Abstract

Quantifying the Relationship Between Infants' Haptic and Visual Response to Word-Object Pairings

Kristi Hendrickson and Margaret Friend

The use of visual and haptic measures as proxies for underlying cognitive abilities has a rich history in infant development research, and perhaps none more so than studies of early vocabulary comprehension. Although visual and haptic measures have displayed long-term predictive value, it remains unclear whether visual attention and haptic responses are analogous and substitutable measures of lexical knowledge. The goal of the current study was to assess the bidirectional relationship between vision and action, and to evaluate the underlying word representations that guide infants' visual and haptic responses. Two measures of visual attention, one macro-level (look accuracy) and one micro-level (proportion of gaze shifts), were measured concurrently with haptic performance during an intermodal word comprehension task. During the task, infants were presented with two images simultaneously on a touchscreen and asked to touch one of the images. Results revealed a somewhat discrepant view on how visual attention relates to haptic performance. Specifically, during trials where an incorrect haptic response was performed, looking-time was significantly greater to the incorrect visual referent, however infants displayed a more sophisticated visual attention style (greater proportion of gaze shifts) known to predict later intellectual functioning. Conversely, during trials where infants failed to perform a haptic response, looking-time to the target was significantly greater than chance however, infants performed significantly fewer gaze shifts. These results will help bridge the gap between literatures that use different response modalities and provide insight on the nature of children's developing knowledge about words.

BUCLD 37 Proceedings
To be published in 2013 by Cascadilla Press
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Quantifying the Relationship Between Infants' Haptic and Visual Response to Word-Object Pairings

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1. Introduction

The application of visual and haptic measures as proxies for underlying cognitive abilities has a rich history in infant development research, and perhaps none more so than studies of early vocabulary comprehension. However it has been documented that infant competence in a number of domains is highly task dependent, such that infants will engage in behavioral dissociations characterized by demonstrating knowledge in one modality but not the other (Diamond, 1985; Hofstadter & Reznick 1996; Ruffman, Garnham, Import, & Connolly, 2001). Although visual and haptic measures have displayed long-term predictive value, it remains unclear whether visual attention and haptic responses are analogous and substitutable measures of lexical knowledge (Charles & Rivera, 2009). Additionally those who implement volitional methods are confronted with the challenge of interpreting the difference, if one exists, between representations that drive incorrect versus absent responses. Visual attention style in infancy has been used as an indicator of later general intellectual function and a predictor of developmental outcomes (Fagan 1984; Colombo 1993; Rose, Feldman, Jankowski, Van Rossem 2011). Consequently analyzing patterns of visual attention concurrently with haptic response creates a ground for determining potential differences between different types of haptic behavior.

Traditionally discrepancies between results obtained visually or haptically have been interpreted as evidence that tasks requiring a haptic response underestimate infant knowledge due to the additional demands of executing an action (Diamond, 1985; Baillargeon, DeVos, & Graber, 1989, Hofstadter & Reznick, 1996, Gurteen, Horne, & Erjavec, 2011). However in recent years a connectionist model based on the graded representations approach has successfully demonstrated that observed behavioral dissociations may reflect that knowledge exists on a continuum; tasks may be differentially sensitive to weaker versus stronger representations (Munakata, 2001; Morton & Munakata, 2003). For example, a weak representation of the word "dog" may permit infants

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to allocate greater visual attention to a matching referent, however this partial knowledge may be inadequate to elicit a haptic response toward the referent, because of the additional effort involved in executing an action. Importantly this is not to say that the action system is delayed, because more robust representations can result in accurate reaching. This approach proposes that knowledge measured by looking and reaching are not necessarily tapping into identical representations but are actually gauging different levels of knowledge. Examining the online dynamics of visual and haptic responses is crucial to determining the level of representation required to generate these responses. This, in turn, is pivotal for understanding how the developing cognitive system is organized.

The study of early language comprehension presents a particularly ripe area within which to investigate these dynamics. At present there are three primary paradigms in use for the assessment of early comprehension vocabulary. These paradigms utilize parent report, haptic responses, and visual attention. Moreover gaining a detailed understanding of how early lexical knowledge transitions to more explicit knowledge states is crucial because it has been well documented that infants who demonstrate both delayed language comprehension and production are at the greatest risk for continued language delay, and later development deficits (Karmiloff-Smith, 1992; Desmarais, Sylvestre, Meyer, Bairati, & Rouleau, 2008; Law, Boyle, Harris, Harkness, & Nye, 2000).

Most of what we currently know about the utility of visual and haptic responses as measures of early language abilities are from studies that have been conducted in a piecemeal fashion, in which investigators selectively use either looking time (Behrend, 1988; Fernald & McRoberts, 1991; Fernald, Zangl, Portillo, & Marchman, 2008; Golinkoff, Hirsh-Pasek, Cauley, & Gordon, 1987; Hirsh-Pasek & Golinkoff, 1996; Houston-Price, Mather, & Sakkalou, 2007; Naigles & Gelman, 1995; Reznick, 1990; Robinson, Shore, Hull Smith & Martinelli, 2000; Schafer, 1998; Thomas, Campos, Shucard, Ramsay & Shucard, 1981) or haptic response (Bates et al., 1988; Snyder, Bates, & Bretherton, 1981; Woodward, Markman, & Fitzsimmons, 1994; Friend & Keplinger, 2003; Friend & Keplinger, 2008; Friend, Schmitt, and Simpson, 2012) but not both. Results from these studies demonstrate that the relationship between looking-time and parent report is highly variable, though they suggest that visual attention may be more sensitive than parent report to newly acquired, less robust word knowledge.

Many visually-based methods adopt global metrics such as overall looking time, and historically more fine-grained, micro-level measures that assess speed of processing, and pattern of visual attention have been ignored (Aslin, 2007). However, within the last decade micro-level metrics have offered interesting insights into underlying cognitive processes. The “looking-while-listening” paradigm first outlined in Fernald, McRoberts, & Swingley (2001) has evolved from the well-documented preferential looking procedure to an on-line measure of saccades in response to speech. Eye movements are monitored by digital camcorders and saccades are coded frame-by-frame to determine infants’ speed in processing words. These continuous data yield a richer, more nuanced picture of language processing than do dichotomous measures obtained by parent report or macro-level looking time measures. To test the predictive validity of measuring individual differences in speed of language processing, Marchman and Fernald (2008) brought back a group of 8-year-old children tested using the looking-while-listening procedure when they were 25-months-old. Their results indicated that the speed with which the target word was processed (as measured by visual reaction time) and the size of children's lexicons at 25-months were predictive of intellectual functioning and language skills at 8 years of age.

Researchers utilizing haptic response measures of early language have obtained comparable findings to visually-based measures (Friend et al. 2003, 2008, 2012; Woodward et al. 1994). Friend and colleagues conducted a series of studies investigating the predictive validity of the Computerized Comprehension Task (CCT), a computer-based measure that uses touch response to gauge early word comprehension. The score on CCT (proportion of correct touches to a named visual referent) was found to be a reliable and valid measure of word comprehension in the 2nd year of life, and a significant predictor of productive language abilities in the 3rd year. Additionally performance on the CCT was significantly correlated with parent report on the MCDI: WG (Friend & Keplinger, 2003; 2008; Friend, Schmitt, & Simpson, 2012). Despite the predictive value of this measure, it suffers from a quandary that exists for all measures that require a volitional response: does one interpret both incorrect and absent responses as indicating a lack of knowledge, or do these two response types differ in a predictable way?

To our knowledge there has been one study that has used both looking and reaching as measures of early language. Using the Interactive Intermodal Preferential Looking Paradigm (IPLP) Gurteen et al. (2011) investigated 13- and 17-month-old's rapid word learning abilities. After being taught a new label for a novel object, infants participated in two trial types: preferential-looking, and preferential-reaching. Results showed that, when prompted with the novel label, 13- and 17-month-olds looked significantly longer at the target object but failed to display recognition haptically. The authors suggest that the discrepancy between results obtained visually and haptically are potentially due to the effort involved in organizing and executing an action, which may divert attention away from the target location. However this claim has never been directly assessed. Indeed very few studies have examined how infants' visual attention relates to executing actions and alternatively how actions can influence visual attention. Using a head-mounted eye-tracker Corbetta, Guan, & Williams (2012), followed one child from 16-49-weeks-old and assessed the congruency between her visual attention and reach location. Similar to previous findings, Corbetta and colleagues found that initially vision and action exhibited a relatively low correspondence but this steadily increased until 8-months-old. After 8-months, looking and reaching became progressively independent such that the child did not consistently direct her reach to the location where she looked longest. Thus throughout development children become less reliant on visual cues to guide reaching, however what drives dissociations between where infants look and reach is still debated.

There is mounting evidence that looking and reaching may reflect different levels of knowledge in diverse domains. Indeed the recent findings from Gurteen and colleagues extend the debate about the meaning of looking and reaching as measures of knowledge, to early word comprehension. Gurteen et al. (2011) measured rapid word learning abilities, which by definition establish less robust word-object knowledge, providing further evidence that looking is a more sensitive measure of gauging partial representations. However Gurteen and colleagues did not measure looking and reaching concurrently, thus the online relationship between these modalities as measures of early language is still unknown. The overarching goal of the current study is to assess the bidirectional relationship between vision and action, and to evaluate the underlying word representations that guide infants' visual and haptic responses. To determine the real-time dynamics between visual and haptic response we used an intermodal word comprehension task, which allows moment-by-moment analysis of looking and haptic behavior. To understand how vision relates to haptic response we will analyze two different measures of visual attention: one macro-level (look accuracy) and one micro-level (proportion of gaze shifts). Moreover, by measuring visual dynamics vis-à-vis haptic behavior we seek to determine what levels of representation guide correct, incorrect, and absent responses.

2. Method

2.1 Participants

Participants were drawn from a larger NICDH-funded, multi-institutional longitudinal project extending the Computerized Comprehension Task (CCT) to the prediction of language production and early literacy in three languages (English, Spanish, and French). Forty-nine 16-18-month-old monolingual English infants (mean age = 16.7) participated in the current study. Data was collected for 52 participants; three were excluded due to fussiness. All participants were exposed to at least 80% English, were full term, and had normal hearing and vision.

2.2 Apparatus

The study was conducted in a sound attenuated room in the Infant and Child Development Laboratory at San Diego State University (see Figure 1). A 3M touch capacitive monitor was attached to an adjustable wall mounted bracket that was hidden behind blackout curtains and between two portable partitions. Two HD video cameras were used to record participants' visual and haptic responses. The eye-tracking camera was mounted directly above the touch monitor and peeked out through a small opening in the curtains. The haptic-tracking camera was mounted on the wall above and behind the touch monitor to capture both the infants' haptic response and the stimulus pair presented on the touch monitor. Speakers were positioned to the right and left of the touch monitor behind the blackout curtains.

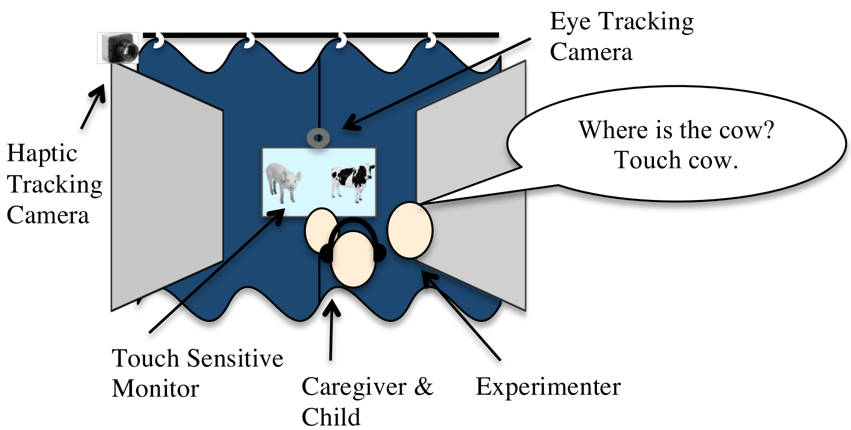

Figure 1 The experimental setting.

2.3 Procedure

Upon entering the testing room, infants were seated on their caregiver's lap approximately 30cm from the touch monitor, and just left of the experimenter. Parents wore blackout glasses and noise-cancelling headphones to control for parental influence during the task. The study began with four training trials containing highly familiar noun pairs to insure participants understood the nature of the task. During the training phase, participants were presented with noun pairs and prompted by the experimenter to touch one of the images. If the child failed to touch the screen after repeated prompts, the experimenter touched the target image for them. If a participant failed to touch during training, the four training trials were repeated once. Only participants who executed at least one correct touch during the training phase proceeded to the testing phase. During testing, each trial lasted until the child touched the screen or until seven seconds elapsed at which point the image pair disappeared. If the participant completed all 41 test trials they were presented with 13 reliability trials that were a random sample of test pairs in the opposite side orientation. All image pairs presented during training, testing, and reliability were matched for word difficulty (easy, medium, hard), part of speech (noun, adjective, verb), and visual salience (color, size, luminance). The experimenter started each trial when the infant's gaze was directed toward the touch monitor. For a given trial, two images appeared simultaneously on the right and left side of the touch monitor. The side the target image appeared was presented in pseudo-random order across trials such that target images could not appear on the same side more than two consecutive trials, and the target was presented with equal proportion on both sides of the screen (Hirsh-Pasek & Golinkoff, 1996). Upon presentation of the image pair, infants were prompted to touch one of the images (target). The sentence frame for the prompt changed as a function of target word part of speech (nouns: *Where is the____? Touch____,* adjectives: *Which one is ____? Touch____,* verbs: *Who is __ing? Touch __ing).* Touches to the target (cow in Figure 1), but not distractor (pig in Figure 1) touches, produced an auditory reinforcement corresponding to the image (e.g., "moo").

2.4 Coding

Videos of infants' eye-movements, haptic response, and a waveform of the experimenter's prompts extracted from the eye-tracking video were synced and coded frame-by-frame (33ms digital time-code) using Eudico Linguistic Annotator (ELAN). Coding occurred in two passes. Coder 1 coded the onset and duration of the target word in the initial prompt and the side of presentation. Coder 2, blind to side of presentation, coded gaze and haptic behavior. Coding for each trial began at the onset of the target word and continued until infants executed a touch or the trial ran to completion. At each frame, gaze was coded as: left fixation, right fixation, or away look. The haptic response was coded starting at the frame in which the arm initiated its trajectory toward the screen resulting in a touch and was terminated at the frame in which infants made contact with the screen. The haptic response was coded as: Target touch (unambiguous touch to the labeled referent), Distractor touch (a touch to the unlabeled referent or both images simultaneously), or No Touch (no haptic response). Gaze data were compiled in two variables: proportion of gaze shifts and accuracy.

3. Results
3.1 Look Accuracy and Haptic Response

The accuracy measure was calculated by dividing looking time to the target by the total looking time toward the screen on a given trial. To investigate the relationship between look accuracy and haptic response we calculated average look accuracy for the three different haptic types (Target, Distractor, and No Touch). Using a one-way Analysis of Variance (ANOVA) there was a main effect of haptic type $F(2,47) = 103.796$, $p < .001$ such that look accuracy changed as a function of where, Target ($M = .649$, $SD = .076$) and Distractor ($M = .390$, $SD = .100$), and whether a touch was executed, No Touch ($M = .547$, $SD = .090$). Post hoc tests using Bonferroni corrections indicated that all pairwise comparisons were significant.

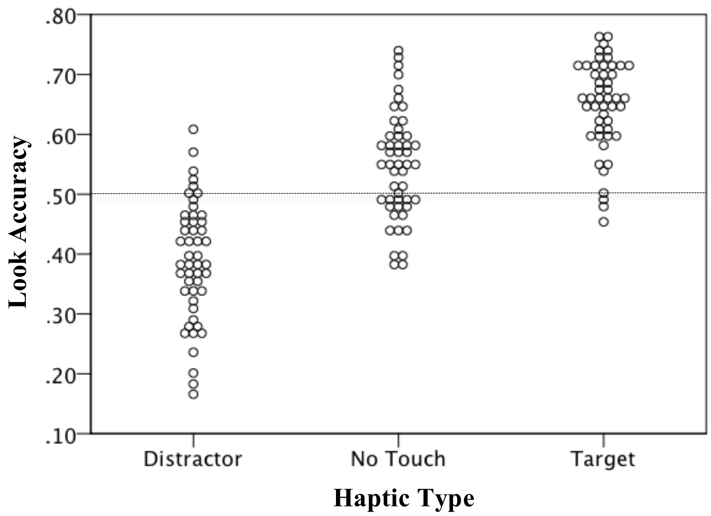

Figure 2 Mean look accuracy by haptic type.

To assess whether eye-gaze alone is purchasing evidence of lexical knowledge above and beyond what is gauged by the haptic measure, we compared average look accuracy on No Touch trials to chance performance (%50). Using a one-sample t test, results show looking to the target on No Touch trials was significantly longer than expected by chance $t(48) = 42.92$, $p < .001$. This lends support to the idea that looking is perhaps a more sensitive measure of early word knowledge than is reaching.

3.2 Proportion of gaze shift and Haptic Performance

Number of discrete looks is a measure of infant visual attention, and is associated with later intellectual functioning (Colombo, Mitchell, Coldren, & Freeseman, 1991; Rose, Futterweit, & Jankowski, 1999). In prior research, discrete looks were operationalized as the number of saccades between a stimulus pair. In the present study, because trial lengths varied, we divided the number of discrete looks by total looking time to obtain a proportion of gaze shifts per trial. To determine if visual attention patterns change as a function of haptic response type we calculated the proportion of gaze shifts for each haptic type. A one-way ANOVA revealed a main effect of haptic type $F(2,47) = 78.1$, $p < .001$.

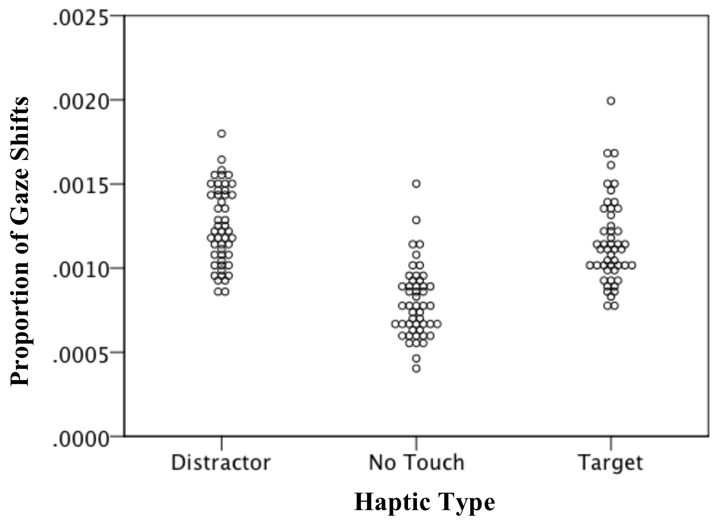

Figure 3 Proportion of gaze shifts by haptic type.

Post hoc tests using Bonferroni corrections indicated that the mean proportion of gaze shifts for No Touches (M = .000796, SD = .000211) was significantly lower than for Target touches (M = .00116, SD = .00257) and Distractor touches (M = .00125, SD = .000232). However Target and Distractor touches were not significantly different.

4. Discussion

The ability to recognize and reference the meaning of familiar words gradually increases over the 2nd year of life. Initially, understanding of familiar words may require contextual cues to support recognition. Eventually stronger, more symbolic representations of word-referent pairings must develop. Consequently, the early lexicon likely consists of both weak (i.e., contextually-dependent) and strong (abstract) word representations (Tomasello, 2003). Although there is a rich literature on early language, few studies have examined how assessments based on different response modalities relate especially in terms of the level of knowledge that these modalities index. The fundamental assumption of looking- and reaching-based methods is that visual and haptic behaviors are proxies for underlying knowledge. However results using looking and reaching to gauge early cognitive abilities occasionally conflict with haptic responses appearing to be less sensitive than visual responses. This is the first study to examine the online relationship between infant visual attention and haptic response.

In the current study we analyzed the relationship between two measures of visual attention, one macro-level (look accuracy) and one micro-level (proportion of gaze shifts). We found that look accuracy significantly predicts haptic behavior, such that infants looked longer to an impending touch location. On No Touch trials looking to the target was significantly longer than expected by chance. This finding is compatible with the view that looking and reaching are not analogous measures of knowledge but in fact gauge different levels of understanding; looking may be more sensitive than reaching to less robust representations (Munakata et al. 1998, Munakata 2001, Munakata et al. 2003). However, we found that visual fixation patterns, characterized by proportion of gaze shifts, changed as a function of action; gaze shifts were more frequent on trials in which a haptic response was performed relative to No Touch trials in which images were passively viewed. Taken together macro-and micro-level measures of visual attention present a somewhat discrepant view on the relation between looking and reaching.

We offer two interpretations for the present results. One interpretation is that these results reflect infants' failure to comply with task demands during haptically-based methods, and consequently haptic measures can systematically underestimate early word knowledge. Look accuracy was greater during Target and No Touch trials, and substantially reduced during Distractor touch trials. This finding suggests that infants have no knowledge of the target referent during Distractor touch trials, but do display knowledge during No Touch trials, suggesting that looking-based measures are more sensitive than haptic-based measures. The significantly greater proportion of gaze shifts during Distractor touch trials may simply be a byproduct of coordinated eye-arm movements. Indeed there is evidence from adult work to suggest that simultaneous arm movements decrease fixation duration and increase speed of saccadic movements (Epelboim, et al., 1997; Snyder, Calton, Dickenson, and Lawrence, 2002). However attractive it is to attribute the greater proportion of gaze shifts during Distractor touches to action execution in general, there is currently no research to suggest infants increase their saccadic rate during action execution.

Another interpretation is that proportion of gaze shifts are not promoted by coordinated action, but instead reflect an attempt, albeit unsuccessful, to reconcile the key features of the target referent relative to the distractor. It has been shown that a more sophisticated attentional style, marked by shorter fixation durations and a high proportion of gaze shifts is reliably predictive of later intellectual functioning (Colombo et al. 1993, Fagan, 1981, Rose et al. 1999). Thus the more sophisticated attentional style demonstrated during Distractor touches potentially represents weak knowledge of the target word, or at the least a greater level of understanding than is present during No Touch trials. From this view the reason look accuracy is poor during Distractor touches is because infants are unsuccessful at reconciling the difference between the two images and choose the wrong referent for the haptic response, which guides their gaze to the intended touch location (the distractor), resulting in a reduced look accuracy. Indeed some researchers have suggested that action diverts infants' attention from the target because of the additional demands involved in planning, organizing, and executing an action (Gurteen et al., 2011). Moreover a diversion to the distractor is more likely if knowledge of the target referent is weak (Munakata 2001). By this account, greater look accuracy during No Touch trials is not due to understanding the target word, but instead is a result of the length of time infants are given to survey the objects. Trials in the current study are longer than traditional looking-based paradigms (Hirsh-Pasek & Golinkoff, 1986; Fernald et al. 2001; Houston-Price et al., 2007) because it takes longer to plan, organize, and execute an action than to orient to a stimulus. There is evidence to suggest that when infants comprehend a word they will fixate on its visual referent spontaneously after it is labeled (Fernald, Pinto, Swingley, Weinberg, and McRoberts, 1998), and the farther in time from the actual word-referent pairing, the less meaningful the response, particularly looking responses which derive from orienting. Therefore it is uncertain how meaningful the look accuracy measure is because of the extended trial length.

It is beyond the scope of the current study to examine whether the increased proportion of gaze shifts during Distractor touch trials is due to action execution, or a weak representation of the target word. To explore these hypotheses we have begun to assess visual reaction time for the three haptic types. Using a measure of reaction time would allow the direct assessment of the speed with which word-object associations are being processed (Fernald et al., 2001, 2008), independent of action. Indeed if visual reaction times for No touch and Distractor touch trials were significantly different it would suggest that infants have partial knowledge of the target referent when they touch the distractor. Conversely if no difference in reaction time exits between the haptic response types, it is more likely the visual attention patterns witnessed here occur because infants, like their older counterparts, tend to make more gaze shifts while executing coordinated actions.

5. Conclusion

To investigate language acquisition in a developmentally-minded way, researchers need to tease partial from fully formed knowledge and latent from active representations. Diverse testing methods allow for such an investigation but they also present the problem of relating results gathered using different response modalities. Much of what we know about early word comprehension is predicated on the assumption that there is some relation between looking, reaching, and lexical knowledge. In the current study we documented how looking and haptic responses as proxies for early vocabulary relate. By altering the level of magnification with which we measured visual behavior, we found different predictive relationships between visual and haptic responses. As Dale and Goodman wrote, “Advances in observational and measurement techniques have often directly stimulated theoretical advances, because they do not simply lead to more precise measurement of what is already studied, but to the observation and measurement of new entities or quantities”(Dale & Goodman, 2005). Understanding the fine-gained details of the relationship between looking and reaching will help bridge the gap between literatures that use different response modalities and provide insight on the nature of children’s developing knowledge about words.

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