving more trials (and thus more opportunities to gesture), we computed the average number of gestures per trial (number of gestures divided by number of trials the child received) and used that as our primary dependent variable, rather than the absolute number of gestures (which could be confounded with Knower Level). Additionally, children had several opportunities to gesture during each trial: when the experimenter first requested the item set ("Can you make 5 ducks jump in the pond?"), after placing the items into the basket, and after the experimenter asked the child to confirm the number requested ("Is that 5?").

Children were classified as either Cardinal Principle Knowers (CP knowers; if they succeeded twice on both 6 trials; $N = 195$; 91 males, $M_{age} = 4.47$ years) or Subset Knowers (if their last two successes occurred on trials less than 6; $N = 148$; 67 males, $M_{age} = 3.54$ years). Subset Knowers were further classified according to their Knower Level, or the largest set size they produced accurately twice (e.g., children were classified as 2-knowers if they succeeded twice on the 2-trial and failed twice on the 3-trial; Le Corre & Carey, 2007). In our sample, we found 32 children who fit the criteria of 5-knowers and have been classified as such. Prior research is mixed on whether to classify 5-knowers as CP Knowers or Subset Knowers (see Posid & Cordes, 2015; Sarnecka & Wright, 2013). We attempted to stay neutral to which category they ought to be placed in by using numerical cognition as a continuous predictor (we coded the highest numbered trial that children passed from: 1–6) rather than categorically (Subset vs. CP Knower) when possible in our analyses.

We also defined the trials on which children gestured not only by their numerical value (e.g., if the number asked for was 3, it was coded as a 3-trial), but also with respect to each child's Knower Level (N). Thus, for a 3-knower, a trial in which they were asked to produce a set of 1 was coded as their N-2 trial (i.e., if N = 3, then N-2 = 1), their 2-trial was coded as their N-1 trial, their 3-trial as their N trial, and so on up to N + 2.

3. Results

Initial analyses revealed no differences in the frequency of gestures across the four experiments or participant gender (p's $>$ 0.05), so all further analyses were collapsed across these variables. Consistent with prior literature (e.g., Le Corre & Carey, 2007), Knower Level was positively correlated with Age, $r(341) = 0.58$, $p < 0.01$, such that children who were older had higher Knower Levels.

In total, 41.40% of children (N = 142) used gesture at least once during the task. Across all children, there were a total of 441 instances of gesture, with the vast majority of these gestures (80.50%) classified as "Point and Count" Gestures (19.50% classified as

Table 1
Number and Percent of Children who Used Gesture by Knower Level and Gesture Type.

Knower Level	N	Number and Percent of Children by Gesture Type					
		Any Gesture		Point and Count		Other Gestures	
		N	%	N	%	N	%
0	5	2	40%	0	0%	2	40.0%
1	20	6	30%	2	10%	4	20.0%
2	39	10	25.6%	4	10.3%	6	15.4%
3	27	8	29.6%	3	11.1%	6	22.2%
4	24	9	37.5%	4	16.7%	5	20.83%
5	32	14	43.8%	10	31.3%	4	12.5%
6	194	97	50.0%	93	47.9%	17	8.8%

“Other”). There was a range of 0–18 gestures per child. Overall, children gestured on average 1.28 (SD = 2.22) times, with a mean of 1.01 (SD = 2.05) Point and Count Gestures and 0.26 (SD = 0.91) Other Gestures per child. Children received anywhere from 2 to 16 Trials, with a mean of 6.73 (SD = 1.65) Trials per child. On average, all children gestured 0.19 times per trial (SD = 0.31). All children, regardless of whether they gestured, were included in the subsequent analyses unless otherwise noted. In order to account for the variation between children for the total number of trials they may have received during the task, all subsequent means reported are per trial (total number of relevant gestures divided by total number of relevant trials for each individual child).

3.1. What predicts children’s individual gesture usage?

Our first question was whether there was a relation between children’s Knower Level, Age, and Mean Gesture Use during the numerical task. Age and children’s Mean Gesture Use across all trials were not correlated, $r(341) = 0.04$, $p = 0.493$. Knower Level, on the other hand, was positively correlated with children’s Mean Gesture Use, $r(341) = 0.19$, $p < 0.01$. Given the strong relation between Age and Knower Level, we ran a partial correlation between Knower Level and Mean Gesture Use while controlling for Age and found that there was still a positive correlation, $r(341) = 0.198$, $p < 0.01$. Therefore, children who had higher Knower Levels also exhibited more instances of spontaneous gesture, and this was not simply because these children were older (Table 1).

We next analyzed the two subtypes of gesture separately. Partial correlations controlling for Age revealed that only the Mean Point and Count Gestures was positively correlated with Knower Level, $r(340) = 0.27$, $p < 0.01$, with no significant correlation between mean number of Other gestures and Knower Level, $r(340) = -0.08$, $p = 0.13$, while also controlling for Age. Therefore, children’s spontaneous Mean Point and Count Gestures in particular was correlated with their Knower Level when controlling for Age.

In light of current theories positing that only Cardinal Principle Knowers or older children know to engage in pointing and counting behavior during numerical tasks (Le Corre & Carey, 2007; Le Corre, Van de Walle, Brannon, & Carey, 2006; Sarnecka & Carey, 2008), we performed identical analyses only with data from subset knowers (0–5 knowers, $n = 148$). That is, we were interested in determining whether Knower-level related to Mean Gesture Use for only Subset-Knowers. This same pattern held when only exploring the relationship with our Subset Knowers: a partial correlation investigating Mean Point and Count Gestures and Knower Level (while controlling for Age) for only the Subset Knowers in our sample again revealed a relationship between Knower Level and Mean Gesture Use, $r(145) = 0.166$, $p = 0.045$, and no relationship between Mean of Other Gestures and Knower Level (while controlling for Age), $r(145) = -0.003$, $p = 0.97$. This suggests that the relationship between Mean Gesture Use and Number Knowledge for pointing and counting was not solely driven by the inclusion of cardinal principle knowers in our analyses, as previous literature has suggested. Instead, Subset Knowers’ use of point and count gestures also increased as a function of number knowledge.

We then explored whether this correlation with Number Knowledge was driven by a greater likelihood of individual children engaging in gesture at all. That is, as children gain number knowledge, do more children gesture, or is it that a constant proportion of children tend to make more gestures? Children were classified using a binary coding scheme as either as having never gestured (dummy coded as 0) or having gestured one or more times during the task (dummy coded as 1). The Spearman’s rho partial correlation between Knower Level and whether the child gestured was statistically significant while controlling for Age, $r(340) = 0.208$, $p < 0.01$. Thus, a greater proportion of children tended to gesture as they gained in Number Knowledge.

Finally, we explored whether the relationship between Knower Level and Mean Gesture Use held for the subset of children who gestured at least once during the task. That is, as children gain number knowledge do they gesture more frequently, or are they simply more likely to gesture at all? We conducted a partial correlation comparing the Mean Gesture Use and Knower Level, while controlling for Age, and did not find significance, $r(140) = 0.133$, $p = 0.114$. Overall, these results suggest that the relationship between Knower Level and gesture use is driven by children being more likely to display any instance of gesture as they gain Knower Levels, rather than an increase in the number of gestures produced by a small proportion of children at all Knower Levels.

3.2. When do children spontaneously use gesture?

We next examined whether the relative difficulty of each trial was related to children’s engagement in spontaneous gestures by

Table 2
Mean Gesture Use on each Trial Type, by Knower Level.

	Trial Type			
Knower Level	N-1	N	N + 1	N + 2
0	[a]	[a]	0.400	0
1	[a]	0.100	0.211	0.050
2	0	0.132	0.154	0.231
3	0	0.179	0.250	0.100
4	0.167	0.333	0.208	0
5	0.186	0.258	0.226	[a]
6	0.2821	0.3744	[a]	[a]

[a] Blank cells indicate that that Trial Type did not exist with the methods used (i.e. no N + 1 for 6 knowers as we did not test up to 7).

examining gesture use on each of the different trial types (Table 2). As the Give-N procedure allowed us to classify the child's number knowledge, we were able to determine which individual trials were most difficult to the child. We hypothesized that children would be most likely to use gestures on trials within their zone of proximal development (Vygotsky, 1978) – that is, trials within the set of values that they had either just mastered or were in the process of mastering (hereafter referred to as the N and N + 1 trials; e.g., when a 3-knower was asked to produce a set of 3 or 4, respectively). That is, children were expected to gesture less on trials that were fairly easy – that is, trials involving set sizes that they had fully mastered (N-1 trials), and to gesture less on trials that were seemingly too difficult for the child (i.e., outside of their realm of mastery, N + 2).

Thus, we first compared the use of spontaneous gestures on N-1 trials (a set size the child would have presumably mastered, thus making these trials fairly easy for the child), to that of on N and N + 1 trials for each child. In particular, we expected that trials at (N) and above (N + 1) each child's own Knower Level would be most difficult and thus most likely to evoke spontaneous gestures. In contrast, we predicted fewer children would gesture at all on trials that were well within the child's Knower Level and were thus easy for the child (e.g., N-1). To test this pattern, we ran a GEE model using Likelihood of Gesturing as the binomial response and Age, Knower Level, and Trial Type (entered as a within-subjects effect; N-1, N, N + 1) for children who were classified as Knower Levels 2–5, such that all children included in this analyses received N-1, N, and N + 1 trials. Initial analyses showed that there was no Trial Type x Knower Level interaction (so this was not included in the model, suggesting that the effect of Trial Type was similar across Knower Levels). The overall model was significant, $\chi^2(1) = 6.650, p < 0.05$ (Fig. 1). Critically, there was a significant effect of Trial Type, $\chi2(2) = 14.575, p < 0.01$, but no effect of Knower Level $\chi2(1) = 2.89, p = 0.09$, or Age $\chi2(1) = 0.00, p = 0.996$. Follow up McNemar's tests with children who were classified as Knower Levels 2–5 showed that N-1 trials differed significantly from N trials ($p < 0.01$), and from N + 1 trials ($p < 0.01$), but N and N + 1 trials did not differ significantly from one another ($p = 0.82$).

Next, we investigated whether children gestured less on trials that were too far outside their current zone of proximal development (e.g. N + 2 trials). In order to test this hypothesis, we ran a second GEE model using Likelihood of Gesturing as the binomial response and Age, Knower Level, and Trial Type (entered as a within-subjects effect; N, N + 1, N + 2), including data from pre-knowers through 4-knowers (as these children had received N, N + 1, and N + 2 trials). The overall model was again significant, $\chi^2(1) = 5.145$, $p < 0.05$. There was also a significant effect of Trial Type, $\chi2(2) = 16.28$, $p < 0.01$, (Fig. 2), but not Age $\chi2(1) = 0.06, p = 0.80$, or Knower Level $\chi2(1) < 0.774, p = 0.379$.) Follow up McNemar's tests with children who were classified as pre-knowers through 4-knowers showed that N + 2 trials differed significantly from N + 1 trials ($p < 0.01$), and from N trials ($p < 0.01$), but again the N and N + 1 trials did not differ significantly from one another ($p = 0.80$).

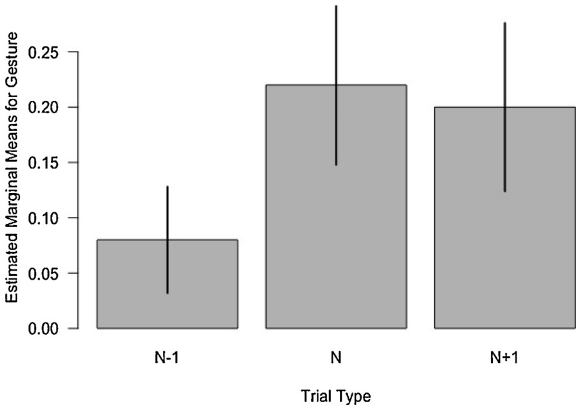

Fig. 1. Mean Gesture Use Across Trials, where N = the child's Knower Level as assessed by Give-N.

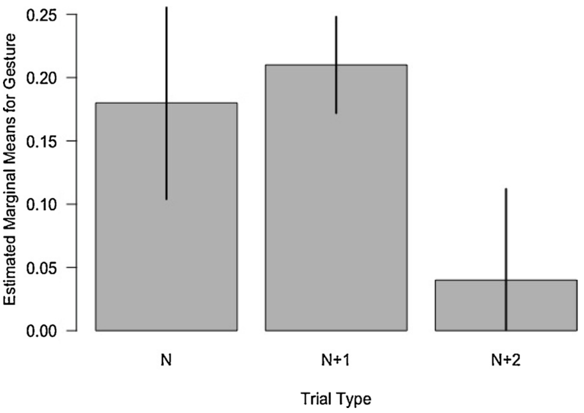

Fig. 2. Shows relation between Mean Gesture Use by trial type, with N = the child's Knower Level as assessed by Give-N.

4. Discussion

Prior work has shown that the use of gesture reduces working memory load (Goldin-Meadow, 2005), directs attention (Ping & Goldin-Meadow, 2008), and increase conceptual understanding (Novack et al., 2014; Valenzeno et al., 2003). The current study provides further evidence that children may use gesture as one strategy to complete cognitively difficult tasks. Notably, our data addresses the novel question of when children implement gesture spontaneously during numerical tasks.

First, the relation between Knower Level and Mean Gesture use suggests that as children become more proficient with relevant knowledge for the task at hand, their gesture use, especially their pointing and counting gestures, increases. Importantly, our finding is not simply accounted for by age-related changes in the use of gesture, suggesting that gesture use may reflect cognitive sophistication rather than simply physical or other types of domain-general levels of maturity. This finding is consistent with previous literature that suggests children's gesture use may track with task difficulty, and their current relevant conceptual understanding. Future work should also explore whether the gestural strategies that occur during tasks such as Give-N map onto the conceptual shift from subset knowers to cardinal principle knowers.

Additionally, our findings diverge from the current theory that only Cardinal Principle knowers use pointing and counting gestures (Le Corre & Carey, 2007). Our secondary analyses involving data from exclusively subset-knowers continued to reveal a significant relationship between pointing and counting gestures and Knower-Level, suggesting that, although gesture use was infrequent among subset knowers, the likelihood of a subset-knower engaging in pointing and counting increased as their knower-level increased. One explanation for this pattern of findings is a bidirectional relationship between gesture use and number concept acquisition; children may begin to use gesture more as their number knowledge increases, and in turn, these gestures help children to successfully create larger set sizes, thus further promoting their number knowledge. Notably, this bidirectional pattern could suggest that children are scaffolding their own learning by employing gesture throughout the process of acquiring the concept of cardinality. Future research using experimental manipulations of gesture may wish to explore whether gesture use during numerical tasks can *promote* the acquisition of number knowledge.

Second, our findings suggest that children internally modulate their gesture usage with respect to task difficulty; they gesture more on numerical trials that they have either recently learned (N), but also on trials they are in the process of acquiring (N + 1), compared to a relatively easy numerical value that they have presumably known for a longer period (N-1; Le Corre & Carey, 2007). That is, children gesture on those trials in which gesture can help them the most. Moreover, they may also be slightly (though not significantly) less likely to employ gesture on trials that are too far off from their current knowledge base (N + 2). These findings align with Vygotsky's theory of a "proximal zone" of development (Vygotsky, 1978). Vygotsky suggested that there was a limited period in which children are able to learn something new based on their current level of requisite skills as well as their related conceptual understanding of that topic. With this in mind, the finding of children's individual patterns of gesture within Give-N (less gestures on trials that they "know"; more gestures on trials they have just learned or are in the process of learning; and fewer gestures on trials well outside the realm of their current abilities) suggests that a child's gestures use could provide insight into their current level of conceptual understanding of cardinality. Thus, gesture use may signal where an individual child is along the learning trajectory associated with number knowledge and use this awareness to specifically promote their learning.

While it is possible that some children at this age are able to subitize sets up to 3 or 4 (i.e. the ability to report the magnitude of a set quickly and accurately; Kaufman, Lord, Reese, & Volkmann, 1949), our findings suggest that that cannot be the whole story. For example, we find that children are slightly more likely to point and count on N and N + 1 trials than on N + 2 trials. For subset-knowers in particular, this means that they are more likely to point and count on trials within the subitizing range than for larger sets outside of that range (e.g., a 3-knower is more likely to point and count for sets of 3 and 4 than for sets of 5). Our findings show that there is less frequent counting on the N + 2 trials, compared to N and N + 1 trials, which goes against a subitizing account.

Furthermore, our findings that children gesture most frequently on N + 1 trials suggest that gesture is not always an accurate strategy. Meaning, if their pointing and counting strategy was accurate, they would have succeeded in producing that set size, and then would have been classified as an N + 1 knower, not as an N knower. But that is not the case, suggesting that pointing and counting did not always produce the accurate set size. Thus, it is important to consider in future research what is an "effective" or "accurate" gesture strategy actually looks like during cardinal knowledge acquisition.

We propose that it is important for future studies to carefully investigate how spontaneous gesture use is related to early math learning. Given that quantitative abilities are predictive of later mathematical abilities (Chu, vanMarle, & Geary, 2015; Feigenson, Libertus, & Halberda, 2013; Geary & Vanmarle, 2016; Starr, Libertus, & Brannon, 2013), it is especially important to understand the predictors of children's early math learning. Our study suggests the intriguing possibility that early gesture serves as a proxy for early math understanding. This finding is consistent with a body of research which shows that gesture has been found to be useful during learning in general (Goldin-Meadow, 2000) as it can work to link abstract concepts in a specific context, in turn promoting learning (Alibali et al., 2014). While our findings cannot support a causal relationship between gesture and early math learning, we would cautiously suggest that encouraging children's gesture use while learning cardinality and associated numerical concepts may help to promote concept acquisition.

It is also important to note these findings could be relevant in addressing current gaps in numerical abilities between high and low-SES children. Previous work has shown that children of lower SES typically display poorer performance on number tasks that tax their verbal abilities (Klibanoff, Levine, Huttenlocher, Vasilyeva, & Hedges, 2006; Ramani & Siegler, 2008; Starkey, Klein, & Wakeley, 2004). However, similar SES driven gaps do not appear for non-verbal numerical tasks (Jordan, Huttenlocher, & Levine, 1992; Jordan, Levine, & Huttenlocher, 1994). Given that gesture is a non-verbal means of communication, one intriguing possibility may be that gesture could help support verbally-based math learning as it provides nonverbal means of linking and expressing concepts.

Future work may also investigate how gesture use changes across development using a longitudinal design, rather than the cross-sectional design that we conducted. Additionally, it is crucial to consider the different types of gesture that could be used or encouraged during learning. Previous literature has shown that it is typically cardinal principle knowers who know to properly engage in counting behaviors during numerical tasks, not subset knowers (Le Corre & Carey, 2007; Le Corre et al., 2006; Sarnecka & Carey, 2008). For subset knowers, when pointing and counting behaviors occur, it is regularly not coordinated with the set of objects being counted, or incorrectly applied in other ways (Fuson, 1988; Gelman & Gallistel, 1978). However, we report that the most useful gestural strategy, pointing and counting, was also used by subset knowers, though at a significantly lower rate than CP-knowers. At minimum, they recognized and employed this task-relevant tool. This study, however, did not concentrate on the nuance of the gestures, such as the difference between a pointing gesture in space and a pointing gesture that makes physical contact with the object. Previous research suggests that there is a distinction between these two types of gesture (Gelman & Meck, 1983), thus indicating the possibility that a specific gesture type, in conjunction with the timing and frequency of when the gesture occurs, could ultimately shape conceptual learning. Future work could explore whether these differences exist between subset knowers and cardinal principle knowers. Moreover, because the focus of this work was on the employment of spontaneous gestures, we did not assess the accuracy of the counting behavior. It is possible that though subset knowers engaged in counting behavior, their counting was less likely to result in an accurate cardinal value. This is another avenue for future work.

Finally, future work may focus on how children's gesture relates to their corresponding speech during math learning. Previous work has explored gesture use in children's explanations of conservation tasks (Church & Goldin-Meadow, 1986) and mathematical equivalence problems (Goldin-Meadow, Alibali, & Church, 1993). Future work may focus on whether children's gestures are indicative of implicit number knowledge by tracking whether gestures match (or don't match) what the child is also doing and saying during counting tasks. Such an investigation would allow us to delve into the implicit knowledge that children may or may not possess while they are in the process of acquiring counting skills.

Overall, we find children of higher Knower Levels gesture more often. Moreover, children use gesture on trials that are difficult to them. These findings suggest that children both implicitly recognize that gesture is a strategic tool during this task and modify their behavior in relation to task demands. Thus, gesture may be one powerful way in which learners scaffold their own abilities to solve the tasks they are faced with.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.cogdev.2019.100818.

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