Nonverbal action interpretation guides novel word disambiguation in 12-month-olds

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Abstract

Whether young infants can exploit socio-pragmatic information to interpret new words is a matter of debate. Based on findings and theories from the action interpretation literature, we hypothesized that 12-month-olds should distinguish communicative object-directed actions expressing reference from instrumental object-directed actions indicative of one's goals, and selectively use the former to identify referents of novel linguistic expressions. This hypothesis was tested across four eye-tracking experiments. Infants watched pairs of unfamiliar objects, one of which was first targeted by either a communicative action (e.g., pointing) or an instrumental action (e.g., grasping) and then labeled with a novel word. As predicted, infants fast-mapped the novel words onto the targeted objects after pointing (Experiments 1 and 4) but not after grasping (Experiment 2) unless the grasping action was preceded by an ostensive signal (Experiment 3). Moreover, whenever infants mapped a novel word onto the object indicated by a communicative action, they tended to map a different novel word onto the distractor object, displaying a *mutual exclusivity* effect. This reliance on nonverbal action interpretation in the disambiguation of novel words indicates that socio-pragmatic inferences about reference likely supplement associative and statistical learning mechanisms from the outset of word learning.

Keywords: action interpretation, word learning, reference, cognitive development, mutual exclusivity

1. Introduction

Infants begin to learn words during the first year of life (Bergelson & Swingley, 2012; Parise & Csibra, 2012; Bergelson & Aslin, 2017a-b). How do they come to ground linguistic symbols in nonlinguistic reality? One of the first steps in this process is to identify arbitrary relationships between linguistic expressions and their immediate referents. While it is generally agreed that referent selection in older children relies heavily on socio-pragmatic information (for reviews, Golinkoff & Hirsh-Pasek, 2006; Hirsh-Pasek et al., 2004; Baldwin & Moses, 2001), it remains a contentious issue whether such information is also used by young infants who might lack sophisticated understanding of others' communicative intentions and practices.

Some argue that, at the beginning of word learning, the ability to set up links between words and objects is the product of domain-general associative and statistical learning mechanisms that track regularities present in one's environment (Smith, 1999, 2000; Plunkett, 1997; Romberg & Saffran, 2010). Indeed, by 12 months of age, infants can link word forms to salient visual percepts that co-occur with them (Smith & Yu, 2008; Taxitari et al., 2019), and the frequency of co-occurrence determines the strength of the encoded association (Smith et al., 2014; cf. Gleitman & Trueswell, 2020). Others suggest that, like older children, infants should be able to take into account the social context in which language is produced to decipher what aspects of the environment might be referred to by the speakers (Baldwin & Moses, 2001; Tomasello, 2008; Akhtar & Tomasello, 2000). Evidence from the literature on action interpretation indicates that, by their first birthday, infants have access to concepts and inferential mechanisms that could guide their discovery of word-object relationships expressed in language. However, experimental evidence exploring this hypothesis is scarce and not conclusive.

Not all actions performed by others warrant referent search. Some are carried out towards purely instrumental goals of changing the state of the world (e.g., lifting a cup to

pour coffee into it), some for epistemic purposes (e.g., lifting a cup to check whether it is filled), and yet others for communicative purposes of transmitting information to others (e.g., lifting a cup to signal to the waiter that one would like a refill). While these three types of actions can (and often do) involve external objects, these objects serve different roles. In particular, only in communication they function as the immediate referents of the accompanying actions. Thus, while trying to make sense of others' behavior, people should look for referents only for actions they regard as communicative.

How to tell what goal motivates an observed action? Although action interpretation often involves reasoning about the actor's mental states (e.g., intentions, desires, beliefs) that might not be available in infancy, it can also be carried out in a non-mentalistic way (Gergely & Csibra, 2003; Jara-Ettinger et al., 2020). Mechanisms to assess what general purpose an action serves include evaluating its means-end structure (Gergely & Csibra, 2003) and matching it against known action concepts (or schemas, e.g., giving: Tatone et al., 2015, 2019; Yin et al., 2020; chasing: Frankenhuys & Barrett, 2013). Additionally, a particular action interpretation can be automatically activated by a trigger stimulus (Csibra, 2003; 2010). For example, ostensive signals naturally render others' behavior communicative (Sperber & Wilson, 1986), such that instrumental actions become interpreted as pedagogical demonstrations (Hernik & Csibra, 2015; see also Pomiechowska & Csibra, 2017).

Developmental evidence indicates that infants benefit from non-mentalistic action interpretation systems that enable them to interpret certain object-directed actions as instrumental towards specific goals (e.g., approach: Woodward, 1998; Skerry et al., 2013; Gergely et al., 1995; Csibra et al., 1999; Woodward & Guajardo, 2002) and also distinguish them from communicative object-directed actions (e.g., deictic reference: Senju & Csibra, 2008; Hernik & Broesch, 2019; for reviews: Csibra, 2003; Gergely & Jacob, 2012). Therefore, early on, infants have access to inferential tools necessary to solve two major

tasks: (1) recognize that only some nonverbal actions require referent identification, and (2) conceive objects targeted by these actions as potential immediate referents.

Studies demonstrate that by 12 months of age communicative gaze (Csibra & Volein, 2008; Senju & Csibra, 2008; Ishikawa & Itakura, 2019; Okumura et al., 2013a) and pointing (Pätzold & Liszkowski, 2019; Daum et al., 2013; Behne et al., 2012) are expected to be directed at objects and enhance their encoding (gaze: Okumura et al., 2013b; 2020; Reid & Striano, 2005; pointing: Hirai & Kanakogi, 2019; Yoon et al., 2008). It remains unclear, however, whether the target objects are conceptualized as referents. Supporting this interpretation, Gliga and Csibra (2009) found that one-year-olds expect familiar kind labels (e.g., “cup”, “duck”, “spoon”) to co-refer with simultaneously produced head turns, gaze shifts, and pointing. That is, they assume that the label should pick out the object indicated by the direction of gaze and pointing. However, no studies to date have provided evidence that the expectation of co-reference between words and actions contributes to referent selection for *novel words* (Hollich et al., 2000). Although 12- to 13-month-olds were shown to acquire word-object mappings coupled with communicative actions (Woodward et al., 1994; Tsuji et al., 2020), their performance could be explained without appealing to action interpretation or reference. Since even non-communicative object-directed actions orient infants’ attention towards targeted items (Daum & Gredebäck, 2010; Daum et al., 2009), successful word mapping following gaze shifts or pointing might have been supported solely by the formation of associative links between stimuli that co-occur (i.e., the attended objects and the concurrently uttered labels).

To assess the role of action interpretation in referent selection, we investigated whether the nature of an object-directed action that accompanied labeling would influence how infants map novel words to objects. In our study, labeling was accompanied either by a pointing or a grasping action. These actions share essential structural and basic kinematic properties while normally serving distinct functions. Structurally, they can be described as

transitive (or object-directed). Kinematically, both involve an arm protrusion away from the body. Functionally, however, pointing is a prototypical communicative action aimed at highlighting some aspects of the environment that are relevant to the speaker's informative intention (Tomasello, 1998; Kita, 2003), while grasping is a prototypical instrumental action aimed at establishing physical contact with objects in order to retrieve or manipulate them (Woodward, 1998). Although grasping can be performed to express communicative intentions (e.g., when one grasps a phone to demonstrate its function or properties), it is most often performed purely instrumentally to realize a goal. Conversely, pointing is rarely performed outside communication, and is universally perceived as a communicative act, whether accompanied by speech or replacing it (Tomasello, 1998; Kita, 2003). In adults, this functional divide between pointing and grasping is reflected in distinct patterns of neural responses during observation of these actions (Pomiechowska & Csibra, 2017).

Infants participated in a series of referent-disambiguation experiments, in which they could map novel labels to unfamiliar objects in one of two ways: by relying either on the interpretation of preceding actions or on the spatiotemporal contiguity between the moving hand and the object it approached. The action that preceded labeling was either communicative, designating the highlighted object as the referent (e.g., pointing) or instrumental, flagging the target as relevant for the goal of the action (e.g., grasping). If infants rely on action interpretation, they should search for a referent only when labeling was accompanied by a communicative action, such as pointing. Upon finding a referent, the expectation of co-reference between pointing and labeling should lead them to map the novel label onto the object identified as the referent (Gliga & Csibra, 2008). In contrast, observing a non-communicative instrumental action, such as grasping, should leave infants without a reason to map the label onto the target object. Alternatively, if infants rely on spatiotemporal contiguity between events without engaging in action interpretation, they should map labels

1 onto targeted objects regardless of which action they observed because both would highlight
2 a specific object in the scene.

3 We tested 12-month-olds because they appreciate the structural properties of both
4 pointing and grasping, as evidenced by their expectation that these actions are transitive and
5 object-directed, whether the target object is visible or occluded (pointing: Gliga & Csibra,
6 2008; Pätzold & Liszkowski, 2019; Daum et al., 2013; Behne et al., 2012; grasping:
7 Southgate et al., 2010; Daum et al., 2009). By this age, infants are also proficient at executing
8 these actions (grasping: von Hofsten & Rönqvist, 1988; pointing: Leung & Rheingold,
9 1981; Carpenter et al., 1998), therefore having (literally) first-hand experience with planning,
10 performing, and monitoring of both actions. Concerning functional differences, infants
11 selectively use pointing to direct others' attention towards objects and events about which
12 they would like to provide (Liszkowski et al., 2006) or receive (Kovács et al., 2014; see also
13 Begus & Southgate, 2012; Liszkowski et al., 2004) information. Therefore, in production,
14 they appreciate the referential nature and communicative significance of pointing. Finally,
15 infants at this age rapidly form associations between words and objects trained in lab settings
16 (Pomiechowska & Gliga, 2019; Tsuji et al., 2020).

17 **2. Experiment 1**

18 Experiment 1 investigated whether 12-month-olds rely on pointing to identify the
19 referents of new words. To this aim, we employed a referent-disambiguation task and measured
20 infants' responses to words using eye tracking. On each trial, we presented infants with two
21 novel objects. Then, they saw a hand pointing to one of the objects before hearing an unfamiliar
22 word (e.g., *A moxi!*). Next, they received a looking-while-listening test (Golinkoff et al., 2013),
23 during which they heard either the trained label (e.g., *Where is the moxi?*) or a novel one (e.g.,
24 *Where is the blicket?*), while being continuously presented with the two objects. We expected
25 that identifying the object targeted by pointing as the referent of both the action and the word

co-occurring with it and would result in mapping the word onto it (Pomiechowska & Gliga, 2019; Yin & Csibra, 2015). The formation of such mapping should be evidenced by infants fixating on the target upon hearing the trained word again during the test. Hence, we predicted that if pointing is interpreted as a communicative action affording referent assignment and expected to co-refer with concurrent speech, infants should look longer at the target object selectively upon hearing the trained, but not the novel, label.

2.1. Methods

2.1.1. Participants

Sixteen healthy full-term 12-month-olds (mean age: 12 months 4 days, range: 11 months 16 days to 12 months 28 days) participated in this experiment. An additional 7 infants were tested but excluded from the analysis because they failed to complete the task ($n = 3$), did not provide enough data ($n = 3$, see below for the inclusion criteria), or were short-sighted ($n = 1$). All infants in this and all following experiments came from monolingual Hungarian-speaking families who volunteered to participate in our research. All parents gave informed consent. Infants received a small gift for their participation. The current sample size was determined a priori based on the literature on early word learning (e.g., Pomiechowska & Gliga, 2019; Yin & Csibra, 2015). The sample size was kept constant for all the following experiments in this study.

2.1.2. Apparatus

Binocular gaze data were collected with a TOBII X60 eye tracker (sampling rate: 60 Hz). The visual stimuli were displayed on a 23-inch monitor (sampling rate: 60 Hz, resolution: 1920×1080 px). The audio stimuli were delivered via loudspeakers placed directly behind the monitor. The stimuli presentation and data collection were administered using Matlab 2014b, Psychophysics Toolbox PTB-3 (Brainard, 1997; <http://psychtoolbox.org/>), and Tobii Pro

1 Analytics software development kit ([http://www.tobiiipro.com/product-listing/tobii-pro-](http://www.tobiiipro.com/product-listing/tobii-pro-analytics-sdk/)
2 analytics-sdk/).

3 **2.1.3. Stimuli**

4 **2.1.3.1. Objects.** We used 8 pairs of novel objects designed and handmade
5 specifically for the current study. Items within each pair differed in shape and color to
6 facilitate perceptual discrimination between them. These pairs of objects were used to create
7 8 experimental videos, each used on one trial. See Design and Procedure for the description
8 of the depicted events.

9 **2.1.3.2. Speech.** We used 8 pairs of CVCV pseudo-words consistent with Hungarian
10 phonotactics: (1) bite - gupa, /bɪtɛ/ - /gʊpɒ/, (2) tegi - kabó, /tɛgi/ - /kɒbo:/, (3) düpi - baku,
11 /dypi/ - /bɒku/, (4) pádu - géte, /pa:du/ - /ge:tɛ/, (5) kitő - püke, /kitø:/ - /pykɛ/, (6) toda -
12 bóta, /todɒ/ - /bo:tɒ/, (7) fego - mize, /fego/ - /mizɛ/, (8) nala - baku, /nɒlɒ/ - /bɒku/.

13 The labels were embedded in the following carrier phrases: “Egy [label]. Hú, egy
14 [label]! Egy [label].” (A [label]. Wow, a [label]! A [label].), during the naming event, and
15 “Nézd csak, hol van a [label]? [Label]. [Label].” (Look, where is the [Label]? [Label].
16 [Label].) during the test phase. All stimuli were recorded by a female native speaker of
17 Hungarian using infant-directed prosody.

Figure 1. Schematic visualization of the experimental design across Experiments 1-4. A Trial structure across experiments. All trials had the same structure within each experiment, but infants were presented with a different pair of objects and pseudo-words on each trial. **B** Examples of speech stimuli at training (B1) and test (B2: test question; B3: response phase). At test, we manipulated whether infants heard the same word as at training (trained-word condition) or a novel previously unheard word (novel-word condition).

2.1.4. Design

The experiment consisted of 8 trials. Each trial had the same structure (Figure 1) but involved a different pair of objects and word forms. Each trial consisted of two phases: *training* and *test*, and involved two novel objects located on the opposite sides of an otherwise empty table covered with dark grey cloth and set against a light grey background.

During training, the objects were displayed for 2 seconds before the onset of the action (i.e., before the first frame during which the hand became visible). Then, a downward-pointing hand appeared above one of the objects (target), moved down (2 s), and remained still above the target while the speech stimuli (e.g., *A mize. Wow, a mize! A mize.*) were delivered (5 s, with the speech starting 0.5 s after the pointing action was completed). After the offset of the speech, the hand moved up and out of the display (1 s) and the objects remained on the table (2 s, pretest period). The test phase followed without interruption: a dynamic gaze-contingent attention getter appeared between the objects in the center of the display. Fixating on the attention getter for 0.5 seconds triggered the onset of the word-recognition test: the attention getter changed its color, and the test question started (e.g., *Hi baby, look! Where is the mize?* 2 s). The beginning of the test response period was timed to the offset of the test question. It lasted 5 s, during which the label was repeated two more times (e.g., *Mize. Mize.*, onsets at 1.5 s and 3.5 s).

On half of the trials, the test question contained the same word as the naming event (e.g., “mize”; trained-word condition) and the other half employed a novel, previously unheard word (e.g., “fegu”; novel-word condition). The order of test questions, the location of the objects (left v. right), and the action side (left v. right) were randomized by shuffling. Additionally, we counterbalanced across participants the assignment between object pairs and word pairs, and the order in which they were presented.

2.1.5. Procedure

Testing took place in a soundproof room. Infants were seated on their parent’s lap, approximately 60 cm away from the monitor. The parents wore opaque glasses and were instructed to remain silent and not interact with the infants throughout the session.

A short infant-friendly calibration procedure preceded the experimental task. A five-point calibration sequence was repeated until at least four points were successfully calibrated.

2.1.6. Data Analysis

We used the following predetermined inclusion criterion: each infant had to contribute a minimum of 2 valid trials per condition. We considered valid a trial during which infants provided at least 50% on-screen gaze data during each of the following events: (a) naming, (b) pretest, (c) test question, and (d) test response period. Overall, there were 52 valid trials in the trained-word condition and 51 in the novel-word condition. Infants contributed on average 3.25 trials ($SD = 0.86$) in the trained-word condition and 3.19 ($SD = 0.98$) trials in the novel-word condition (for the descriptive data on infants' attention to the screen across experiments, please see *Table S1* in the Supplementary Materials).

To assess referent selection, we compared the time they spent looking at the target (i.e., object targeted by the action) and distractor after hearing the test question. We used *difference scores* computed on AOI hits recorded during 1-second-long time bins throughout the test response period (after Yin & Csibra, 2015) as our main dependent variable. To derive difference scores, we followed the following steps: first, we defined two rectangular areas of interest (AOIs: 805×535 px), one encompassing the target object and the other one the distractor object. Then, we calculated AOI hits (i.e., gaze points falling within a given AOI) for each AOI throughout the test response period. We binned the AOI hits into 4 bins: (1) 0-1 s (corresponding to: 1-60 samples), (2) 1-2 s (corresponding to: 61-120 samples), (3) 2-3 s (corresponding to: 121-180 samples), (4) 3-4 s (corresponding to: 181-240 samples). Next, we summed the AOI hits within each time bin, separately for the target and the distractor, and used these data to compute difference scores for each time of interest. This was done by subtracting the time spent looking at the distractor from the time spent looking at the target and dividing this by the total time spent looking at both objects: $(target - distractor) / (target + distractor)$. Finally, for each participant, we computed the mean of the contributed difference scores across trials within each condition (trained word vs. novel word). Such calculated difference scores ranged from -1 (looking only at the distractor) to 1 (looking only

at the target). Positive values indicate longer looking at the target object and negative values indicate longer looking at the distractor object. Hence, a pattern of results in which difference scores computed in the trained-word condition are positive and differ from those computed in the novel-word condition would indicate successful referent selection and word-mapping. Because we did not have specific predictions regarding how rapidly the differences between conditions should emerge or how sustained they should be over time, we analyzed the average difference scores using a repeated-measures ANOVA with condition (trained word v. novel word) and test bin (0-1 s v. 1-2 s v. 2-3 s v. 3-4 s) as within-subject factors. Furthermore, we compared the difference scores to 0 using one-sample *t* tests. For all *t* tests, we report Cohen's *d* effect size estimates and 95% confidence intervals (CI) for mean differences.

2.2. Results and Discussion

A repeated-measures ANOVA with condition (trained word v. novel word) and test bin (0-1 sec v. 1-2 sec v. 2-3 sec v. 3-4 sec) on the average difference scores yielded a significant interaction between condition and time, $F(3,45) = 3.490, p = .027, \eta_p^2 = 0.18$. Follow-up paired-samples *t* tests revealed that infants responded differently to trained and novel words, $t(15) = 4.211, p = .003$ (Bonferroni corrected), $d = 1.05$, 95% CI = [.31, .95], during the first test bin (remaining test bins: $ps > .35$, Figure 2). During this period, infants looked preferentially at the target objects previously singled out by pointing only when presented again with the trained words ($M = .34, SD = .39$). This preference was significantly above chance, $t(15) = 3.489, p = .003, d = .87$, 95% CI = [.13, .54]. During the remainder of the test, their responses did not differ from chance ($ps > .130$). Together, these results indicate that infants identified the objects targeted by pointing as referents and linked them with the co-occurring words, albeit their looking response was short-lived. Such temporal profile of response conforms with the dynamics of infants' looking behavior reported in the looking-

1 while-listening tasks (e.g., Schaffer & Plunkett, 1998; Tsuji et al., 2020). A complementary
2 analysis of infants' first looks performed after the test question indicated that their referent
3 selection and ensuing word mapping were also evident at the level of first gaze shifts
4 executed in response to the test words (i.e., more saccades directed to the targets of pointing
5 than to distractors in the trained-word condition, see Supplementary Materials *SM2 First*
6 *Looks*).

7 Interestingly, upon hearing the novel words, infants initially oriented towards the
8 distractor objects (test bin 0-1 s: $M = -.29$, $SD = .51$). Their average difference scores were
9 lower than expected by chance, $t(15) = 2.294$, $p = .036$, $d = .57$, 95% CI = $[-.56, -.02]$ during
10 the first second of the test phase, but not later ($ps > .129$). This pattern is consistent with the
11 idea that infants may have employed the mutual-exclusivity principle (i.e., the expectation
12 that distinct names refer to different objects, Markman, 1989; see also Pomiechowska et al.,
13 under review) to infer the referents of the novel words. This finding suggests that the
14 representations set up by the infants for the words that accompanied pointing must have been
15 richer (e.g., referential, symbolic) than simply auditory percepts, as these would not license
16 inferences about the denotation of novel words.

Figure 2. Difference scores measured in Experiments 1-4 as a function of condition (trained word v. novel word). For illustration, the data are split by test bin (test bin 1: 0-1 s; test bin 2: 1-2 s; test bin 3: 2-3 s; test bin 4: 3-4 s). *Line plots*: dots indicate means and error bars indicate standard error of the mean. *Box plots*: Black horizontal lines indicate medians. The bottom and the top of the boxes represent the first and the third quartiles. Whiskers extend from the middle quartiles to the smallest and largest values within 1.5 times the interquartile range. Dots represent the individual means of the contributed difference scores across trials within each condition.

3. Experiment 2

Experiment 1 provided evidence that infants linked the objects highlighted by pointing with the subsequently provided words. In Experiment 2, we investigated what process led to this outcome: a communicative-referential interpretation of pointing actions or a pure association between an object and a word heard when this object was highlighted by an external stimulus in the form of pointing. To this aim, we modified the task from Experiment 1 by replacing pointing actions with grasping actions matched in duration and gross kinematics. If referent selection relies on interpreting the observed object-directed action as communicative, infants should not link the co-occurring label to the object targeted by grasping. This is because, absent further evidence, grasping is interpreted by infants as an instrumental means towards object retrieval (e.g., Woodward, 1998), hence not directly related to the ambient speech. If, on the other hand, infants' performance in Experiment 1 was underlaid by associative learning, they should map new words to the objects highlighted by grasping as readily as when the objects were highlighted by pointing.

3.1. Methods

3.1.1. Participants

A new group of 16 infants took part in this experiment (mean age: 12 months 10 days; range: 11 months 15 days to 12 months 26 days). An additional 8 infants were tested but excluded from the final analysis due to a failure to complete the task ($n = 4$), crying ($n = 1$), or not providing enough valid data ($n = 3$).

3.1.2. Stimuli, Design, and Procedure

The stimuli and procedure were the same as those in Experiment 1 except for the object-directed action: pointing actions were replaced with grasping actions matched in speed and duration. Each grasping action resulted in direct contact between the hand and the target object, maintained throughout the naming event. The grasp was carried out in such a way that the hand did not obscure the object (see Figure 1). At the offset of speech, the hand released the object, moved up and left the display (1 s). The design of the test phase was the same as that of Experiment 1.

3.1.3. Data Analysis

To analyze the data, we followed the same steps as in Experiment 1. Overall, infants contributed a total of 48 valid trials ($M = 3.00$, $SD = .82$) in the trained-word condition and 53 valid trials ($M = 3.31$, $SD = .95$) in the novel-word condition.

3.2. Results and Discussion

A repeated-measures ANOVA on average difference scores with condition (trained word v. novel word) and test bin (0-1 sec v. 1-2 sec v. 2-3 sec v. 3-4 sec) as within-subject factors did not reveal any significant main or interaction effects (all $ps > .68$). For comparisons to chance (0), we collapsed the data across time. Upon hearing any label, trained and novel alike, infants looked longer at the object that was previously grasped (Figure 2). Their difference scores rose significantly above chance level (trained-word condition: $M = .19$, $SD = .34$, $t(15) = 2.155$, $p = .048$, $d = .54$, 95% CI = [.002, .37]; novel-word condition ($M = .18$, $SD = .27$, $t(15) = 2.603$, $p = .020$, $d = .65$, 95% CI = [.03, .32]). Infants' first looks mirrored these results (Supplementary Materials *SM2 First Looks*).

The same pattern of responses to trained and novel words indicates that spatiotemporal contiguity between the grasping action and the grasped object was insufficient for infants to associate this object with the label that accompanied the action. Upon observing an instrumental action during training infants inspected the targeted object, but without ascribing it the role of referent (see Supplementary Materials *SM3. Attention to the Locations Highlighted during Naming*; *SM4. Attention to the Objects during Pretest*). Instead, they likely conceived this object as involved in the goal of the grasping action and stored this representation in their working memory. Such process would explain an overall visual preference for the target object at test, even though the displayed looking patterns did not reflect any influence of the test label.

3.2.1. Comparison between Experiments 1 and 2

Referent-selection performance across experiments was compared by entering average difference scores into a mixed-model ANOVA with experiment (1 v. 2) as a between-subject factor, along with condition (trained word v. novel word) and test bin (0-1 sec v. 1-2 sec v. 2-3 sec v. 3-4 sec) as within-subject factors. This analysis yielded a significant interaction between experiment, time, and condition, $F(3,90) = 2.915, p = .039, \eta_p^2 = .09$, confirming that pointing and grasping had different effects on referent selection. Follow-up ANOVAs conducted separately within each time bin showed that the differential effects of pointing and grasping were manifest immediately after naming, as indicated by a significant interaction between experiment and condition in the first time bin (0-1 sec), $F(1,30) = 11.3001, p = .002, \eta_p^2 = .27$. No significant main effects or interactions were observed in the remaining time bins (1-2 sec: $ps > .705$; 2-3 sec: $ps > .12$; 3-4 sec: $ps > .096$).

Thus, Experiments 1 and 2 jointly indicate that the type of action observed before hearing a novel label critically influenced whether infants established a referential link between this label and the object singled out by the action. Only communicative

1 interpretation of pointing resulted in conceptualizing the targeted object as a referent and
 2 prompted infants to map the concurrent word onto it. To disambiguate novel words in the
 3 current task, infants prioritized the use of socio-pragmatic information resulting from action
 4 interpretation over spatiotemporal regularities.

5 In contrast to pointing, grasping an object did not facilitate mapping the word that
 6 accompanied grasping to the grasped object and this result was not due to lower level of
 7 attention to the grasped than to the pointed location during naming (see Supplementary
 8 Materials *SM3. Attention to the Locations Highlighted during Naming*) or immediately after
 9 naming (*SM4. Attention to the Objects during Pretest*). We take this finding as confirming
 10 that grasping is understood by one-year-olds as an instrumental action performed to get
 11 access to particular objects (Woodward, 1998). Such interpretation of an object-directed
 12 action does not license inferences about objects as potential referents, hence providing no
 13 grounds for linking the grasped objects and the subsequent speech.

14 What did infants make of the speech following instrumental grasping in Experiment
 15 2? While our results suggest that they considered speech irrelevant to the objects that were
 16 grasped, at least two other possibilities remain open. First, infants might have engaged their
 17 associative word-learning mechanisms but did not have enough time to form stable links
 18 between the target objects and trained words. Second, they might have considered the new
 19 words in relation to the observed action. For example, the novel labels might, in principle,
 20 have been construed as action labels. Although lab-based verb learning has not been reliably
 21 documented until around 15-18 months of age (He & Lidz, 2017; Jin & Fisher, 2014), word-
 22 recognition tasks targeting verbs learned in the natural contexts report rudimentary verb
 23 knowledge to emerge between 10 and 13 months (Bergelson & Swingley, 2013). Future
 24 research shall shed light on the question of whether young infants might spontaneously take
 25 instrumental actions as referents of concurrent words.

4. Experiment 3

The findings of Experiments 1 and 2 suggest that one-year-olds spontaneously interpret pointing, but not grasping, as a communicative act, which in turn enables them to find the referents of new words co-occurring with pointing. It is important to note, however, that actions which are typically carried out towards instrumental goals can be repurposed towards communicative goals — as long as other accompanying signals indicate this purpose (e.g., by explicitly addressing one’s audience in action demonstration contexts, Pomiechowska & Csibra, 2017; Futo et al., 2010; Hernik & Csibra, 2015).

In Experiment 3 we tested whether we could trigger a communicative interpretation of grasping and make infants use it in the referent search process. We operationalized this idea by modifying the order of events in our task. Here, we presented the speech stimuli *before* the execution of the grasping action (and not *after*, as in Experiment 2). Infant-directed speech intonation is an ostensive signal itself (Csibra, 2010; Sirri et al., 2020; Zangl & Mills, 2007) and could lead infants to expect subsequent actions to be communicative (Senju & Csibra, 2008; Okumura et al., 2013a). Although the change of order between speech and action seems subtle, we predicted that it should be sufficient to influence the infants’ take on the grasping action, because the initial ostensive signal could facilitate a communicative, and inhibit an instrumental, interpretation of the subsequent action (see also, Baker et al., 2009).

4.1. Methods

4.1.1. Participants

The final sample consisted of 16 participants (mean age: 12 months 3 days; range: 11 months 15 days to 12 months 28 days). Three additional infants were tested but failed to complete the task.

4.1.2. *Stimuli, Design, and Procedure*

We used the same stimuli and general procedure as in the previous experiments. The design was modified such that speech preceded grasping during the naming event. First, the objects were shortly presented in silence (.5 s). Then, the naming stimuli, identical to those of Experiments 1 and 2, were played (5 s). Only at the offset of the speech, a hand appeared above one of the objects and reached downwards to grasp it (2 s). The grasp was presented for 2 seconds, after which the hand released the object and moved upwards, leaving the display (1 s). The grasping actions were identical to those of Experiment 2. The subsequent word-mapping test had the same structure as in Experiments 1 and 2 (Figure 1).

4.1.3. *Data Analysis*

To accommodate the modification in the design, we amended our trial inclusion criteria such that a trial was considered valid if infants provided a minimum of 50% onscreen data during each of the following events: (a) action, (b) pretest, (c) test question and (d) test response period. Overall, there were 46 valid trials ($M = 2.88$, $SD = .95$) in the trained-word condition and 47 valid trials ($M = 2.94$, $SD = .77$) in the novel-word condition. The remainder of the analysis was the same as in Experiments 1 & 2.

4.2. **Results and Discussion**

Difference scores were entered into a repeated-measures ANOVA with condition (trained word v. novel word) and test bin (0-1 sec v. 1-2 sec v. 2-3 sec v. 3-4 sec) as within-subject factors. This analysis revealed a significant main effect of condition, $F(1,15) = 14.881$, $p = .002$, $\eta_p^2 = .50$, indicating that infants reacted differently to trained words and novel words (Figure 2). As there was no significant main effect of time or interaction with this factor (all $ps > .25$), further analyses were carried out on the data averaged across time bins. Trained words led to a preference for the target objects previously highlighted by

grasping ($M = .26$, $SD = .36$), while novel words led to a preference for the distractors ($M = -.19$, $SD = .31$). Comparisons to chance (0) indicated that changes in looking in both conditions were significantly different from chance: higher than chance for the trained words, $t(15) = 2.943$, $p = .010$, $d = .74$, 95% CI = [.07, .45]; and lower than chance for the novel words: $Z = -2.50$, $p = .006$, by a Wilcoxon signed-rank test applied because the data were not normally distributed. This pattern of results, observed also in infants' first looks (Supplementary Materials *SM2 First Looks*), provides evidence that the infants (1) linked the trained words to the grasped objects and (2) inferred that the distractor objects might be referents of the novel words (see also Pomiechowska et al., under review).

Here, unlike in Experiment 2, infants successfully adopted the target of a grasping action as the referent of the trained word. This outcome was likely due to the change in the temporal order of events between experiments: i.e., that the labelling came before, not after, the action. The ostensive signal in the form of infant-directed speech was the first dynamic stimulus infants were exposed to in each trial, and which they could exploit to make sense of the observed events. Because ostensive signals prompt the interpretation of otherwise instrumental actions as communicative and, hence, referential (Pomiechowska & Csibra, 2017; Csibra & Senju, 2008; Futo et al., 2010; Király et al., 2013; Mamo & Csibra, 2015; Hernik & Csibra, 2015), the presence of infant-directed speech before the action likely triggered a communicative interpretation of the action, which was then maintained throughout the event. In other words, having experienced an ostensive signal first, infants construed the following grasping action as a deictic gesture. As such, they could then use it to disambiguate the referent of the preceding speech by assuming co-reference between speech and gesture (Gliga & Csibra, 2008).

Why did the order in which an ostensive signal and a normally non-communicative action were presented matter? Inferences about others' goals are continuously revised as their behavior unfolds (e.g., Baker et al., 2009; Baker et al., 2017; see also, Pomiechowska &

Csibra, 2017). Our experiments rested on the assumption, supported by our findings, that infants would settle on the interpretation of the event using the earliest available evidence. In Experiment 2, where speech followed an instrumental action, infants likely adopted the instrumental reading of the events based on the interpretation of the first observed action. Subsequently, they were either not willing to or did not have enough time to reconsider this interpretation upon receiving further information in the form of speech.

5. Experiment 4

Together, Experiments 1 to 3 demonstrated that 12-month-old infants engage their action interpretation system for reference identification. Note that the tasks used in these experiments did not require them to remember anything else but the location of the labeled objects. In Experiment 4, we investigated the contents of the object representations that infants set up to keep track of referents. To this aim, we presented a new group of infants with a modified version of the task used in Experiment 1.

Here, pointing and labelling were followed by a short occlusion of the stage, after which the locations of the objects were swapped. If infants map labels onto object representations that contain visual features of the referent, they should re-identify the referent even if it appears at a different location following occlusion. Hence, they should display a similar pattern of looking as the one recorded in Experiment 1 (i.e., orienting to the object targeted by pointing following the trained word; orienting to the distractor object following the novel word). Alternatively, if infants encode the referents using location-based representations lacking visual features (Leslie et al., 1998; Kibbe, 2015; Samuelson et al., 2011, 2017), the pattern of their visual preferences should flip relative to Experiment 1. Namely, the trained word would elicit longer looking to the distractor object (placed now at the location of the object targeted by pointing), while the novel word would elicit longer looking towards the target object (placed now at the location of the distractor object).

5.1. Methods

5.1.1. Participants

The final sample consisted of 16 participants (mean age: 12 months 10 days; range: 11 months 18 days to 12 months 28 days). An additional 10 participants were tested but excluded from the analysis because they failed to complete the calibration ($n = 1$), failed to complete the task ($n = 4$), or did not provide enough data ($n = 5$).

5.1.2. Stimuli, Design, and Procedure

The stimuli and procedure were generally the same as in the previous experiments. However, the design of Experiment 1 was extended to include a short occlusion between the training and test phases (Figure 1). After the hand disappeared from the display following the action, a curtain went down (0.55 s) and covered the stage. The objects remained invisible for 3 seconds before the curtain went up (0.55 s), revealing the objects on the opposite side of the scene to where they had previously been located. A short jingle sound was played half-way through occlusion to maintain the infants' attention on the screen. As in the previous experiments, a silent pretest period (2 s) preceded the test question.

5.1.3. Data Analysis

We applied the same data analysis as in the previous experiments. Infants provided a total of 55 trials ($M = 3.44$, $SD = .73$) in the trained-word condition and 55 trials ($M = 3.44$, $SD = .73$) in the novel-word condition.

5.2. Results and Discussion

A repeated-measures ANOVA with condition (trained word v. novel word) and test bin (0-1 sec v. 1-2 sec v. 2-3 sec v. 3-4 sec) as factors on the average difference scores

yielded a significant main effect of condition, $F(1,15) = 6.766, p = .020, \eta_p^2 = .31$, and a significant interaction between condition and time, $F(3,45) = 3.000, p = .040, \eta_p^2 = .18$. This interaction was driven by different looking patterns upon hearing trained words and novel words at test (Figure 2). This effect was significant only during the first second of the measurement, $t(15) = 3.288, p = .020$ (Bonferroni corrected), $d = .82$, 95% CI = [.22, 1.05] (in the further time bins, $ps > .22$, Bonferroni corrected). As in Experiment 1, during the initial period of test measurement, the trained words elicited longer looking towards the objects targeted by pointing ($M = .19, SD = .49$), and the novel words elicited longer looking towards the distractor objects ($M = -.45, SD = .39$). For distractor objects, the difference was significantly different from chance, $t(15) = 4.625, p < .001, d = .45$, 95% CI = [-.66, -.24], while for the target ones, it was not, $t(15) = 1.535, p = .146, d = .38$, 95% CI = [-.07, .45]. Similar responses were manifest in infants' first looks (Supplementary Materials *SM2 First Looks*).

Despite a short occlusion period resulting in the swap of object locations, we observed a similar pattern of results as in Experiment 1. The difference scores were positive in response to the trained words and negative in response to the novel words, confirming reference assignment for trained words to objects identified by their visual features. This finding indicates that the object representations set up to track referents included featural information that enabled infants to re-identify the referents after their location had been swapped. Further, the current results also confirm that infants readily use the newly formed symbol-referent associations to disambiguate novel words via mutual-exclusivity inferences.

6. General Discussion

We conducted four experiments that investigated whether infants use socio-pragmatic information in the form of nonverbal actions that accompany language to guide their interpretation of novel words. Our findings make three main theoretical contributions. First,

Experiments 1 and 2 jointly show that nonverbal action interpretation underlies linguistic reference disambiguation and rapid formation of new word-object mappings. Twelve-month-olds who heard a novel word in the presence of two unfamiliar objects linked this word to the object that was targeted by a communicative action affording referent ascription (i.e., pointing, Experiment 1), but not to the object that was targeted by an instrumental action affording goal ascription (i.e., grasping, Experiment 2). This process was evidenced by the pattern of infants' eye movements: when tested with the word that co-occurred with pointing during training (i.e., trained word), infants looked preferentially at the object that was highlighted by the action; when tested with a novel word, infants tended to orient towards the other object, which had not been acted upon. Conversely, following grasping, infants did not differentiate between the trained and novel words, but consistently oriented towards the objects previously targeted by grasping. This pattern of findings indicates that reference ascription was conditional on interpreting the nonverbal action that preceded naming and singled out one of the objects as communicative. Infants identified objects highlighted by communicative actions, but not those highlighted by instrumental actions, as potential referents and, further, they assumed that these actions co-referred with the concurrent words (Gliga & Csibra, 2008).

Second, Experiment 3 conceptually replicated the findings of Experiment 1 and extended its conclusions. The availability of an ostensive signal in the form of infant-directed speech before the observation of grasping enabled infants to use this action for referent selection. This result suggests that the presence of an ostensive signal prompts infants to interpret subsequent actions as communicative and, consequently, consider the objects targeted by these actions as referents. Although we used a single instrumental action (grasping), we expect that infants would re-interpret other transitive actions (e.g., touching, poking, moving, shaking) as referential after ostensive signals.

Third, Experiment 4 provided another replication of Experiment 1 and insights into the contents of representations that infants set up to keep track of referents. Even though the objects were occluded after training and emerged from the occlusion in different locations, at test infants recognized the referents of the trained labels. This success indicates that (1) object representations onto which infants mapped novel words contained sufficient featural information to enable referent re-identification and that (2) this information proved relevant enough to be maintained in working memory when the referent went out of view.

In sum, our results provide evidence that young infants use nonverbal aspects of communication to find out what others refer to when using novel words and set up mappings between these words and referent objects. In particular, they can recruit their action interpretation skills, which predate their mastery of language, to decode the nonverbal social information that accompanies verbal communication and use this information to bind lexical entities to object representations. This process is fast, requiring no more than a single-trial exposure to the novel word accompanied by a communicative action. Note that our findings do not entail that purely associative and statistical learning mechanisms do not contribute to word learning. Rather, it is likely that in contexts where co-occurrences between words and objects are sporadic and short-lived, such as those of the present experiment and also of many naturalistic parent-child interactions (Gleitman & Trueswell, 2020), action interpretation provides preverbal infants with a powerful cognitive shortcut to uncover referential relations between symbols and objects.

Which aspects of action knowledge do infants recruit to make sense of new words? Woodward (2000) suggested that it is the understanding of relational structure of actions that provides infants with word-world mappings. From early on, infants appreciate that object-directed actions express meaningful relations between agents and the targeted objects (e.g., Woodward, 1998, 1999; Skerry et al., 2013; Liu et al., 2019). Hence, action analysis could serve as a filter for potential referents. Analyzing an action as object-directed could make

1 infants flag the target object as a likely referent, while discarding other objects present in the
2 environment from consideration. Our findings, however, speak against this proposal, since
3 pointing and grasping, despite both being object-directed and transitive, had different effects
4 on referent selection. Instead, we believe that it is the inferred purpose of the observed action
5 that prompted (or inhibited) the ascription of referential relations.

6 We propose that infants have access to (at least) two distinct classes of action
7 interpretation mechanisms, each serving a different function (cf. Csibra, 2003, see also
8 Gergely, & Jacob, 2012): one to interpret communicative actions (Csibra, 2010; Sperber &
9 Wilson, 2002) and the other to interpret instrumental actions (Gergely & Csibra, 2003). The
10 operation of each system is triggered by separate sets of cues (e.g., ostensive signals v.
11 agency cues) and leads to qualitatively different representations of the environment: objects
12 highlighted via communicative actions are taken as potential referents of communicated
13 information, whereas objects highlighted by instrumental actions are construed as part of the
14 goal to be realized. The ensuing representations support inferences about different domains of
15 human activity.

16 Communicative action interpretation does not necessarily require reasoning about the
17 mental states of the communicator. In infants, such an understanding can be triggered by
18 ostensive signals, such as eye contact, infant-directed speech, or contingent reactions (Csibra,
19 2010). Gradually, with learning and social experience, the set of behaviors that are
20 understood as communicative and, hence, referential, extends to cover a range of typical
21 communicative actions from the human repertoire (talking, pointing, gesturing, drawing,
22 etc.). Our findings indicate that infants interpret pointing as communicative by one year of
23 age even in the absence of preceding ostensive signals. However, other actions that do not
24 normally serve communicative functions, such as grasping, require ostensive signals to be
25 (re-)interpreted as referential.

Our findings also speak to the debates on the nature of early words (for a review, see Waxman & Gelman, 2009). By one year of age, infants expect words to be more than just sounds that correlate with objects. Rather, they treat words as symbolic referential devices whose function is to single out objects and concepts in communication. Words are part of a system that supports inferences about reference and meaning, such as mutual exclusivity (Markman, 1989). This idea is corroborated by our finding that infants in our experiments went beyond selecting the referents of the words introduced with communicative actions and linking the two together. They used these symbol-referent mappings productively to identify also the referents of completely novel, previously unheard, words. This likely happened by discarding the object onto which they had already mapped a label as a potential referent of the novel label. This finding is in line with recent work demonstrating that infants at this age are equipped with the necessary (lexical, pragmatic, and/or logical) inferential tools to perform mutual-exclusivity computations during referent search (Pomiechowska et al., under review). That infants made such inferences in our study was probably due to the fact that the communicative action made the local word-referent mapping explicit for them. In more traditional mutual-exclusivity studies, which report that disambiguating novel words using mutual-exclusivity inferences does not emerge before 16-17 months of age (e.g., Halberda, 2003), children are expected to spontaneously recover the lexical item linked to a familiar object.

Finally, note that we presented infants with new words and new object pairs on each trial, and their referent selection was tested shortly after. We employed this methodology for two reasons: first, stimulus variability was meant to maximize infants' interest in the procedure and the number of collected data points; second, the temporal proximity of training and test was meant to minimize the memory resources required for successful re-identification of the referents and maximize the chance of retention of the ensuing symbol-referent mapping. Infants were not required to encode the newly formed mappings in their

1 long-term memory, only to maintain them for a couple of seconds in working memory. We
2 thus acknowledge that the current design was tailored specifically to address our interest in
3 the links between action interpretation and referent selection, and our findings do not indicate
4 whether the newly formed word-object mappings were integrated into long-term semantic
5 knowledge systems. Whether such minimal exposure would be sufficient for word learning,
6 i.e., that the word-object mappings would be retained beyond the actual trial, remains a
7 question for future investigation.

8 In conclusion, by 12 months of age, infants successfully use action interpretation to
9 identify referents of novel linguistic expressions and establish links between these
10 expressions and objects in the world. Nonverbal object-directed actions that infants
11 understand as communicative — either because they have already acquired this interpretation
12 (such as pointing) or because the action takes place in an ostensive context (such as
13 communicative grasping) — but not those that are given an instrumental interpretation (such
14 as instrumental grasping) make them conceptualize the targeted objects as referents. This, in
15 turn, promotes the formation of mappings between these objects and novel words taken to co-
16 refer with nonverbal communicative acts. Therefore, infants' word learning might be assisted
17 by rudimentary socio-pragmatic inferences supplied by their action interpretation skills.

19 **Data and materials availability**

20 The data analyzed in the manuscript and the materials used in the study have been made
21 publicly available through the Open Science Network: <https://osf.io/f4q62/>

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Nonverbal action interpretation guides novel word disambiguation in 12-month-olds

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Supplementary Materials

SM1. Attention to the Screen

SM2. First Looks

SM3. Attention to the Locations Highlighted during Naming

SM4. Attention to the Objects during Pretest

SM1. Attention to the Screen

Table S1 shows the proportion of time infants spent looking at the screen, separated by different phases of the experiments. These proportions were calculated in three steps: (1) for each participant and each valid trial, the total number of on-screen data points was divided by the total duration of the respective experimental phase; (2) then the resulting values were averaged within-condition for each participant, and last, (3) these were averaged within-condition across participants. Note that in Experiment 3 *naming* occurred before action; the values in the table were computed for the highlighting period that followed naming and during which the hand remained still holding the object.

		Naming*	Pretest	Test question	Test response
Experiment 1	Trained-word	$M = 93\%$, $SD = 8\%$ $Mdn = 97\%$ range: 76% to 100%	$M = 93\%$, $SD = 11\%$ $Mdn = 96\%$ range: 56% to 100%	$M = 96\%$, $SD = 3\%$ $Mdn = 98\%$ range: 87% to 99%	$M = 85\%$, $SD = 12\%$ $Mdn = 90\%$ range: 59% to 96%
	Novel-word	$M = 92\%$, $SD = 7\%$ $Mdn = 93\%$ range: 72% to 100%	$M = 88\%$, $SD = 14\%$ $Mdn = 91\%$ range: 55% to 100%	$M = 95\%$, $SD = 8\%$ $Mdn = 97\%$ range: 68% to 100%	$M = 91\%$, $SD = 8\%$ $Mdn = 92\%$ range: 74% to 100%
Experiment 2	Trained-word	$M = 92\%$, $SD = 11\%$ $Mdn = 96\%$ range: 58% to 100%	$M = 90\%$, $SD = 12\%$ $Mdn = 96\%$ range: 60% to 100%	$M = 91\%$, $SD = 10\%$ $Mdn = 96\%$ range: 66% to 98%	$M = 87\%$, $SD = 11\%$ $Mdn = 89\%$ range: 58% to 98%
	Novel-word	$M = 89\%$, $SD = 15\%$ $Mdn = 96\%$ range: 51% to 100%	$M = 90\%$, $SD = 13\%$ $Mdn = 94\%$ range: 53% to 100%	$M = 92\%$, $SD = 12\%$ $Mdn = 96\%$ range: 55% to 99%	$M = 86\%$, $SD = 13\%$ $Mdn = 90\%$ range: 52% to 99%
Experiment 3	Trained-word	$M = 91\%$, $SD = 11\%$ $Mdn = 95\%$ range: 66% to 100%	$M = 90\%$, $SD = 10\%$ $Mdn = 94\%$ range: 71% to 100%	$M = 95\%$, $SD = 5\%$ $Mdn = 97\%$ range: 80% to 98%	$M = 82\%$, $SD = 13\%$ $Mdn = 82\%$ range: 63% to 100%
	Novel-word	$M = 90\%$, $SD = 11\%$ $Mdn = 91\%$ range: 62% to 100%	$M = 90\%$, $SD = 13\%$ $Mdn = 97\%$ range: 55% to 100%	$M = 95\%$, $SD = 5\%$ $Mdn = 97\%$ range: 80% to 98%	$M = 81\%$, $SD = 10\%$ $Mdn = 81\%$ range: 65% to 97%
Experiment 4	Trained-word	$M = 94\%$, $SD = 6\%$ $Mdn = 95\%$ range: 80 to 99%	$M = 92\%$, $SD = 8\%$ $Mdn = 94\%$ range: 74% to 100%	$M = 97\%$, $SD = 1\%$ $Mdn = 98\%$ range: 95% to 99%	$M = 88\%$, $SD = 8\%$ $Mdn = 89\%$ range: 71% to 89%
	Novel-word	$M = 95\%$, $SD = 3\%$ $Mdn = 96\%$ range: 90 to 100%	$M = 90\%$, $SD = 11\%$ $Mdn = 94\%$ range: 68% to 100%	$M = 92\%$, $SD = 8\%$ $Mdn = 95\%$ range: 72% to 99%	$M = 89\%$, $SD = 7\%$ $Mdn = 91\%$ range: 72% to 99%

Table S1. The amount of attention to the display during valid trials as a function of the phase of trials (naming, pretest, test question, and test response) and condition (trained v. novel-word).

SM2. First Looks

During the test question, infants' gaze was attracted to the center of the display by a dynamic attention getter, the disappearance of which coincided with the offset of the question (i.e., the offset of the label placed at the end of the phrase). To investigate whether the first saccades away from the attention getter towards one of the two objects stimuli reflected referent selection, we calculated the proportion of the saccades directed at the target object following the disappearance of the attention getter. In this calculation, we only used the trials in which during the period extending from the offset of the attention getter displayed during the test question and the first saccade (1) no data were missing (i.e., the gaps between registered data points were not larger than 2 missing samples); and (2) the data were spatially accurate (i.e., AOI hits were not scattered across more than one AOI). This resulted in the exclusion of additional trials relative to the main analysis (Experiment 1: $n = 1$ due to missing data, $n = 3$ due to dispersion; Experiment 2: $n = 7$ due to missing data; $n = 4$ due to dispersion; Experiment 3: $n = 11$ due to missing data; $n = 2$ due to dispersion; Experiment 4: $n = 14$ due to missing data; $n = 3$ due to dispersion). Overall, the first looks were available in 357 trials (Experiment 1: $n = 49$, $M = 3.06$, $SD = 0.93$ in the trained-word condition, $n = 48$, $M = 3.0$, $SD = 0.80$ in the novel-word condition; Experiment 2: $n = 43$, $M = 2.69$, $SD = 0.87$ in the trained-word condition, $n = 47$, $M = 2.94$, $SD = 1$ in the novel-word condition; Experiment 3: $n = 38$, $M = 2.38$, $SD = 1.02$ in the trained-word condition, $n = 39$, $M = 2.44$, $SD = 1.03$ in the novel-word condition; Experiment 4: $n = 46$, $M = 2.88$, $SD = 1.02$ in the trained-word condition, $n = 47$, $M = 2.94$, $SD = 0.93$ in the novel-word condition).

The patterns of eye movements triggered by the test question mirrored the results of the analysis based on looking duration (Figure S1A). In Experiments 1, 3, and 4, which involved communicative actions, the first looks were distributed differently in response to trained versus novel words (Experiment 1: $Z = -2.321$, $p = 0.020$; Experiment 3: $Z = -2.255$, $p = 0.024$;

Experiment 4: $Z = -2.417$, $p = 0.016$, by Wilcoxon signed-rank tests). Hearing the trained words led infants to saccade towards the target objects (one-sample Wilcoxon signed-rank tests were used to carry out comparisons to chance (.05); Experiment 1: $M = 0.69$, $SD = 0.26$, $Z = -2.266$, $p = 0.024$; Experiment 3: $M = 0.71$, $SD = 0.31$, $Z = -2.191$, $p = 0.029$; Experiment 4: $M = 0.57$; $SD = 0.32$, $Z = -0.734$, $p = 0.463$), while upon hearing the novel words they tended to saccade towards to the distractor objects (Experiment 1: $M = 0.43$, $SD = .28$, $p = 0.353$; Experiment 3: $M = 0.42$, $SD = 0.3$, $p = 0.436$; Experiment 4: $M = 0.23$; $SD = 0.29$, $Z = -2.615$, $p = 0.008$).

In contrast, in Experiment 2, the only task that involved an instrumental action, the first looks in the trained-word condition did not differ from those in the novel-word condition, $t(15) = 0.332$, $p = 0.745$, and remained around chance in both conditions (trained word: $M = 0.54$, $SD = 0.31$, $p = 0.644$; novel word: $M = 0.50$; $SD = 0.33$, $p = 1$).

SM3. Attention to the Locations Highlighted during Naming

During naming (5 s, or 300 samples) in Experiments 1, 2, and 4, a still hand highlighted the target object either via pointing at it or grasping it. We verified that infants attended to the two objects during this phase by counting the total of target and distractor AOI hits (Experiment 1: $M = 189$, $SD = 48$; Experiment 2: $M = 220$, $SD = 71$; Experiment 4: $M = 178$, $SD = 61$). Then, we assessed infants' attention to the target objects during this period by calculating difference scores between the two AOIs the same way as in the main analysis (Figure S1B). Overall, infants prioritized the objects highlighted by the actions in all three experiments (Experiment 1: $M = 0.24$, $SD = 0.42$; Experiment 2: $M = 0.42$, $SD = 0.37$; Experiment 4: $M = 0.43$, $SD = 0.36$) and their attendance to target AOIs was higher than expected by chance (Experiment 1: $t(15) = 2.869$, $p = 0.012$, $d = 0.72$, 95% CI = [0.06, 0.42]; Experiment 2: $t(15) = 5.3147$, $p < 0.001$, $d = 1.33$, 95% CI = [0.25, 0.59]; Experiment 4: $t(15) = 5.507$, $p < 0.001$, $d = 1.377$, 95% CI = [0.26, 0.59]. The patterns of infants looking behavior were comparable across experiments, as revealed by a one-way ANOVA with experiment (1 v. 2 v. 4) as a between-subject factor, $F(2, 45) = 1.803$, $p = 0.177$, $\eta_p^2 = 0.07$. This indicates that the differential word-mapping performance observed in response to pointing (Experiments 1 and 4) and grasping (Experiment 2) was not a result of unequal levels of attention to the locations highlighted by these actions.

We acknowledge that while the pointing hand never touched the object and remained outside of the target AOI, the grasping hand made contact with the object, getting inside the AOI. Therefore, in the case of grasping, we cannot disentangle how long infants looked at the object itself relative to the hand holding it. This, however, does not affect our conclusion that infants prioritized the location highlighted by grasping over the distractor object.

Unlike in Experiments 1, 2, and 4, described above, in Experiment 3, the naming and action were dissociated in time. First, infants heard the naming phrase and then saw one of the

1 objects being grasped. The hand remained still, maintaining contact with the object for 2
2 seconds. During this time, infants looked to the target location about twice as much as the
3 distractor ($M = 0.65$, $SD = 0.41$, $Z = -3.198$, $p < 0.001$).

SM4. Attention to the Objects during Pretest

To explore how the observed actions affected infants' attention to the objects after the hand disappeared from the display, we quantified their looking behavior during the pretest period (i.e., after the hand moved out from the display and before the dynamic attention getter appeared, marking the beginning of the test phase). As above, we modeled this analysis on our main analysis. We computed difference scores on AOI hits summed over the duration of the pretest (2 s) and entered them into a one-way ANOVA with Experiment (1 to 4) as a between-subject factor. This analysis yielded a significant main effect of experiment, $F(3, 60) = 3.073$, $p < 0.034$, $\eta_p^2 = 0.13$, with post-hoc comparisons revealing that infants' looking behavior at pretest was significantly different only between Experiments 3 and 4 ($p = 0.035$, other $ps > 0.09$, Tukey corrected). The difference scores were positive in Experiments 1, 2, and 3 (Experiment 1: $M = 0.14$, $SD = 0.49$; Experiment 2: $M = 0.18$, $SD = 0.42$; Experiment 3: $M = 0.23$, $SD = 0.58$) and negative in Experiment 4 ($M = -0.08$, $SD = 0.28$), which indicates a tendency to look towards the object previously targeted by the action. These results suggest that during the pretest periods, infants tend to focus on the objects previously targeted by the actions and provide further evidence that the differences in word-mapping performance following pointing and instrumental grasping were not due to lower attendance to objects and locations highlighted by grasping.

Figure S1. Results of complementary analyses. **A** Proportion of first looks to the object targeted by the action (1 indicates that all first looks were directed at the object targeted by the action; 0 indicates that all first looks were directed at the distractor object). **B** Difference scores during naming (Experiments 1, 2, 4) and during the period when the still hand highlighted the object following naming (Experiment 3). **C** Difference scores during pretest. **A, B, C** Blue diamonds indicate means, and blue bars indicate standard error of the mean. Black horizontal lines indicate medians. The bottom and the top of the boxes represent the first and the third quartiles. Whiskers extend from the middle quartiles to the smallest and largest values within 1.5 times the interquartile range. Dots represent the individual means across trials within each condition.