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Journal of Cognition and Development

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/hjcd20

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To cite this article: Haley Weaver & Jenny Saffran (27 Apr 2025): Object Functions and Words Reexamined: Toddlers' Recognition of Function Depends on Object Type, Journal of Cognition and Development, DOI: 10.1080/15248372.2025.2495783

To link to this article: https://doi.org/10.1080/15248372.2025.2495783

JOURNAL OF COGNITION AND DEVELOPMENT
https://doi.org/10.1080/15248372.2025.2495783

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ABSTRACT

The role of function in toddlers' object labeling has been debated for decades in developmental science. We aimed to clarify the relation between toddlers' understanding of functions and words using a set of everyday objects that varied in the number of associated functions (e.g., balls can be bounced, thrown, or rolled while toothbrushes primarily brush teeth). Forty 23- to 25-month-old monolingual English-learning toddlers in the U.S. completed a preferential looking paradigm in which objects were used in conventional and unconventional ways, designed to measure expectations about object functional expectations. We also measured toddlers' lexical knowledge about these objects using a looking-while-listening task. Finally, we assessed productive vocabulary size using the MacArthur-Bates Communicative Development Inventory: Words and Sentences. The results suggest that toddlers have expectations about the functions of some objects, but not others. In particular, these expectations were stronger for objects that are tightly linked with their functions in everyday experiences, and for children who have larger vocabularies. These findings also suggest that toddlers' ability to demonstrate functional knowledge may depend on the specific objects included in the task.

Introduction

Word learning is not an all-or-none process. Indeed, it is well-attested in the literature that infants' word knowledge develops incrementally. Word meanings may be initially broad extending to many referents (Weaver et al., 2024), and subsequently become more refined. With experience, infants become able to identify a word's referent in the presence of perceptually similar (Ellis Weismer et al., 2016; Wojcik & Saffran, 2013), categorically similar (Arias-Trejo & Plunkett, 2013; Bergelson & Aslin, 2017; Styles & Plunkett, 2009), and thematically similar (Arias-Trejo & Plunkett, 2013) distractor objects. These word recognition abilities, as measured in lab tasks, point to the emerging richness of infants' lexical representations across the first 2 years of life.

One important open question concerns the relationship between infants' developing lexical representations and their emerging understanding of objects' semantic features. That is, when infants can more accurately identify a label's referent, do they also have a richer semantic representation of that referent? Prior research examining perceptual features provide hints that infants' semantic representations are related to their lexical development.

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Supplemental data for this article can be accessed online at https://doi.org/10.1080/15248372.2025.2495783

For example, toddlers prioritize perceptual features such as shape when extending newly learned words to new exemplars (Landau et al., 1998). Perceptual features are also the strongest predictor of early-learned words in analyses of infants' lexicosemantic networks (Peters & Borovsky, 2019). Furthermore, as vocabularies grow or include more shape-based words, toddlers increasingly attend to shape as an important property when generalizing words to new exemplars (Perry & Samuelson, 2011; Samuelson & Smith, 1999). Together, these findings suggest that as language skills expand, toddlers increasingly represent shape as a critical semantic feature of referents.

The association between maturing lexical representations and other kinds of semantic features, such as an object's function, has received relatively less examination. Theories of word learning have often contrasted perceptual features (i.e., shape) with functional features, and conclude that infants and adult prefer to use perceptual features to extend word meanings to new exemplars (Graham et al., 1999; Landau et al., 1998). While infants do, indeed, demonstrate an early bias to attend to object shape, it is possible that later lexical development is also facilitated by other forms of semantic knowledge. For example, words with later age of acquisition are often organized by functional or categorical relations (Peters & Borovsky, 2019). Older infants (e.g., 18- to 24-month-olds) and infants with extensive experience with an object's function can extend labels to new referents that share a common function (Gathercole & Whitfield, 2001; Kemler Nelson, Frankenfield, et al., 2000; Kemler Nelson, Russell, et al., 2000; Madole et al., 1993; Zuniga-Montanez et al., 2021). Together, these findings indicate that infants who represent function as an important semantic feature may have more advanced language and/or word comprehension.

Why might function play a critical role in lexical development? Function is a critical component of many objects, including some whose names are learned early in language development (e.g., spoon; Keil, 1996). Notably, function has been operationalized in different ways by developmental scientists, including the use of an object (Booth & Waxman, 2002), the creator's intent for an object's use (Casler & Kelemen, 2005), and the conventional action afforded by an objects' features (Kemler Nelson, Russel et al., 2000; see Oakes & Madole, 2008, for a comprehensive review). Researchers have argued that infants use function to categorize objects (Booth & Waxman, 2002), to accomplish specific goals in the world (Casler & Kelemen, 2005, 2007), and to learn words (Kemler Nelson, Russell, et al., 2000). This lack of consensus in what counts as a function across studies has resulted in mixed evidence concerning which aspects of function infants attend to, as well as the age at which infants demonstrate knowledge of object function.

Function is an object property that encompasses many interacting factors, potentially explaining the myriad conflicting definitions put forth in infant research. For example, our representation of how to use a toothbrush includes knowledge that it has a bristled head, that it was designed as a tool to clean teeth, and that people typically use it to scrub teeth or other small areas (i.e., clothing stains). Infants' functional knowledge, however, is often probed by manipulating a single aspect of function that is directly related to the researcher's definition. For instance, study results may depend on whether researchers create novel objects with functions that reflect an object's physical features (Kemler Nelson, Russell, et al., 2000), an objects' use (Landau et al., 1998), an object's designed use (Jaswal, 2006), or previous experience with objects (Zuniga-Montanez et al., 2021).

Real-world objects, unlike those often designed for experiments, integrate many aspects of function, and are inextricably linked with language experiences. Indeed,

several lines of research have asked how young children learn about the objects they encounter and the nouns that refer to them. One proposal is that infants learn through rich, multimodal experiences with language and objects. This experience with objects often involves interacting with objects directly or observing others engage with objects in systematic ways (Custode & Tamis LeMonda, 2020; Goldenberg et al., 2022; Hunnius & Bekkering, 2010; Suanda et al., 2017; Suarez-Rivera et al., 2022; Tamis-Lemonda et al., 2017, 2018). Children are particularly attuned to these social aspects, learning functions that are consistent, intentional, and performed by reliable individuals (Diesendruck et al., 2010; Hernik & Csibra, 2015; Oláh & Király, 2019; Wohlgelernter et al., 2010; Zmyj et al., 2010). For example, toddlers expected the conventional function of an object to be an action that a person previously performed intentionally and consistently across demonstrations rather than an action that occurred accidentally or varied (Wohlgelernter et al., 2010). These findings underscore the critical role that social interactions play in infants' understanding of conventional functions.

Social interactions involving objects with conventional functions tend to be embedded in daily routines (e.g., grooming) and bound to particular locations (e.g., bathroom). It is precisely during these routine interactions with objects that caregivers are more likely to provide labels (Clerkin & Smith, 2022; Custode & Tamis LeMonda, 2020; Goldenberg et al., 2022; Roy et al., 2015; Tamis-Lemonda et al., 2018; West & Iverson, 2017). For example, when hearing the word "toothbrush" a toddler might be brushing their teeth in the bathroom with their caregiver. During such interactions, the toddler has opportunities to learn about the functional properties of toothbrushes as well as the object's label. Toddlers' everyday activities, therefore, are rife with information about objects' functions and their labels. This rich experiential backdrop suggests that infants likely have ample opportunity to link word knowledge with function knowledge, at least for certain objects.

Despite the importance of object function in the ecology of young children's lives, relatively little research has focused on early knowledge concerning the functions of familiar objects. One study examined infants' predictions about the likely end location for an object's function (Hunnius & Bekkering, 2010). By 6 months of age, infants were able to anticipate the location that was consistent with objects' functions (e.g., looks to the mouth when they see someone moving a cup), suggesting that even very young infants have some association between familiar objects and their functions. Another set of studies investigated whether object-specific actions influenced toddlers' noun comprehension (Hagihara & Sakagami, 2020; Hagihara et al., 2022). Eighteen- to twenty-three-month-olds were better at recognizing a noun when they saw its referent performing its conventional function compared to when the object performed a different action (Hagihara & Sakagami, 2020) or when a different object performed the target object's function (Hagihara et al., 2022).

While these studies provide some evidence that toddlers have expectations about familiar objects' functions, and that early word meanings include functional knowledge, several limitations impact the conclusions that can be drawn. Hunnius and Bekkering (2010) only assessed infants' looks to a specific end location; thus, it is unclear whether infants associated the objects with specific functions or locations. Furthermore, they did not assess whether infants' noun comprehension was related to predictive looks to the location consistent with the object's function. While Hagihara et al. (2022) did measure noun comprehension and function in tandem, they measured both constructs using a single

task; thus, it is unclear what expectations toddlers have about object function in the absence of guiding language.

In the present study, we investigated two questions: (1) do toddlers have expectations about the conventional functions of familiar objects? and (2) is their word knowledge related to their knowledge of objects' functions? Given the mixed evidence from prior research about whether toddlers prioritize function in their word meanings, we examined these questions in a sample of 23- to 25-month-olds. We expected toddlers in this age group to vary in their understanding of objects' functions, allowing us to examine whether individual differences in functional knowledge are related to differences in word knowledge. There were two experimental tasks. In the first task, we measured comprehension of the nouns that refer to four familiar objects (apple, ball, crayon, toothbrush) using a looking-while-listening (LWL) task. We intentionally selected these objects for the current experiment because their labels are learned early, and they vary in the number of ways they can be used. Each target label was tested many times in order to better estimate toddlers' understanding of each word. In the second task, we tested toddlers' understanding of the functions of the same objects seen in the LWL task by presenting pairs of videos that demonstrated conventional and unconventional functions (i.e., brushing teeth with a toothbrush vs. eating a toothbrush). The videos were presented with background music, but without any guiding language. We predicted that toddlers would be surprised by (i.e., look longer at) the unconventional functions suggesting that they have prior expectations about objects' conventional functions. Furthermore, we predicted that the strength of toddlers' functional expectations would be related to their word knowledge as measured by LWL and/or parent report (MacArthur-Bates Communicative Development Inventory, MB-CDI; Fenson et al., 1994).

Method

Participants

The final sample included forty 23- to 25-month-old (M = 23.94; 26 females) typically-developing, English-learning toddlers. Seven participants were also exposed to other languages in the home (i.e., American Sign Language, Dutch, German, Hebrew, Hmong, and Spanish) less than 3 h per week according to caregiver report. The sample size was determined using post-hoc and sensitivity power analyses in G*Power prior to data collection. The target sample size has 100% power to detect effects as small as those reported in prior investigations of functional knowledge (Hunnius & Bekkering, 2010) and 80% power to detect item-level effects in functional knowledge as small as $f = 0.07$. Eleven additional participants were excluded for insufficient data contribution (<50% of trials in an eye-gaze task; N = 4), computer error (N = 5), or inattention (looking off-screen >50% of the time; N = 2). Toddlers were recruited from the surrounding area of a midwestern city in the U.S. and via targeted social media advertisements (Bacon et al., 2021). All recruitment methods were approved by the local institutional review board. The sample identified as predominantly White (N = 36) and not Hispanic (N = 37). Most of the participants' caregivers were wealthy (modal income range = $100,000 to $150,000) and highly educated (39 primary caregivers and 34 secondary caregivers had bachelor's degrees or higher).

Stimuli

We selected a set of four early-learned nouns/referents (apple, ball, crayon, toothbrush) to use in the two eye-gaze tasks. These objects are highly familiar, have at least one conventional function, and have frequent labels (CHILDES; MacWhinney, 2000) that are produced by most toddlers in the target age range (MB-CDI; Frank et al., 2017), see Table 1. These four words also vary in superordinate category and the number of actions prototypically associated with the object. For example, a ball is a toy and can be thrown, bounced, kicked, or caught. By contrast, a toothbrush is a tool and has a single primary function. These differences allowed us to probe whether toddlers' functional knowledge differs depending on the functional specificity of the object.

Images: LWL task

We selected object images to serve as target referents for the four nouns used in the LWL task. Three different images for each of the four nouns were chosen from a database of standardized stimuli (BOSS; Brodeur et al., 2014) that varied in color, shape, and/or orientation (Figure 1). The objects were isolated and placed on a gray 360 × 360-pixel background.

Videos: function task

During the Function task, toddlers viewed yoked pairs of videos in which an actor picked up an object, demonstrated a function, and placed the object back on the table (Figure 2). The actor demonstrated either a conventional or unconventional function for the object. For instance, the conventional function of a toothbrush was brushing one's teeth and the unconventional function was eating a toothbrush. These pairs of conventional and unconventional functions were matched on the location of the action on the body (e.g., brushing one's teeth and eating both occur at the mouth). Additionally, the unconventional function for each object matched the conventional function of another object (Table 2). For example, the unconventional function for the toothbrush (i.e., eating) was the conventional function for the apple.

The videos were recorded in 1080p HD using an iPhone 11 camera at a rate of 30 frames per second (fps) and edited using iMovie to an average length of 6300 ms and exported at a resolution of 540p. For each video, the onset of the function occurred at 2300 ms and ended at 4500 ms (Figure 2). The videos for each object were identical other than the 2200 ms when the critical function was demonstrated.

Table 1. Production and frequency for target objects used in both tasks. Production percentages for 23-month-olds for the target nouns as reported on the MD-CDI (Frank et al., 2017) and frequency counts (per million words) for 23- to 25-month-olds in CHILDES (MacWhinney, 2000.).

Object	WordBank production	CHILDES Frequency
apple	88%	1,979.55
toothbrush	70%	625.02
ball	98%	3,322.38
crayon	53%	951.58

Figure 1. Image stimuli for the looking-while-listening task. Images were selected from the BOSS database (Brodeur et al., 2014).

Audio

For the LWL task, a native speaker of American English recorded 12 sentences using infant-directed speech. Each sentence included one of three carrier phrases followed by a target noun: "Look at the [target label]," "Find the [target label]," "Where's the [target label]." The audio stimuli were recorded in a sound attenuated booth using Praat (Version 6.1.41; Boersma & Weenink, 2021) and normalized to an average intensity of 65 dB. Each sentence was edited to 4500 ms with the onset of the target noun occurring at 1774 ms.

For the Function task, clips of 6300 ms of instrumental music were edited to an average intensity of 55 dB. Each clip had 50% dB gain from 0 ms to 1000 ms and 50% dB reduction from 5300 ms to 6300 ms.

Procedure

The study was administered using the videoconferencing platform Zoom (Version 5.4.7.; Zoom Video Communications Inc., 2021). Families joined a password-protected Zoom conference and completed a home set-up procedure to improve video quality. Caregivers muted computer notifications, maximized their screen's brightness, turned on overheard lighting, and adjusted the computer's volume to a comfortable level. They then deployed the HTML experiment in a browser on their

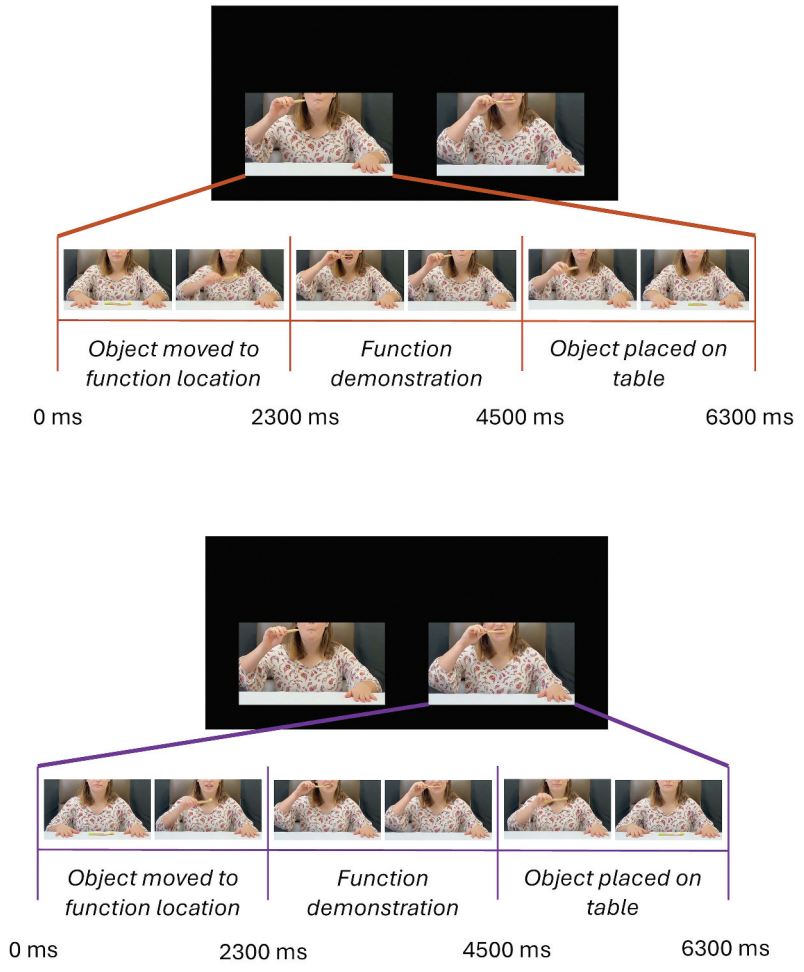

Figure 2. Example trial for the Function Task. Panel A demonstrates the time course of a typical function (brushing) video for a toothbrush. Panel B demonstrates the time course of an atypical function (eating) video for a toothbrush. Infants viewed each video once alone before viewing them simultaneously.

Table 2. Conventional and unconventional functions for the target objects in the function task. The conventional function for one object is the unconventional function for another object to match action and location on the body where the function occurs.

Object	Conventional Function	Unconventional Function
apple	eating	brushing one's teeth
toothbrush	brushing one's teeth	eating
ball	bouncing	drawing
crayon	drawing	bouncing

local machine. Caregivers used the share screen function to allow the researcher to see the family and experimental window simultaneously. They configured their Zoom settings so that video and the meeting control panels were both minimized.

We instructed caregivers to close their eyes during the experiment and refrain from talking or pointing to their child to minimize bias. Toddlers were positioned so that the researcher could see their eyes (e.g., seated on a caregiver's lap, standing, seated in a highchair). The Zoom session was recorded for manual eye-gaze coding using peyecoder (Olson et al., 2020).

The experiment included two tasks: a LWL task and a Function task. The tasks were presented in a fixed order with the LWL task always preceding the Function task. This design choice was preregistered to increase the likelihood of toddlers successfully completing both tasks. We reasoned that the videos in the Function task would be more engaging for toddlers than the static images in the LWL task. While presenting the task in a fixed order may have resulted in carryover effects, we tried to combat fatigue by presenting the more engaging task when toddlers were likely to start losing interest.

After obtaining informed consent, toddlers completed the LWL task (Fernald et al., 2008), assessing their word recognition of the four target objects (apple, ball, crayon, toothbrush). During each trial, two images appeared on the screen 540 pixels apart and toddlers heard a sentence labeling one of the objects (e.g., *Find the toothbrush!*). Toddlers were presented with 6 test trials for each word for a total of 24 trials. Each object appeared on the screen 12 times, half as the target item and half as the distractor item. Targets occurred equally often on the left and right sides of the screen. Trials were presented in a pseudorandom order in blocks of six separated by an attention-getter. The same target item did not occur on more than two consecutive trials.

Immediately following the LWL task, toddlers completed a preferential-looking paradigm that measured their preferences for conventional versus unconventional functions. We used conventionality as our primary measure of toddlers' preference because prior literature demonstrates an early (i.e., 14-months) sensitivity to this aspect of functions (Wohlgelernter et al., 2010; Zmyj et al., 2010). Each trial presented two videos simultaneously, one on each side of the screen 400 pixels apart. The conventional and unconventional function videos depicting the same object were yoked together (e.g., brushing one's teeth with a toothbrush was always paired with eating a toothbrush; Table 1). We presented each video pair four times for a total of 16 test trials. Conventional and unconventional functions were presented equally often on the left and right side of the screen. Video pairs were presented once per block in a random order and pseudorandomized across blocks such that the same object did not appear sequentially. Blocks were interspersed with attention-getter videos to maintain interest in the task.

In addition to the two experimental tasks, caregivers completed the MB-CDI: Words and Sentences form to assess their child's productive vocabulary.

Coding

Trained research assistants coded eye movements using peyecoder (Olson et al., 2020) at a frame rate of 25 fps (average frame rate for Zoom recordings). Coders indicated whether toddlers were looking left, right, or off (i.e., shifting between images or looking off-screen). Videos were coded in silence to reduce coding bias. When coding the Function task videos, the locations of the conventional vs. unconventional function videos were occluded. Twenty percent of the final sample was independently recoded to determine inter-coder reliability. We assessed three measures of reliability: (1) the proportion of frames in which coders agreed on gaze location (frame agreement) (2) the proportion of gaze shifts (within

one frame) in which coders agreed (shift agreement), and (3) the proportion of trials that coders agree on the number of shift events coded (comparable trials). On average, we achieved 94.85% frame agreement, 91.04% shift agreement, and 82.44% comparable trials. These reliability metrics are comparable to prior studies coding eye gaze in online paradigms (Weaver et al., 2024).

Eye gaze data preprocessing

Zoom recordings have a variable frame rate due to trial-by-trial fluctuations in internet speed. To account for this variability, we calculated an average by-trial frame rate for each child and adjusted the timing data frame-by-frame. We then binned the adjusted data into 40 ms increments to have comparable time data across all participants (e.g., an event occurring 43 ms was adjusted to 40 ms; Bacon et al., 2021). Trials with insufficient looking data (<50% of the critical window; see below) were excluded from the analyses. On average, infants contributed 22 out of 24 possible LWL trials ($SD = 2.57$) and 14 out of 16 possible Function task trials ($SD = 2.94$).

Results

Analytic approach

We conducted a series of linear mixed-effects models (LMEMs) to investigate whether (1) toddlers had expectations about objects' conventional functions and (2) whether these expectations were related to toddlers' word knowledge. All models were conducted in R (Version 4.2.2) using the lme4 package (Version 1.1.31). The deidentified data and analysis scripts are available on the *Open Science Framework (https://osf.io/nuecw/?view_only=30c9a71b04734f27907cecdc443b9a4d)* .

We predetermined a set of dependent variables from toddlers' continuous looking behavior on the two experimental tasks. For the Function task, we defined toddlers' preference for the unconventional functions (i.e., novelty preference) as the proportion of fixations to the unconventional functions compared to the total number of fixations to either function ($\frac{unconventional\,function}{unconventional\,function+conventional\,function}$) during a critical window (2300–4500 ms). The critical window reflects the time during the videos when the object function was demonstrated (Figure 1). Word knowledge on the LWL task was defined as toddlers' word recognition accuracy: proportion of fixations to the target image out of the total number of fixations to either the target or distracter image ($\frac{target}{target+distracter}$) during a critical window (300–1800 ms after the onset of the noun). This window is typically used to assess familiar word recognition in this age range (Fernald et al., 2006; Swingley & Aslin, 2000) and reflects the time to plan and execute an eye movement. The measure of overall vocabulary was the total number of words produced on the MB-CDI.

Preregistered analyses

Our primary question was whether toddlers would recognize the conventional functions of familiar objects and whether they would have stronger expectations about some objects' functions compared to others. We intentionally included objects from different categories (i.e., foods, toys, and tools) which could influence toddlers' expectations about the

unconventional uses of those objects. To test these questions, we fit a LMEM testing toddlers' preference for unconventional functions against a chance level of 50%: $preference \sim 1 + object + (1 + object|subject_{id})$. We included a predictor for object to examine whether preferences for unconventional functions varied depending on the specific object. The dependent variable was centered around chance (50%) and the independent variable was dummy coded for planned pairwise comparison. Thus, the intercept in the model tested average preference for each object and the fixed effect for object compared preferences between the objects. For example, the fixed effect tests whether preferences for the unconventional function for apple are similar to preferences for the unconventional function for toothbrush. All *p*-values were corrected for multiple comparisons using Holm-Bonferroni corrections (Holm, 1979).

As seen in Figure 3, toddlers preferred the unconventional functions significantly above chance for crayon $(M = 60.86\%, b = 0.11, F(1, 38.33) = 7.02, \mathrm{p} = 0.01)$ and toothbrush $(M = 70.88\%, b = 0.209, F(1, 37.87) = 30.76, \mathrm{p} < 0.05)$, but not for apple $(M = 47.68\%, b = -0.02, F(1, 38.07) = 0.40, \mathrm{p} = 0.53)$ or ball $(M = 42.42\%, b = -0.08, F(1, 37.04) = 4.09, \mathrm{p} = 0.05)$. Compared to preferences for the unconventional function for

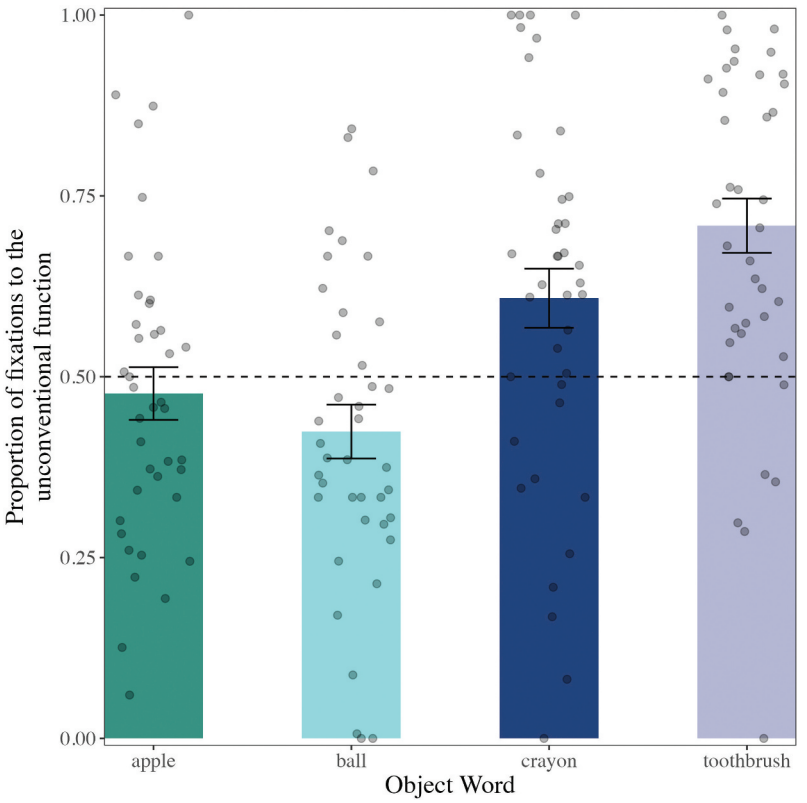

Figure 3. Preference for the unconventional functions by object. For each trial, preferences for the unconventional function are measured as the average proportion of fixations to the unconventional function during a critical window of analysis from 2300ms-4500ms. Error bars represent +/- 1 SE of the mean.

apple, toddlers had a greater preference for the unconventional functions for crayon ($b = 0.13, F(1, 38.47) = 6.25, \mathrm{p} = 0.05$) and toothbrush ($b = 0.23, F(1, 38.46) = 16.93$, $\mathrm{p} < 0.05$). Similarly, toddlers preferred the unconventional functions for crayon and toothbrush significantly more than the unconventional function for ball ($b = 0.18$, $F(1, 38.50) = 9.59, \mathrm{p} = 0.01 \text{and} b = 0.28, F(1, 37.79) = 31.97, \mathrm{p} < 0.05$ for the comparisons for ball vs crayon and ball vs toothbrush, respectively). No other comparisons reached statistical significance after correcting for multiple comparisons. Overall, toddlers had stronger preferences for the unconventional functions of crayon and toothbrush than for the unconventional functions of apple and ball. These results were robust to analytic decisions such as the specific outcome measure for surprisal (see Supplementary Materials S3 for a measure of total fixation time). We return to this difference in preference for these two sets of objects in the exploratory analyses.

Our second question was whether toddlers' preferences on the function task were related to their word comprehension as measured by the LWL task at both the individual and group levels. To test this question, we regressed preference for the unconventional function on word recognition accuracy including a by-subject random intercept and slope for word recognition accuracy and a by-item random intercept and slope for word recognition accuracy ($preference \sim 1 + wordrecognitionaccuracy) + (1 + wordrecognitionaccuracy|subject_{id})$ $+(1 + wordrecognitionaccuracy|item)$. Toddlers' word recognition accuracy did not predict their preferences for the unconventional functions ($b = -0.11, F(1, 2.73) = 0.50, p = 0.54$). An analogous LMEM using reaction time on the LWL task as the predictor variable found similar results (see Supplementary Materials S4).

Given the limited predictive power of word recognition accuracy, we wanted to verify that our participants were familiar with the nouns included in the experiment. We also wanted to identify whether some of the nouns were overall more difficult to comprehend compared to the other nouns. To address these two questions, we fit a LMEM to examine whether word recognition accuracy was significantly above chance (50%) and whether accuracy differed depending on the noun: $wordrecogntionaccuracy \sim 1 + word + (1 + word|subject_{id})$. We centered word recognition accuracy around 50% and dummy coded the word variable for planned pairwise comparisons. The intercept in the model, therefore, tests whether toddlers' word recognition accuracy is significantly above chance and the fixed effect for word compares word recognition accuracy between each of the nouns. Toddlers' word recognition accuracy was significantly above chance for all nouns (Figure 4; apple: $M = 64.76\%, b = 0.15, F(1, 37.50) = 59.14, p < 0.05$; ball: $M = 70.72\%, b = 0.21$, $F(1, 38.79) = 73.75, p < 0.05$; crayon: $M = 61.28\%, b = 0.11, F(1, 38.62) = 22.14$, $p < 0.05$; toothbrush: $M = 67.77, b = 0.18, F(1, 37.85) = 89.31, p < 0.05$). Pairwise comparisons revealed that toddlers were significantly more accurate in recognizing the word ball compared to the word crayon ($b = -0.09, F(1, 38.57) = 10.23, p = 0.02$). No other comparisons were statistically significant after correcting for multiple comparisons. Thus, as a group, the toddlers recognized all the target nouns, but were slightly more accurate in recognizing the word ball than the word crayon.

Exploratory analyses

The preregistered analyses suggest that toddlers were sensitive to the conventional functions for some, but not all the objects. Toddlers' functional preferences, however, were not

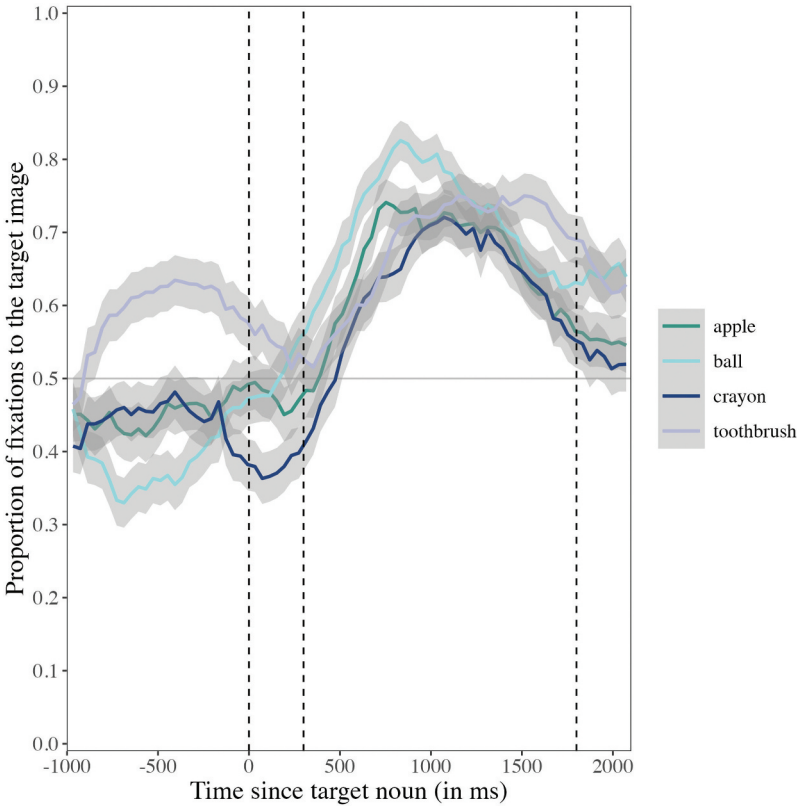

Figure 4. Word recognition accuracy by object. Time course plot of toddlers' word recognition for each object. Participants' fixations to the target image for each object were averaged across each 40ms bin of time between -1000ms and 2000ms. Thus, each data point represents average proportion of looks to the target image across participants and trials for a given time bin. Error bands represent +/- 1 SE of the mean.

associated with their level of accuracy in recognizing the labels for those objects. There are several factors that may have contributed to our predicted results differing from our hypotheses: (1) preferences may have changed with repeated exposure across the function task, (2) some actions may have been more interesting than others, (3) some objects may be more or less associated with a single primary function than other objects, and (4) toddlers' word recognition accuracy may be less variable than their productive vocabularies. In the subsequent sections, we examined each of these factors with a series of exploratory analyses.

It is possible that toddlers' preferences for the unconventional functions changed over the duration of the experiment leading to item-level differences in preferences on the function task. To demonstrate a preference for unconventional functions, toddlers must find them novel or surprising. We designed our task to include functions that should be very surprising to toddlers, but we also showed each video pair three times over the course of the function task. Toddlers' novelty preference may have decreased during the experimental task as they became accustomed to seeing the actor perform unconventional functions. Therefore, we examined whether preferences in the first block of the function

task were significantly different from preferences in blocks two and three of the task using the following model: $preference \sim 1 + blocknumber + (1 + blocknumber|subject_{id}) + (1 + blocknumber|item)$. The fixed effect for block number was contrast coded with block one as the reference group. The fixed effect for block number, thus, tests whether preferences for the unconventional functions in block one were significantly greater than preferences in block two or block three. Toddlers' preferences for the unconventional functions in block one were not significantly different from their preferences for the unconventional functions in block two ($b = -0.053, F(1, 3.157) = 0.615, p = 0.487$) or block three ($b = -0.066, F(1, 3.344) = 0.654, p = 0.472$). Thus, it seems unlikely that the observed pattern of preferences was due to toddlers becoming familiar with the unconventional functions of objects over the course of the study.

Next, we investigated whether some actions were more interesting than others, resulting in preferences for particular functions. We intentionally yoked actions (i.e., eating with brushing and bouncing with drawing) to control for potential saliency effects. This design also allowed us to directly examine whether toddlers preferred certain actions significantly more than expected by chance, regardless of whether the function was conventional or unconventional for a given object. For example, if toddlers find eating more interesting than brushing, we should observe a preference for the conventional function when the object was an apple and a preference for the unconventional function when the object was a toothbrush. If surprisal is driving our patterns of observed preferences, however, we would expect toddlers' preferences for particular actions to depend on the object the actor is using. That is, we would expect toddlers to look more at eating actions when the actor is eating toothbrush than when they are eating an apple.

To test toddlers' preferences for different actions, we calculated the proportion of fixations to each action for each trial during the critical window for the Function task (2300–4500 ms). We then regressed this proportion on action, object, and their interaction. We fit two separate, but analogous, LMEMs to test each yoked action pair. The model testing preferences for eating and brushing revealed a significant effect of action ($b = 0.224, F(1, 38.87) = 15.293, p < 0.05$) and a significant interaction between action and object ($b = -0.360, F(1, 38.44) = 22.967, p < 0.05$). These results suggest that, on average, toddlers preferred the action eating; however, they preferred the action eating significantly more when they observed the actor eating a toothbrush than when they observed the actor eating an apple (Figure 5(a)). For the model testing preferences for bouncing and drawing, we found a significant effect of action ($b = 191, F(1, 38.87) = 10.7153, p = 0.002$), but we did not find a significant interaction ($b = -0.064, F(1, 38.72) = 0.476, p = 0.494$). These findings suggest that toddlers preferred the action bouncing, and that, although they looked slightly more at an actor bouncing a crayon ($M = 0.612$) than an actor bouncing a ball ($M = 0.578$), this difference was not significant (Figure 5(b)). Therefore, we have evidence to suggest that toddlers' preference for the unconventional toothbrush action (i.e., eating) cannot be explained by an overall preference for the eating action. However, we cannot rule out an overall preference for bouncing as an explanation for toddlers' preference for the unconventional crayon action (i.e., bouncing).

An alternative possibility is that some objects are more tightly associated with the functions that we tested than others. On this view, objects that have a more prototypical function may be more likely to elicit surprise from toddlers when the connection between

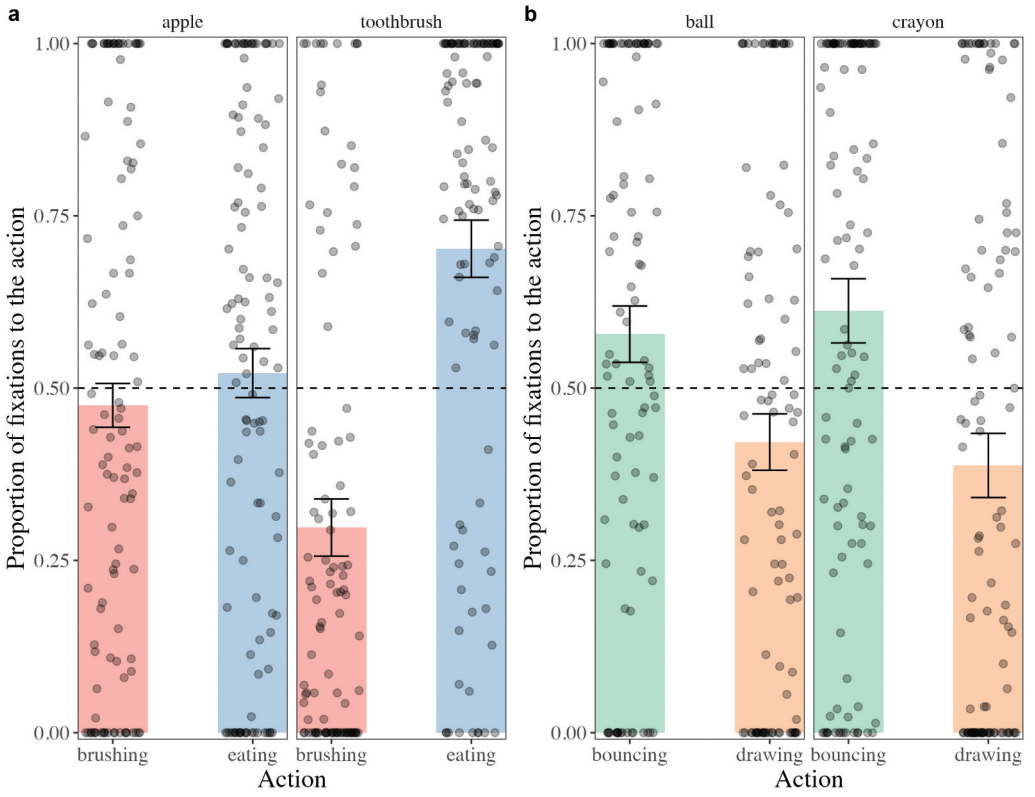

Figure 5. Preference for the action by object. **A)** Average proportion of fixations to brushing and eating actions when the object depicted is apple or toothbrush. Each data point reflects average proportion of fixations for a given trial during a critical window of analysis from 2300ms to 4500ms. Error bars represent +/- 1 SE of the mean. **B)** Proportion of fixations to bouncing and drawing actions when the object depicted is ball or crayon. For each trial of the PLP task, fixations to the target action were averaged during a window of analysis from 2300ms to 4500ms. Error bars represent +/- 1 SE of the mean.

the object and the function is violated. For other objects, however, the link between the tested function and the object may be less predictive (because the object is associated with multiple functions). To address this explanation for the observed pattern of function preferences, we investigated the extent to which the conventional functions we tested are associated with our selected objects in children's naturalistic experience. We did not have any data concerning our participants' experiences with the selected objects and functions. As a proxy, we examined naturalistic data from language input to toddlers in the CHILDES database. The question of interest was how often each of the four object nouns from our study co-occurred with different action verbs. We reasoned that word co-occurrences in linguistic input could approximate toddlers' lived experiences with each of our objects and therefore shed light on the functional expectations that toddlers demonstrated in the present experiment (Lewis et al., 2019). If a noun tended to co-occur with many verbs (e.g., balls being kicked, thrown, or caught), toddlers may have more flexible expectations about how that object can be used. By contrast, nouns that co-occur with very few verbs in toddlers' input (e.g., hearing input about brushing teeth with a toothbrush), may be more

strongly associated with the conventional function used in the present experiment. Violations of these conventional functions may be more noticeable to toddlers.

To test these hypotheses, we searched publicly available transcripts of North American English-learning 4- to 25-month-olds interacting with their caregivers in their home environment (Brent, Davis, Peters, & Providence corpora in CHILDES; Brent & Siskind, 2001; Davis & MacNeilage, 1995; Demuth et al., 2006; A. M. Peters, 1987). The details of the search can be found in the supplementary materials (S1). We examined co-occurrences between each of the selected object nouns and action verbs. Specifically, we calculated the number of unique verbs (i.e., types) and the number of total verbs (i.e., tokens) that co-occurred with each of the four nouns. We then compared these co-occurrence counts to the strength of toddlers' functional expectations in our experiment. Fewer verb types and tokens co-occurred with the nouns *crayon* and *toothbrush* than the nouns *apple* and *ball* (see Table S1 in the Supplementary Materials). Thus, some object nouns occurred in more constrained linguistic contexts (i.e., *toothbrush* and *crayon*) than other object nouns (i.e., *apple* and *ball*) in this sample of naturalistic language input. These linguistic contexts likely reflect functional usages in real-world contexts and may explain why toddlers were more likely to prefer the unconventional usage of toothbrush and crayon than the unconventional usage of apple and ball in our preferential looking task.

Lastly, we examined whether differences in toddlers' overall productive vocabulary, rather than LWL accuracy, explained variance in their preferences for the unconventional functions. Toddlers were very familiar with the nouns tested on the LWL task. It is possible that there was not enough variability in performance on the word comprehension task to capture meaningful individual differences in toddlers' functional knowledge. However, productive vocabulary as measured by the MB-CDI is more variable (Fenson et al., 1994, 2007), 24-month-olds in the 10^{th} percentile produce as few as 64 words, while infants in the 90^{th} percentile produce up to 530 words. To examine whether functional preferences were related to productive vocabulary, we fit a linear model predicting toddlers' overall preference for the unconventional functions from their productive vocabulary size as measured by the MB-CDI: *preference* ~ *CDIrawscore*. Toddlers' productive vocabularies ranged from 6 to 631 in the current sample and produced and average of 279 words. As seen in Figure 6, toddlers with larger productive vocabularies preferred the unconventional functions significantly more than toddlers with smaller productive vocabularies $\left(b = 0.2118, F(1, 36) = 5.769, p = 0.022, n_p^2 = 0.138\right)$. Productive vocabulary explained 13.8% of the variance in preferences for the unconventional functions.

Discussion

In the current study, we examined (a) English-learning toddlers' expectations about objects' conventional functions, and (b) whether these expectations were related to their word knowledge. During the Function task, toddlers saw objects used in ways that were consistent and inconsistent with each object's conventional function. Toddlers also completed a LWL task including the labels of the objects seen in the Function task. Toddlers preferred the unconventional functions for crayons and toothbrushes, but not for apples and balls. We interpret toddlers' preferences as evidence that they were surprised by, and therefore preferred to look at, toothbrushes and crayons being used in ways that violated their

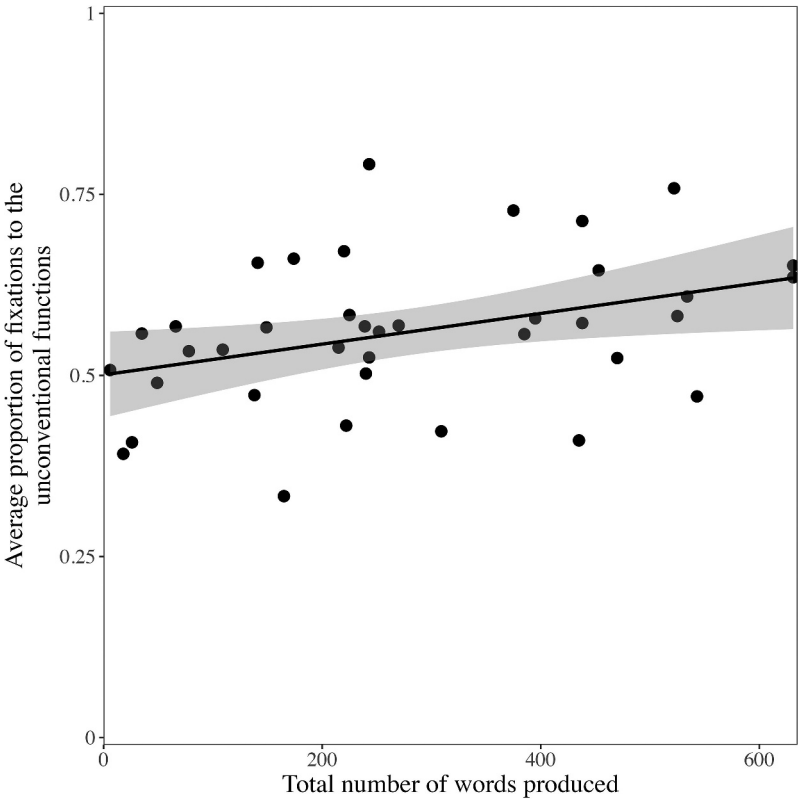

Figure 6. Preference for the unconventional functions by MB-CDI score. For each toddler, proportion of fixations to the unconventional functions were averaged across all objects during the critical window (2300–4500 ms). Preferences are plotted as a function of MB-CDI productive vocabulary. Error bars represent +/- 1 SE of the point estimate.

expectations. Moreover, these preferences were not related to toddlers' comprehension of the object labels but were related to productive vocabulary size. We discuss these findings in the context of prior research on the role of object function in labeling and propose a possible explanation: toddlers' stronger expectations about the functions of crayons and toothbrushes may be supported by their previous experiences with these objects.

Toddlers demonstrated expectations for the functions of some, but not all, of the objects tested in this experiment. This finding is interesting given that prior studies have found no evidence of function knowledge or robust evidence of function knowledge (Casler & Kelemen, 2005, 2007; Kemler Nelson, Russell, et al., 2000; Landau et al., 1998; Madole et al., 1993; Oakes & Madole, 2008; Trouillet et al., 2024). The present study demonstrates a more nuanced result; toddlers' expectations depended on the specific objects and function being tested. In particular, toddlers expected an actor to use a toothbrush to brush her teeth and to use a crayon to draw. However, they did not strongly expect an actor to eat an apple or bounce a ball. The conventional functions included in the present study could fit a variety of definitions put forth in the literature including the use of an object, the use afforded by an object's features, and how an object is used based on prior experience. By investigating

functions that varied in definition, we were able to directly probe how these stimuli choices influenced toddlers' expectations about function. Critically, our results suggest that methodological variations in *how* function is defined and tested in a given experiment may be one explanation for the mixed findings regarding toddlers' functional knowledge.

Toddlers' expectations about certain objects (i.e., toothbrushes and crayons) may best be described by one definition of function: an object's use is based on prior experience (Oakes & Madole, 2008). Toddlers may experience some items being used in more constrained contexts and, therefore, more strongly associate those objects with their conventional functions. In support of this interpretation, the corpus findings suggest that the nouns *crayon* and *toothbrush* co-occured with fewer action verbs than the nouns *apple* and *ball*. For example, the noun *toothbrush* co-occurred with the action verb *brush* and with a few directive verbs (i.e., *put*, *get*). The noun *ball*, by contrast, co-occurred with the action verbs *bounce, throw*, and *play* in addition to several directive verbs. Toddlers may be more flexible in the kinds of functions or actions they attribute to apples and balls, which participate in a wider range of actions than toothbrushes or crayons. The object-level differences in preferences for the conventional functions observed in our experiment, therefore, may reflect toddlers' experiences with, or associations between, the objects and the functions we selected. In the present study, however, we did not directly measure participants' associations between the target objects and their functions.

While the exploratory corpus analysis may support an experience-based interpretation for the differences in functional expectations for different objects, the data also suggest that toddlers' functional expectations may be supported by their action preferences. That is, toddlers demonstrated overall preferences for some of the actions (i.e., eating and bouncing). In a follow-up study, we could disentangle action preferences from toddlers' functional expectations by varying the kinds of unconventional functions that toddlers see paired with each object. For example, future stimuli could include using a crayon to hammer a nail or to brush hair in addition to being bounced. The stimuli could also include unconventional functions that vary in how often the target action co-occurs with the object in natural child-direct speech corpora. This future work could help to elucidate whether experience with objects and their functions underlies children's understanding of object functions.

In addition to understanding toddlers' recognition of function, we were primarily interested in clarifying the relationship between object function and word knowledge. Our results demonstrated that toddlers' overall productive vocabulary, but not their object noun comprehension, was related to their functional expectations. Toddlers with larger productive vocabularies were more surprised by objects being used in unconventional manners. These results are consistent with the possibility that a larger productive vocabulary allows children to request objects which in turn increases caregiver discussions about objects and interactions with objects (Custode & Tamis LeMonda, 2020; Suarez-Rivera et al., 2022; Tamis-Lemonda et al., 2018). Toddlers with higher MB-CDI scores may have the sophisticated vocabulary necessary to seek information about different objects and their uses. By having a larger productive vocabulary, toddlers may actively shape the input they receive from caregivers regarding different objects and therefore, develop stronger expectations about objects' functions than their peers with smaller vocabularies. The present data, however, cannot rule out the alternative possibility that productive vocabulary is accounting for a third unmeasured variable, such as cognitive ability.

While functional knowledge was related to vocabulary size, we found no evidence that toddlers' noun comprehension was predictive of their expectations about objects' functions. That is, toddlers who were more accurate recognizing an object label were not surprised when that object was used for an unconventional function. These results suggest that knowing an objects' label may be separable from understanding how an object is used. Although we did not predict this pattern of results, they are consistent with classic studies examining the role of functional knowledge in labeling. For example, Landau et al. (1998) demonstrated that toddlers do not extend words to objects similar in function. Rather, attention to function as a cue to word meanings increases with development (Kemler Nelson, Frankenfield, et al., 2000; Landau et al., 1998) or with extensive experience with including labeling during functional demonstrations (Zuniga-Montanez et al., 2021).

It is possible that toddlers' noun comprehension would be related to their functional expectations if we used a different set of stimuli. Toddlers can extend labels to functionally related objects when they learn names for novel artifacts that have physical features that are causally related to the function (Kemler Nelson, Russel et al., 2000; Kemler Nelson, Frankenfield et al., 2000). In the current study, we did not control whether the unconventional functions of the familiar objects could be afforded by their physical features. Toddlers may be more surprised by seeing unconventional functions that are not plausible given the appearance of the objects. It would be interesting for future studies to examine whether using different unconventional functions or whether using all man-made artifacts would result in a stronger noun–function relation.

Limitations

While our results demonstrate that the specific objects tested influence toddlers' understanding of function, it is important to note that we only tested four objects in this study. When selecting items, we considered several competing alternatives. We could have tested many different objects allowing our findings to encompass a variety of different functions and provide stronger external validity. Alternatively, we could have included only a small number of items and include many test trials for each affording analyses at the item level. Ultimately, we decided to examine individual items at the expense of broad generalization. Thus, our findings are well suited to elucidate the role that specific objects play in toddlers' functional expectations. However, our findings regarding the links between words and functions more broadly are likely limited to the current set of object labels and functions.

Conclusions

Twenty-three- to twenty-five-month-olds in the U.S. showed evidence of having expectations for objects' conventional functions, but the strength of these expectations depended on the object tested. They had stronger functional expectations for objects that were highly associated with their function (e.g., toothbrush) in child-direct speech. Toddlers who had larger productive vocabularies also demonstrated stronger expectations for objects'

functions. While our results are constrained by the limited number of functions included in the present study, they demonstrate that the object stimuli used to investigate function influences toddlers' ability to demonstrate their functional knowledge.

Acknowledgments

We would like to express our gratitude for the participating families and members of the Infant Learning Lab. In particular, we thank Louisa Forest for her help in preparing the stimuli, Dasha Yermol and Emily Kassens for their assistance with data collection, and the many research assistants who manually coded eye-gaze. We are also immensely grateful to Maryellen MacDonald, Martha Alibali, and Karen Schloss for their intellectual discussions at the initial stages of this project which strengthened its theoretical and methodological rigor.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was funded by grants from the NICHD awarded to JS [R37HD037466] and the Waisman Center [U54 hD090256].

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Data availability statement

The materials, data, and analytic code that support our research findings are publicly available on the *Open Science Framework (https://osf.io/nuecw/?view_only=30c9a71b04734f27907cecdc443b9a4d)*. Data from the experimental tasks have been deidentified according to privacy regulations. The corpora data can be derived from CHILDES (https://childes.talkbank.org/access/).

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