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Type of object motion facilitates word mapping by preverbal infants

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ABSTRACT

This study assessed whether specific types of object motion, which predominate in maternal naming to preverbal infants, facilitate word mapping by infants. A total of 60 full-term 8-month-old infants were habituated to two spoken words, /bæf/ and /wem/, synchronous with the handheld motions of a toy dragonfly and a fish or a lamb chop and a squiggly. They were presented in one of four experimental motion conditions—*shaking*, *looming*, *upward*, and *sideways*—and one *all-motion* control condition. Infants were then given a test that consisted of two mismatch (change) and two control (no-change) trials, counterbalanced for order. Results revealed that infants learned the word–object relations (i.e., looked longer on the mismatch trials relative to the control trials) in the shaking and looming motion conditions but not in the upward, sideways, and all-motion conditions. Infants learned the word–object relations in the looming and shaking conditions likely because these motions foreground the object for the infants. Thus, the type of gesture an adult uses matters during naming when preverbal infants are beginning to map words onto objects. The results suggest that preverbal infants learn word–object relations within an embodied system involving matches between infants' perception of motion and specific motion properties of caregivers' naming.

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Introduction

The task of word learning is an arduous process for preverbal infants. Although by the end of the first year of life infants begin to assign meaning to words (Halliday, 1975) and say their first words (Benedict, 1979), word learning is by no means an easy task to accomplish. For infants to comprehend language, they must first learn to perceive the connection between the spoken word and the referent. This perceptual ability, also known as word mapping, is an essential building block for language comprehension and production (Bates, Benigni, Bretherton, Camaioni, & Volterra, 1979; Gogate, Walker-Andrews, & Bahrick, 2001; Golinkoff, Mervis, & Hirsh-Pasek, 1994; Huttenlocker, Haight, Bryk, Seltzer, & Lyons, 1991; Quine, 1960). But how exactly do infants come to learn that a word maps onto a specific referent? More specifically, when an adult names an object, how do infants disambiguate between the correct referent and different objects nearby?

For decades, it has been theorized that an infant maps words onto objects in spite of referential ambiguity within the communicative environment owing to innate constraints that humans are purportedly endowed with right from the start. As a case in point, Quine (1960) theorized that a novice speaker of any language (e.g., an infant) knows that a word refers to an object amid several other potential referents, despite referential ambiguity, because of innate constraints. More recently as well, researchers have theorized that innate constraints limit the number of possible referents that an infant will selectively attend to during word learning (Golinkoff et al., 1994; Markman, 1989). In these views, built-in constraints enable the infant to learn word–object relations despite referential ambiguity. For example, the poverty of stimulus argument predicts that it is only with a language acquisition device (LAD) that infants can learn word–object relations in an impoverished language environment (Pinker, 1995).

In contrast, in our view, similar to many others (Yoshida & Smith, 2007; Yu, Ballard, & Aslin, 2005), one way in which infants solve the word-mapping puzzle is by focusing on an adult's gestures with an object that the adult is naming. How infants disambiguate among potential and competing referents, therefore, can be addressed in part by focusing on research that delves into the gestural origins of word-mapping development (Gogate, Bahrick, & Watson, 2000; Gogate, Bolzani, & Betancourt, 2006; Gogate, Maganti, & Laing, 2013; Yoshida & Smith, 2007; Zukow-Goldring, 1997; Zukow-Goldring & Ferko, 1994). As a case in point, recent research suggests that mothers provide gestures, such as *shaking* and *looming* motions with a handheld object, more often than others when naming objects during play and that these motions predict preverbal infants' word-mapping success (Matatyaho & Gogate, 2008). To narrow in on this topic, in the current experimental study we examined whether an adult's use of these predominant motions during naming is causally related to word mapping by preverbal infants.

In the current article, the general hypothesis is that word-mapping development is an embodied process where "intelligence emerges in the interaction of an organism with an environment and as a result of sensory–motor activity" (Smith, 2005, p. 279). An important assumption underlying the embodied process is that word mapping emerges from perceptual development. The perception of visual, auditory, and intersensory properties from caregivers' naming can occur only when two systems interact—infants' perceptual mechanisms and caregivers' input during naming. More specifically, word-mapping development involves the infant's detection of invariant properties in caregivers' naming in the auditory and visual domains and across auditory–visual domains (Gogate & Hollich, 2010). Invariance detection is the process by which the perceptual system seeks to reduce uncertainty in the stimulus flux and seeks order amid change by attending selectively to stable patterns in the stimulus array (Gibson, 1969). In turn, by providing unimodal invariance (e.g., object motion or phonetic quality of utterance) and intermodal invariance (e.g., synchrony) and reducing uncertainty in the stimulus array for infants (Gibson, 1966), caregivers educate or scaffold infants' attention to salient aspects of verbal and gestural communication, including word–referent mappings (Matatyaho & Gogate, 2008; Zukow-Goldring, 1997). Thus, invariance detection is a mechanism by which infants attend to salient and relevant properties of caregivers' communication and serves as a perceptual gateway to the learning of word–object relations (Gogate & Hollich, 2010).

A second important assumption underlying the embodied process of word mapping is that at some points during development, matches likely exist between the properties available in caregivers' communication and the properties that infants perceive from this communication (Gogate & Hollich, 2010). Recent research suggests that several properties of maternal naming contribute to the development of word mapping and support the possibility that such matches exist. Infants' communicative environment is modified by caregivers (Brand, Baldwin, & Ashburn, 2002; Gogate et al., 2006; Schafer, 2005) in numerous ways to match infants' perceptual abilities and make the communicative input more comprehensible during mother–infant interaction. For example, mothers modify their speech (Fernald & Simon, 1984; Masur, 1997; Messer, 1978; Snow, 1972), their gestures (Brand et al., 2002; Gogate et al., 2000; Goodwyn, Acredolo, & Brown, 2000; Matatyaho & Gogate, 2008), and the timing between their gestures and their speech (Gogate et al., 2000, 2006) to capture their infants' attention. The modifications, which occur only when caregivers interact with their infants, contain invariant properties that infants find salient and attend to easily (Gogate & Hollich, 2010).

With respect to modifications in the timing between gestures and speech, caregivers' naming contains invariant amodal properties. Amodal properties refer to information that is shared, for instance, across auditory–visual modalities (speech and gestures). For example, during synchronous naming, when mothers speak a word and simultaneously move an object, the spoken word and object motion share a common onset, offset, and duration that unify the auditory and visual information across modalities (Gogate et al., 2000), make the word–object relations salient for preverbal infants, and facilitate learning of the relations (Gogate et al., 2006). The synchrony unifies the otherwise unrelated elements, the word and the object, for preverbal infants. Consequently, caregivers unify object motions with their word utterances to capture preverbal infants' attention (Gogate et al., 2000), and in turn infants attend to and relate novel words and simultaneously presented objects in motion.

With respect to speech modifications, caregivers' infant-directed speech, also referred to as "motherese," comprises syntactic, semantic, phonological, and prosodic modifications (Fernald, 1982; Fernald & Simon, 1984; Snow, 1972). Infants attend to this modified speech (Pegg, Werker, & McLeod, 1992; Werker, Pegg, & McLeod, 1994) because it is simpler and more redundant or repetitive than adult-directed speech (Snow, 1972). In addition, it contains exaggerated intonation and stress, a higher pitch, wider pitch excursions, longer pauses, shorter utterances, a slower tempo, and prosodic repetitions (Fernald & Simon, 1984). This modified speech captures infants' attention and might aid in the development of word mapping.

Caregivers also modify their gestures when communicating with infants to make objects or actions more salient (Brand et al., 2002; Matatyaho & Gogate, 2008; Zukow-Goldring & Ferko, 1994). For instance, when mothers name and present objects to their young infants, they use showing gestures (Gogate, Maganti, & Laing, 2013; Zukow-Goldring & Ferko, 1994) that consist of looming and shaking actions. Matatyaho and Gogate (2008) found that 24 mothers used looming and shaking motions, during play when teaching their 6- to 8-month-old infants two novel word–object relations, more often than *upward* and *sideways* motions. In this teaching context, several other object referents were present on the scene within the infants' visual field. Subsequently, on a two-choice intermodal word-mapping test, the infants mapped the two words onto the two objects better if their mothers had presented the objects more often using either looming or shaking motions simultaneously with their word utterances, but not if they had used upward or sideways motions or no motion at all (Matatyaho & Gogate, 2008). Based on these empirical findings, which predicted infant word-mapping success, the authors concluded that mothers use looming and shaking motions more often to highlight or foreground and facilitate disambiguation of novel word–object relations for their word-mapping novices. Reciprocally, preverbal infants find these motions salient and learn word mappings better when given these motions in synchrony with novel spoken words.

However, given the non-experimental design of Matatyaho and Gogate's (2008) study, it is not possible to infer that the motions the mothers predominantly used during naming caused the infants to learn the word–object pairings. This is because mothers used these motion types in varying proportions but did not use shaking or looming motions in isolation. Thus, the authors could not establish a causal relation between mothers' motion use during naming and their infants' word mapping success. Furthermore, although it is well documented that looming motions (and sounds) elicit greater attention across species (Maier & Ghazanfar, 2007; Nanez & Yonas, 1994; Pickens, 1994; Schiff, 1965; Sun & Frost, 1998; Walker-Andrews & Lennon, 1985; see also Judd, Sim, Cho, von Muhlenen, & Lleros, 2004; von Muhlenen & Lleras, 2007), no experimental evidence exists to document that shaking motions elicit greater infant attention relative to other motions. In the context of word learning, in particular, no experimental study to date documents that shaking and looming gestures bear a causal relation to word mapping in preverbal infants.

Gestures are a critical component of caregiver communication and facilitate early language development (Goodwyn et al., 2000). Although it is clear that gestures play a role in word mapping, the role of specific object motions in adults' naming in infants' word mapping remains unclear. In the absence of an adult's gesture, infants of 14 months learn word–object relations better when objects mechanically move sideways or loom, but not when they remain static. In contrast, infants of 12 months or younger do not learn word–object relations when the objects move sideways (Werker, Cohen, Lloyd, Casasola, & Stager, 1998), but might learn such relations when certain handheld motions (gestures) are presented by a caregiver (Matatyaho & Gogate, 2008). Which specific object motions do infants find salient during word mapping? More specifically, is there a causal relation between specific object motions used by adults during naming and infants' ability to map words onto objects?

The main purpose of the current study was to assess whether specific types of object motion, in synchrony with a spoken utterance, facilitate word mapping by preverbal 8-month-old infants. We assessed the causal effect of these object motions by isolating them from all other motion types and other cues, maternal or otherwise, typically found in complex naming contexts. Therefore, infants were presented with the word–object relations from an adult in lieu of multiple mothers (Matatyaho & Gogate, 2008) and, furthermore, viewed only the adult's disembodied hand to reduce complexity. If in fact looming and shaking motions facilitated word mapping in the current experiment with reduced complexity, then we can surmise that infants are capable of using these motions to learn novel word mappings in more complex naming contexts that require disambiguation (as in Matatyaho & Gogate, 2008). We hypothesized that if the type of motion matters, then shaking and looming motions would lead to heightened learning of word–object relations because these motions likely foreground the objects for the infant. Looming motions, in particular, tend to substantially increase the size of an object in the infant's line of sight. Although shaking (lateral) motions do not increase the scale of the object, the rapid movements in succession (i.e., relative speed of saccadic motion) could highlight the object relative to its static background and recruit the infant's attention to the object (see Gibson, 1969). In contrast, upward and sideways motions would lead to attenuated learning because these motions do not foreground the objects for the infant. In addition, we hypothesized that if the type of motion matters, then infants will show attenuated learning of word–object relations in an "all-motion" condition, where the four motions are concatenated together in equal proportions, because this condition does not resemble an act of showing. Alternatively, if consistency of motion matters during word mapping, but type of motion does not, then infants will learn the word–object relations in each of the motion conditions equally but not in the all-motion condition because this condition does not contain consistent motion.

To address these hypotheses, infants were first habituated to two word–object pairings, followed by two no-change post-habituation trials. Next, infants received two switch trials in which the word–object pairings were mismatched and two control trials in which the word–object pairings remained the same as during habituation. Infants' longer looking to the switch trials relative to the control trials served as an index of learning of the word–object relations. Many versions of this method have been used in previous studies to test for infants' learning of syllable–object relations (e.g., Gogate & Bahrick, 1998, 2001; Gogate, Prince, & Matatyaho, 2009; Werker et al., 1998).

Method

Participants

A total of 60 full-term, healthy 8-month-old infants (M = 243.61 days, SD = 6.05), participated in this study. Infants were recruited from a well baby clinic at the SUNY Health Science Center at Brooklyn and were screened for normal vision and hearing prior to participation. At birth, infants weighed more than 5 pounds 6 ounces and had an estimated gestational age of more than 37 weeks. The ethnic composition of this sample was as follows: African American ($n = 54$), Hispanic ($n = 2$), Caucasian ($n = 2$), and biracial ($n = 2$). The languages spoken at home by the families of the participants were as follows: English ($n = 52$), Spanish ($n = 2$), Creole ($n = 5$), and Chinese ($n = 1$). The current sample included only infants whose mothers had at least 12 years of education because maternal education correlates with the extent of speech produced to infants as well as with infants' vocabulary (Hart & Risley, 1995; Huttenlocher et al., 1991). An additional 17 infants were excluded from the final sample because of failure to meet one or more of the following inclusion criteria: fussiness and/or fatigue ($n = 2$), equipment failure and/or experimenter error ($n = 10$), longer looking to the post-habituation trials relative to the baseline trials ($n = 4$), and a visual recovery score less than or greater than 2 standard deviations from the mean ($n = 1$).

In the current design, 8-month-olds were selected because some prior research suggests that 9-month-olds map labels onto object categories in the absence of motion (Balaban & Waxman, 1997). In other words, by 9 months of age, object motion might not be critical for infants' learning of word–object pairings. In contrast, 7-month-olds learned the arbitrary relations between two vocalic open syllables (/a/ and /i/ or /tah/ and /gih/), each paired with an object, when object motion was synchronous with the spoken syllable, but not in the absence of object motion (Gogate & Bahrick, 1998; Werker et al., 1998). In addition, the syllables in the current study were more distinct and complex than those in the prior study by Gogate (2010) because that study used open syllables (/tah/ and /gih/), whereas the current study used closed (consonant–vowel–consonant) syllables (/bæf/ and /wem/). Furthermore, in prior studies (Gogate, 2010; Gogate & Bahrick, 1998; Matatyaho & Gogate, 2008) a variety of motions were used randomly without any consistency, whereas the current design required consistency of motion—one type of motion in each experimental condition. Owing to these added degrees of difficulty in the stimuli relative to prior studies, 8-month-olds were chosen to increase the likelihood of infant learning under the different motion conditions. Infants of this age have already learned some word–referent mappings from their natural environment (Bergelson & Swingley, 2012, 2013).

Stimuli

Videotapes of word–object pairings were created in which an adult female native speaker of American English held and moved an object while simultaneously speaking a word. The objects were filmed, using two Sony digital camcorders (DSR-PD170), against a black background to display the objects in the foreground and the actor's forearm and hand, but not her body or face, in the background. The object in each video display consisted of one of two toy animals, a dragonfly and a fish, or one of two toy non-animals, a lamb chop and a squiggly (see Fig. 1).

The objects were filmed showing only the disembodied hand to simplify the stimulus for infants as in prior experiments of word learning (Gogate, 2010; Gogate & Bahrick, 1998; Gogate et al., 2009). Infants tend to focus on caregivers' hands, not on their faces, in word learning contexts when caregivers name objects (Smith, Yu, & Pereira, 2009; Yoshida & Smith, 2007). In a previous observational study by Matatyaho and Gogate (2008), mothers predominantly used looming and shaking motions to present novel objects during naming in the presence of other objects, potentially creating referential ambiguity. In the current study, the experimental stimuli were simplified to eliminate referential ambiguity and to examine the causal effect of type of motion on infants' word mapping.

Each object was paired with the words /bæf/ and /wem/. These distinct words were selected because 7-month-olds map distinct syllables such as /a/ and /i/ or /tah/ and /gih/ onto objects, but not similar-sounding syllables such as /tah/ and /gah/ (Gogate, 2010; Gogate & Bahrick, 1998). The words were spoken in synchrony with handheld object motions in one of four experimental motion conditions—*looming*, *upward*, *shaking*, and *sideways*—and an *all-motion* control condition. Thus, the rate of motion and the rate of utterance were identical because they were synchronous. The stimuli in the current study were modeled using the same synchrony threshold (0–450 ms) as in Gogate and Bahrick (1998, 2001); see also (Gogate, 2010), where infants clearly perceive their synchrony.

The *looming* motion condition consisted of each object moving from the center or 2 cm above the center (0–2 cm) of the 50.8-cm video monitor and looming toward the bottom of the monitor in a

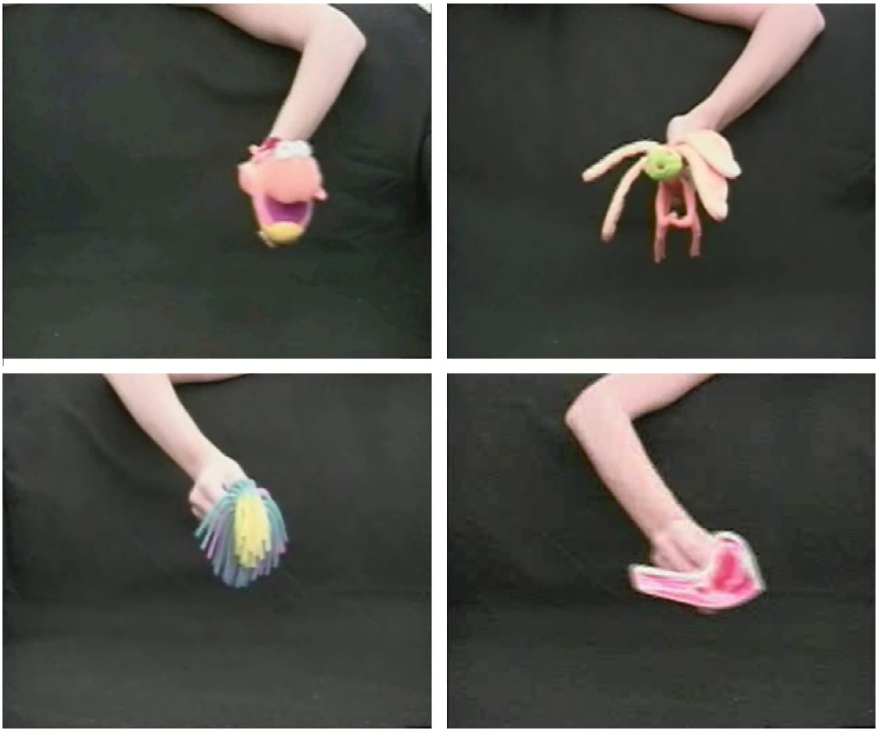

Fig. 1. The two animal objects (fish and dragonfly) and two non-animal objects (squiggly and lamb chop) used in the video displays.

lateral and linear fashion. The object was moved forward every 3 s simultaneously with a spoken word. The change in scale of the object, computed over 50 occurrences randomly selected across the videos, ranged from 12.7 to 13.7 cm at the start of the motion to 14.6 to 15.6 cm at the end of the motion. The *shaking* motion condition consisted of each object moving repetitively and quickly, with short distances, in a lateral path from right to left or from left to right. These particular motions were selected because, as discussed earlier, mothers predominantly used looming and shaking motions when teaching their 6- to 8-month-olds novel word–object relations, and the extent of these motions in maternal naming significantly predicted infants' word-mapping success on a test (Matatyaho & Gogate, 2008). The *upward* motion condition consisted of each object moving from a low position to a relatively high position on the video monitor in a linear fashion. The *sideways* motion condition consisted of each object moving from side to side, beginning on one side and ending laterally at the opposite side of the video monitor. Finally, the *all-motion* control condition consisted of each object in one of the four motions for 6 s until the next motion played for 6 s and so forth. The concatenated motions always occurred in the same sequential order: sideways, looming, shaking, and upward. Each video display contained dubbed audio–visual versions of the first minute for a total duration of 6 min. An additional videotape of a green and white frog, whose arms spun up and down to make a whirring noise, was played at the beginning and end of the procedure on pretest and posttest trials to measure infants' level of alertness and/or fatigue.

Rate of utterance and motion

In all conditions, the motion was always in synchrony with an utterance despite variability in the duration and intensity shifts of the motions. To control for the rate of utterance across motion conditions, the actor heard a single model audio segment while filming for all motion conditions and performed a single motion per utterance. Because the actor uttered a word simultaneously with each movement of an object, the rate of utterance equals the rate of motion. The first minute of each audio segment was later analyzed for rate of utterance, whereas the remaining portion of each segment was not analyzed because this portion contained dubbed versions of the first minute. The mean rate of utterances (and motion) per minute across the video displays was 35.35 (SD = 1.764, range = 32–38).

Procedure

Infants were randomly assigned to one of five motion conditions: looming, shaking, upward, sideways, or all-motion. They were placed in an infant seat 50.8 cm (20 inches) away from, and facing, a television monitor. The infant seat was located in a testing booth consisting of a 50.8-cm (20-inch) color video monitor (Sony, KV 22M10) surrounded on all sides by a black screen. The monitor was connected to four video decks (Panasonic, AG 1980P) via a 4×4 input selector (Radio Shack). Whereas the video signal was played on the monitor, the audio signal was played via a central speaker located under the monitor that was connected to the decks via a switcher and a sound amplifier. The data were recorded online in an adjacent computer room on an IBM computer (AT 486) and printed online on an Epson LQ 870 printer. Observers' button presses were converted to signals from the computer, which were relayed via a mini-amplifier (Radio Shack) to an experimenter who played the stimuli. Infants received an infant-controlled habituation procedure consisting of a habituation phase and a test phase.

Habituation phase

The video of the green and white frog was shown to infants to direct their attention to the monitor during a pretest trial. Following the pretest trial, infants were shown the video stimuli of the word–object pairings in one of the five conditions. Half of the infants received the two animal objects (fish and dragonfly) with /bæf/ and /wem/, whereas the other half received the two non-animal objects (lamb chop and squiggly). These trials consisted of alternate presentations of synchronous word–object pairs, such as a dragonfly with /bæf/ and then fish with /wem/, and so forth until the habituation phase ended. The trials began when infants visually fixated on the monitor and ended when infants looked away from the monitor for more than 1.5 s or after 60 s of cumulative looking. The habituation phase ended when infants' looks on two consecutive trials decreased to less than 50% of the mean of the first two habituation trials (baseline). This particular habituation criterion has been used previously (Bahrick, 1992, 1994, 2001; Gogate & Bahrick, 1998, 2001). Immediately following the habituation phase, infants received two no-change post-habituation trials, identical to the habituation trials, to eliminate chance habituation and allow for spontaneous regression to the mean (Bertenthal, Haith, & Campos, 1983).

Test phase

During this phase, immediately following the post-habituation trials, infants received two mismatch (change/switch) trials and two control (no-change) trials. For example, if infants received two word–object pairings (e.g., /bæf/–dragonfly and /wem/–fish) during habituation, interchanging the pairings (e.g., /wem/–dragonfly and /bæf/–fish) on the mismatch trials was expected to result in longer looking relative to the no-change control trials. The order of test trial presentation was counterbalanced so that half of the infants in each motion condition received the two control trials first, whereas the other half received the two mismatch trials first.

The procedure ended with a posttest trial consisting of the same frog display as was shown during the pretest trial. To assess the level of alertness/fatigue during the entire procedure, infants' looking time to the posttest trial was divided by their looking time to the pretest trial. Infants whose looks on the posttest trial were less than 20% of their looks on the pretest trial were determined to be excessively fatigued and were excluded from the final sample.

One or two observers recorded infants' visual fixations to the displays. Interobserver reliability was reported as a Pearson correlation r and a Cronbach's α between the two observers' records of infants' visual fixations ($p \leqslant .05$) for 20% of the recorded data (n = 12). The Pearson r was .97 (SD = .08), and the Cronbach's α was .89.

Results

Primary analyses

A paired samples t test assessed infants' visual recovery to change or difference score between mismatch and control trials within each condition (see Table 1). This analysis revealed, as predicted, that infants' mean looking to the mismatch trials was significantly greater than their looking to the control trials in the looming and shaking conditions, but not in the upward, sideways, and all-motion conditions (Table 1). These results indicate that learning of word–object relations occurred in the looming and shaking conditions, but not in the upward, sideways, and all-motion conditions.

To assess whether type of motion or consistency of motion mattered during learning of word–object pairings, a one-way analysis of variance (ANOVA) of the mean visual recovery scores by motion condition was performed. This analysis revealed a significant main effect of motion condition (type), $F(4, 55) = 5.95$, $p < .001$, $\eta^2 = .31$. Post hoc analyses (Scheffe's multiple comparison, $p < .05$) revealed, as predicted, that infants' mean visual recovery scores were significantly higher in the looming and shaking conditions than in the upward, sideways, and all-motion conditions (see Table 1). To reiterate, infants learned the word–object pairings in the looming and shaking motion conditions but not in the upward, sideways, and all-motion conditions.

Secondary analyses

Infants' visual fixation on each of four habituation measures—baseline, number of seconds to habituate, number of trials to habituate, and mean looking on the last two habituation trials—was compared across the five motion conditions. Two one-way ANOVAs of seconds to habituate and trials to habituate revealed a main effect of motion type, $F(4, 55) = 3.506$, $p < .01$, $\eta^2 = .20$, and $F(4, 55) = 2.823$, $p < .03$, $\eta^2 = .17$, respectively (see Table 2). The post hoc analyses of these two measures showed that despite the opportunity to look equally across the five motion conditions during habituation, infants preferred to look longer in the shaking motion condition than in any other condition. In contrast, two one-way ANOVAs of baseline and mean looking on the last two habituation trials revealed no main effect of motion type, $F(4, 55) = 1.203$, $p > .10$, and $F(4, 55) = 1.031$, $p > .10$, respectively.

An analysis of covariance (ANCOVA) of the visual recovery scores by motion condition, using seconds to habituate as the covariate, assessed whether the time it took for infants to habituate was a factor in the learning of word–object relations. This analysis revealed a significant main effect of motion condition, $F(4, 55) = 2.92$, $p < .05$, $\eta^2 = .31$, and a marginally significant covariate effect, $F(4, 55) = 3.956$, $p = .051$, $\eta^2 = .02$. Thus, greater time to habituate marginally predicted infants' learning of word–object relations across motion conditions. However, as can be seen in infants in the current looming condition, quicker habituation might also reflect more sustained attention, leading to greater learning (see also Colombo, 2002; Colombo, Mitchell, Coldren, & Freesemen, 1991; Fantz & Fagan,

Table 1
Means (and standard deviations) and paired t tests of mismatch versus control trials by motion condition.

Motion type	Looming	Shaking	Upward	Sideways	All-motion
Mean mismatch (*SD*)	19.2 (9.88)	22.1 (11.60)	13.1 (16.03)	13.8 (7.14)	6.79 (3.87)
Mean control (*SD*)	7.4 (5.39)	11.8 (5.95)	14.1 (15.24)	13.5 (4.98)	6.72 (2.86)
Visual recovery (*SD*)	11.8 (4.49)	10.3 (5.56)	−1.0 (0.79)	0.3 (2.16)	0.07 (1.01)
t Value	6.44*	3.03*	−0.31	0.12	0.09
p Value	.00	.01	.77	.90	.93

* $p \leqslant .01$.

Table 2
Means (and standard deviations) of secondary variables by motion condition.

Motion	Looming	Shaking	Upward	Sideways	All-motion
Baseline	42.33 (13.3)	43.48 (16.4)	36.58 (17.8)	37.00 (17.3)	31.05 (13.7)
Seconds to habituate	174.22[b] (86.2)	281.85[a] (123.9)	170.33[b] (127.6)	153.40[b] (90.7)	147.37[b] (67.7)
Trials to habituate	6.67[b] (0.98)	10.00[a] (4.71)	7.42[b] (1.56)	6.75[b] (1.14)	8.58[b] (3.82)
Last two habituation trials	9.57 (3.9)	10.00 (4.9)	8.21 (4.1)	9.97 (5.6)	6.94 (3.9)

[a,b]One-way ANOVA, $p \leqslant .05$.

1975). In contrast, in some atypically developing populations, quicker habituation leads to attenuated learning (Gogate, Maganti, & Perenyi, 2013).

Several univariate ANOVAs were performed to assess whether stimulus pairing, test order, ethnicity, language, or gender influenced infants' learning of the word–object relations. The analyses revealed no significant main effects or interactions of stimulus pairings, test order, ethnicity, language, or gender on infants' learning of word–object relations across motion conditions (all *ps* > .10).

Analyses of rate of utterance by motion condition

An ANOVA of the rate of utterances by motion condition revealed a significant main effect, $F(4, 39) = 3.26$, $p < .05$, $\eta^2 = .27$. Post hoc analyses showed a greater number of utterances in the all-motion condition ($M = 37.00$, $SD = 1.07$) relative to the shaking ($M = 35.25$, $SD = 2.19$), upward ($M = 35.25$, $SD = 2.05$), and sideways ($M = 35.50$, $SD = 1.60$) conditions. Despite the greater number of utterances in the all-motion condition, learning did not occur. Thus, the greater frequency of an adult's naming alone did not contribute to infants' learning of word–object relations. Furthermore, because the rate of motion was equal to the rate of utterance, it appears that the greater frequency of object motion in the all-motion condition also did not, in and of itself, contribute to infant learning of word–object relations.

Synchrony estimates by motion condition

A computational analysis quantitatively estimated the degree of synchrony in the audio–visual stimuli to determine whether the degree of synchrony differed across the motion conditions. The computational analyses revealed that the mean audio–visual synchrony estimates for the looming, upward, and sideways motion conditions were significantly greater than the synchrony estimates for the shaking and all-motion conditions. These differential synchrony estimates did not correspondingly affect learning (or lack thereof) of word–object relations under the various motion conditions. That is, we did not observe attenuated learning in the all-motion and shaking conditions and greater learning in the looming, upward, and sideways conditions, once again suggesting that type of motion was a key factor in influencing word mapping (see supplementary material for details).

Discussion

The current findings clearly demonstrate that type of motion during an adult's communication matters when preverbal infants map words onto objects. In particular, the current findings demonstrate that shaking and looming motions lead to heightened learning of word–object relations. These motions highlight or foreground the object for infants and most resemble an act of "showing" an object while naming it. Conversely, the upward and sideways motions lead to attenuated learning of word–object relations, probably because these motions do not highlight, or foreground, the object for infants and do not resemble an act of showing an object to infants. In addition, infants showed attenuated learning of word–object relations in the all-motion control condition because in this condition as well the concatenated motions (in equal proportions) did not resemble an act of showing an object to infants. If, in contrast to type of motion, consistency of motion had mattered during word mapping, then infants would have learned the word–object relations equally well in all of the experimental motion conditions, but not in the all-motion control condition, because this condition did not contain a consistent motion. However, this was not the case. Thus, we conclude that in this experiment, type of motion influenced infants' learning to map words onto objects.

The current experimental findings add to the limited body of knowledge on type of gesture and word learning. A prior field study showed that caregivers provide showing gestures consisting of looming motions while naming objects for their infants (Zukow-Goldring & Ferko, 1994). An observational study showed that caregivers abundantly provide looming and shaking motions when naming objects to their preverbal infants and that these motions in maternal naming predicted infants' success during word mapping (Matatyaho & Gogate, 2008). The current findings complement these observational findings and provide the first experimental evidence for a causal relation between shaking and looming gestures of an adult and word mapping success at 8 months of age.

In addition, taken together with the findings of Matatyaho and Gogate (2008), the current findings add to the existing body of emergent knowledge on the embodied process of word mapping. To reiterate, in an embodied system, the organism and its environment are tightly intertwined and constantly adapting to one another (Gogate & Hollich, 2010; Smith, 2005). During the process of word-mapping development, matches occur between what infants perceive and what caregivers provide. Therefore, the current study, which shows superior word mapping in the looming and shaking motion conditions, along with the prior study (Matatyaho & Gogate, 2008), which shows predominantly shaking and looming motions in maternal naming, are evidence for the aforementioned embodied adaptation. These two studies, taken together, provide evidence that a match exists between infant perception of specific motion types and the motion properties that maternal naming provides for infants to learn word–object relations.

The current findings, along with those of Matatyaho and Gogate (2006, 2008), also emphasize that infants' ability to disambiguate a referent amid referential ambiguity lies in the embodied adaptation and interaction between caregivers and infants. Matatyaho and Gogate showed that caregivers provide novel words in synchrony with perceptually salient object motions to highlight or foreground the word–referent relations for their infants (also Gogate, Maganti, & Laing, 2013). In that study, mothers named the two novel objects in a manner conducive to learning these novel relations among several other potential referents. The current study suggests that infants perceive these salient motions during an adult's naming under tightly controlled conditions. Infants learned to map words onto objects only when they were presented in synchrony with shaking and looming motions, but not when presented with upward and sideways motions or with all of these motions concatenated together. The two studies, taken together, suggest that referential ambiguity can be reduced using synchronized shaking and looming motions and spoken words during embodied real-time interactions between infants and caregivers without the need for a priori or built-in constraints (see also Yu et al., 2005).

In accordance with the embodied account of word mapping, the current findings, taken together with those of Matatyaho and Gogate (2008), suggest that in this ongoing interaction between the infant and the caregiver (both of whom reduce referential ambiguity), the infant learns correct word–object mappings. Thus, word-mapping constraints need not be built into the mind of the infant from the start; they become available in the embodied interaction between the infant and the caregiver's naming during the process of language development. Caregivers constrain naming contexts for their infants by providing invariant or relatively stable properties during communication. These properties include object motion—shaking and looming—to highlight the intended object amid other object referents during naming. As discussed earlier, looming motions substantially increase the size of an object in the infant's line of sight and narrow the number of potential referents the infant can attend to during naming. Although shaking motions do not increase the scale of the object, the rapid movements in succession (i.e., relative speed of saccadic motion) likely foreground the object relative to its static background and enable perception of its invariant properties across different transformations (Gibson, 1969). Thus, whereas some rapid caregiver motions might foreground the object and render all else to the background, others simply enlarge the object in the infant's visual field, eliminating other potential referents from the scene. In turn, at 8 months of age, the perceptual–attentional system is adapted to pick up these very same motion properties (showing gestures). Thus, infants attend to these very same motion properties during word mapping. During this embodied process, infants likely disambiguate the correct referent from the incorrect ones (Gogate & Hollich, 2010; see also Hockema & Smith, 2009; Yu et al., 2005).

Consequently, what we are seeing at 8 months of age across the two studies (the current findings and those of Matatyaho & Gogate, 2008) is a constraint for word mapping emerging during the embodied real-time interaction, as evidenced in the match between the enriched motion properties of caregivers' naming and infants' perception of these motions. The constraint emerges as a result of interacting factors—some organismic (e.g., infants' increased attention to shaking and looming motions) and others environmental (e.g., caregivers' provision of these motions). It does not does preexist for word mapping in infants' heads as a result of impoverished caregiver communication. Infant perception and attention to these motions and the matching environmental properties are important components of the embodied system.

A further contribution of the current findings is that preverbal infants are able to map entire, albeit distinct, novel words (CVC) onto objects. Although we know that human infants are especially sensitive to speech (e.g., Vouloumanos & Werker, 2004), relatively little is known about how infants apply their knowledge of the sounds of their language to the problem of linking novel words to referents (Gogate, 2010; Graf-Estes, Evans, Alibali, & Saffran, 2007; Hollich, Jusczyk, & Luce, 2002; Saffran & Graf-Estes, 2006; Stager & Werker, 1997).

Older (14-month-old) infants learned word–object pairings if the syllables were highly distinct (i.e., /nim/ and /lif/; Werker et al., 1998), but not when they were similar (i.e., /bIh/ and /dIh/; Stager & Werker, 1997). Infants as young as 6 to 8 months map distinct open syllables, /gow/ and /chi/, onto objects when presented in synchrony with object motions by their mothers (Gogate et al., 2006). Furthermore, in controlled experiments, 8-month-olds map similar sounding syllables such as /tah/ and /gah/ onto toy objects, whereas 7-month-olds can map only highly distinct syllables such as /tah/ and /gih/ or /gah/ and /tih/ onto the same toy objects when synchrony is provided between the spoken words and object motions (Gogate, 2010). In yet another study, 6- and 12-month-olds preferred the words *toma* and *modi*, but not tones, in object categorization tasks (Fulkerson, Waxman, & Seymour, 2006). Although these prior studies shed light on infants' mapping of syllables onto objects and their preference for words over tones in categorization tasks, this study is the first to demonstrate that infants as young as 8 months can map entire novel words onto referents (for mapping of familiar words onto objects, see Bergelson & Swingley, 2012 Tincoff & Jusczyk, 1999, 2011). These findings, therefore, shift what researchers once thought to be the age at which word mapping emerges to an earlier point in time.

The current findings also emphasize the adaptive significance of certain motions over others. In animals (Maier & Ghazanfar, 2007) and in humans (Judd et al., 2004; von Muhlenen & Lleras, 2007), auditory and visual systems are well adapted to respond at behavioral and neuronal levels to looming sounds and sights (Maier & Ghazanfar, 2007). In particular, the cross-species similarity in response to looming allows the speculation that human infants have developed a preference for looming motions because it is abundantly present in the environment. Young infants discriminate between looming and receding sights and sounds of objects (Pickens, 1994; Walker-Andrews & Lennon, 1985; see also Nanez & Yonas, 1994). Looming motions are also perceptually salient to other species (see Schiff, 1965; Schiff, Caviness, & Gibson, 1962; see also review by Maier & Ghazanfar, 2007). For example, rhesus monkeys defensively move their heads back when viewing an approaching object (Schiff et al., 1962). Rhesus monkeys and human infants find auditory looming (increasing sound intensity) more salient than auditory fading (decreasing sound intensity) (see review by Maier & Ghazanfar, 2007). The salience of looming manifests across species as increased attention to looming sights and sounds, estimation of time to arrival, and/or estimation of loudness change (Maier & Ghazanfar, 2007).

These adaptive responses to auditory and visual looming signals are mediated by specialized neural circuitry (Maier & Ghazanfar, 2007; Sun & Frost, 1998). For example, Maier and Ghazanfar (2007) found that rhesus monkeys showed heightened neuronal firing in the lateral auditory belt to looming sounds relative to receding ones. Similarly, pigeons possess three types of looming-selective neurons (Sun & Frost, 1998), each for different parameters of the expansion of an approaching object. This adaptive mechanism serves as a warning device for detecting large approaching objects, including prey.

Although auditory and visual looming serve to avoid danger across species, for humans, as was demonstrated in the current study, looming also serves another highly important function—that of learning about word–object relations. To reiterate, infants learned word–object relations in the looming condition because object looming increased the scale of the object, recruited infants' attention to the object, and facilitated learning. Fortunately, caregivers often loom objects in synchrony with naming for infants of 6 to 8 months of age (Matatyaho & Gogate, 2008). In addition, toddlers, who are more in control of their naming environment, move objects of interest closer to their heads and eyes (sensors)—obstructing the view of other objects—which eliminates surrounding clutter (Smith et al., 2009; see also Fantz & Fagan, 1975, for infants' preference for objects of a larger size). In that study, the size of the dominating object was always more than 50% of the total size of other objects in the head-mounted camera view. Within an embodied system, manual engagement (e.g., object looming) by caregivers or toddlers naturally leads to one object dominating infants' (toddlers') visual field by being close to the sensors, blocking the view of other objects to reduce referential ambiguity and facilitate word mapping.

To provide further insight into the developmental trajectory of the perceptual mechanisms underlying early word mapping, future infant studies need to examine the periods during which infants are most sensitive to specific motion types during word learning. Such studies would elucidate any developmental shifts in the importance of each motion type, looming and shaking, as word mapping develops during infancy. In the current study, 8-month-olds were assessed based on prior research suggesting that infants of this age unified the word and moving object and learned the relation between a word and a referent when synchrony unified the two. In contrast, older infants learned word–object relations in the absence of motion (Balaban & Waxman, 1997). A longitudinal study examining the shifting importance of these motions would highlight the sensitive periods for each motion type during word-mapping development. In addition, further cross-sectional studies need to examine younger ages, perhaps 7 or even 6 months, when infants can map words using looming and shaking motions as well as older ages when the motions might not be relevant.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.jecp.2013.09.010.

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