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ARTICLE

Object Shape and Depth of Word Representations in Preschoolers

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Abstract

This study examined the effect of a shape cue (i.e., co-speech gesture) on word depth. We taught 23 preschoolers (*M* = 3;5 years, *SD* = 5.82) novel objects with either shape (SHP) or indicator (IND) gestures. SHP gestures mimicked object form, but IND gestures were not semantically related to the object (e.g., an upward-facing palm, extended toward the object). Each object had a unique IND or SHP gesture. Outcome measures reflected richer semantic and phonological learning in the SHP than in the IND condition. In the SHP condition, preschoolers (a) expressed more semantic knowledge, (b) said more sounds in names, and (c) generalized more names to untaught objects. There were also fewer disruptions to prime picture names in the SHP condition; we discuss the benefit of a co-speech shape gesture to capitalize on well-established statistical word learning patterns.

Keywords: shape bias; semantics; phonology; word learning; gesture

Introduction

One mechanism that infants as young as 1;4 years use to learn new words is the shape bias (Landau, Smith & Jones, 1988; Perry, Meltzer & Kucker, 2021; Smith, Jones, Landau, Gershkoff-Stowe & Samuelson, 2002). The shape bias is the tendency to use shared shape as a criterion to generalize the name of an object to a novel exemplar of its category (Landau et al., 1988; Smith et al., 2002). The shape bias is acquired from the earliest word learning context. Infants are repeatedly hearing caregivers name objects that share shape with the same word label. The alignment of rigid objects, shared shape and hearing names comes to be expected because it occurs with statistical regularity (Smith et al., 2002); it is an expectation that develops implicitly in most children. Once the shape bias emerges, 1;4 to 2;0-year old toddlers use the shape bias to extend a word label such as "car" to all car-shaped objects, regardless of size or color, but do this with many categories of objects by 2;0 years. Generalizing names with the shape bias makes word learning efficient, quickly, because each member of an object category does not need to be taught explicitly.

Soon after word generalization is established, the 2;0 year old shows a rapid increase in word learning often referred to as a vocabulary spurt (e.g., Gershkoff-Stowe & Smith, 2004; Samuelson, 2002; Smith et al., 2002). The vocabulary spurt expands breadth of vocabulary. Breadth of vocabulary is the number of words in the lexicon but does not indicate how well a word is mapped into memory. Mapping occurs first when a word label is associated with a semantic referent (fast mapping; Carey, 1978). Knowing a word well (i.e., word depth) also contributes to vocabulary growth particularly in how a word is used (Beck & McKeown, 1991). Depth of word knowledge accrues over time (i.e., slow mapping; Carey, 1978). More exposure to a word enriches its semantic representation, but also its phonological and lexical representations (i.e., sounds and the word label, respectively) and the connections between them. The shape bias reflects the role shape plays in the earliest stage of word learning – namely, aligning categories of objects by name (Borgström, Torkildsen, Sahlén & Lindgren, 2019). Little is known about the influence shape has on deepening the word representation after that. For example, some shape features are linked to less obvious object features such as object function. Attention to object shape might help discern object function more readily. We return to this below. The current study manipulated an explicit cue to object shape to learn more about the relationship between object, the feature of shape, and the word label in a word learning context. We then examined the effect of a shape cue on depth of lexical-semantic representation using various outcome measures. First, we review how depth of word representation is defined. Second, we review how previous studies manipulated attention to object shape using an explicit cue.

Defining deep word representations: meaning, sounds, and connections with other words

Children as young as 1;4 to 2;6 years are deepening word representations alongside the expansion of vocabulary breadth (Borovsky, 2022; Peters & Borovsky, 2019; Schmitt, 2014). The number of perceptual features predicts when a word will be acquired with words richer in perceptual features being acquired earlier by toddlers (Peters & Borovsky, 2019). Deeper semantic representations have more sensory-motor nodes (i.e., details) connected to individual words than shallower representations (Beck & McKeown, 2007; Peters & Borovsky, 2019; Storkel, 2009). Semantic details of an object include its shape and physical parts, the object function, and its taxonomy (e.g., tines, handle, eat, category; Wojcik, 2018; Wojcik & Saffran, 2013). Each node can share a connection with each other and its word label. Connections between related words also contribute to semantic depth (e.g., eat-fork-spoon).

Connections between the semantic representation (e.g., tines, handle, eat) and its word form (fork) can stabilize encoding and retrieving the word form, specifically the coherence of sounds in the phonological representation (e.g., f-or-k; p. 13464; Levelt, 2001; Patterson, Graham & Hodges, 1994). Semantic binding theory contends that meaning creates a durable phonological trace in memory (Patterson et al., 1994). When the referent and word label co-occur, the referent's semantic details can bind to the sound traces through bidirectional connections. The semantic details, the bidirectional connections, and the phonological representations are then stored and retrieved together as a unique pattern of neural activation (Jefferies, Frankish & Lambon Ralph, 2006). What is relevant to the current study is that phonological integrity within the words learned may be bound to deeper semantic representations because deeper semantic representations have more

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connections and durable connections to retain the phonological sequence in memory (e.g., Capone Singleton & Anderson, 2020).

Connections are essential when it comes to integrating new words into memory and retrieving a word from memory (e.g., Gershkoff-Stowe, Connell & Smith, 2006; McClelland & Rogers, 2003; Wojcik, 2018). Competitors for word retrieval may share similar semantic features such as the shape (e.g., *moon* and *ball*, *blanket* and *towel*) or phonological structure (e.g., *escalator* and *elevator, decorations and instructions*). Deeper word representations are distinguishable with less overlap between them (Peters & Borovsky, 2019). Word retrieval is more likely to occur when many nodes with their connections are traveling to the intended word. This depth spreads activation in the network. Networks can be local (i.e., just surrounding a word; Wojcik & Saffran, 2013) or distant to encompass many categories throughout the lexicon (Borovsky, 2022). A word receives excitatory activation from connections between semantic representation and the word form. Word retrieval is likewise dependent on the inhibition of competing words (Gershkoff-Stowe et al., 2006; Wojcik, 2018). The simultaneous excitatory (to the target) and suppressive (to inhibit competing words) connections rely on the nonoverlapping semantic representations (e.g., Gershkoff-Stowe et al., 2006). When a new word is integrated into the lexicon excitatory and inhibitory connections grow as part of the semantic representation.

Word retrieval errors

Word retrieval errors are more likely to occur when word representations are shallow or connections between them are missing. Competing activation from a similar word may override a weak or nonexistent word representation (e.g., Gershkoff-Stowe, 2001; Gershkoff-Stowe & Smith, 1997). Word retrieval errors result such as saying "ball" while looking at the *moon*. Word retrieval errors provide a window onto how the lexical-semantic network is organized (e.g., McGregor, 1997). Indeed, analysis of naming errors is a traditional approach to studying word representations (e.g., Gershkoff-Stowe & Smith, 1997; Gershkoff-Stowe et al., 2006; McGregor, 1997; McGregor, Friedman, Reilly & Newman, 2002a; McGregor, Newman, Reilly & Capone, 2002b).

Semantic errors are the most common error type for toddlers and preschoolers (Gershkoff-Stowe & Smith, 1997; McGregor, 1997). They are indicative of weak or absent connections to the word form, or the meaning itself is underspecified as in our "ball" for *moon* example. One type of semantic error that indicates deeper semantic knowledge than other types of errors is the circumlocution error (e.g., saying "stirring" for *spoon*). Circumlocution errors tell the listener explicitly what the child knows about a word whereas other errors like "ball" for *moon* or an indeterminate error reflect minimal knowledge by the child (e.g., "I don't know what that is."; McGregor, 1997). The toddler who says "ball" while looking at the *moon* reveals sparse knowledge of *moon.* She relies on shared circular shape to name *moon* by retrieving "ball". Even as *moon* is learned unstable connections among words briefly disrupt retrieval of both the new word and the known word (Gershkoff-Stowe, 2001; Gershkoff-Stowe & Smith, 1997). Gershkoff-Stowe and Smith (1997) found a curvilinear function characterized the time course of word retrieval errors for KNOWN words while toddlers experienced their vocabulary spurt. Specifically, as 1;6-year olds learned their first 50 to 150 new words quickly, they also had an increase in word retrieval errors of words they already knew. Many of the word retrieval errors were

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semantically or perceptually like the intended target word as in our *moon* and *ball* example.

Gershkoff-Stowe et al. (2006) developed an off-line priming task to elicit word retrieval errors in 2;0 and 4;0-year olds. The task presented an experimental object (e.g., a circle with a pie-shape cut-out), preceded by a picture that was either high (i.e., fish with open mouth) or low (i.e., ball) in visual similarity. Children were led to assume the pictures seen in sequence were from the same category. Highly similar prime pictures impacted the names children gave the experimental objects more than the pictures with low visual similarity. As children deepen their knowledge of *ball* and *moon,* word representations further differentiate from each other with nodes of knowledge and connections to inhibit each other. Eventually, *ball* is inhibited to say "moon" despite shared round shape (Gershkoff-Stowe, 2001). Accurate naming depends on how well practiced the connections are between semantic representations, a word form, and the contexts that promote some competitors over the target word (p. 473; Gershkoff-Stowe et al., 2006).

Given shape's influence on establishing object categories and on naming errors, we were interested in the relationship between shape and word depth as children learned more about words over time. We first turn to prior studies that manipulated attention to object shape in word learning contexts, over time.

Gesture as an explicit cue to object shape

Deepening word representations takes time. It is unavoidable that exposure to an object provides its own semantic enrichment. In prior studies we controlled frequency of exposure but manipulated shape enrichment with an explicit co-speech gesture cue (e.g., Capone & McGregor, 2005; Capone Singleton, 2012; Capone Singleton & Anderson, 2020). A gesture is co-speech when the word and gesture occur simultaneously (e.g., two index fingers in a cross-position to mimic roto-blades + "helicopter"). A cue facilitates intentional engagement to activate semantic information in memory and/or facilitates a retrieval process (Lindsey, Bunker, Mozeiko & Coelho, 2020).

All our studies were repeated measures designs so that children served as their own controls by participating in each experimental condition. In one study, 2;6 year olds learned six teaching objects between three conditions. In the Shape (SHP) condition, a co-speech shape gesture mimicked the overall form or a salient feature of the object. In another condition, function gestures mimicked the object's action (Function condition). A No gesture condition provided the experimental word model only to serve as control. After one exposure the 2;6-year olds identified referents reliably if its word was taught with a co-speech shape gesture; words taught with a function gesture or without a gesture resulted in guessing. After three teaching visits, toddlers spontaneously named more objects in the SHP condition than the No gesture condition. In the No gesture condition 2;6-year olds could only recognize objects but could not name them. The Function condition fell between the other conditions. If the experimenter provided a function gesture, it cued the 2;6-year olds to name more often than cues in the No gesture condition. There was an added benefit to co-speech shape gestures in Capone and McGregor. In addition to learning taught nouns, when 2;6-year olds saw co-speech shape gestures they also created more verbs to describe the functions than in the No Gesture condition to describe how they used the objects in a verb generation task. In summary, co-speech shape gestures led to richer semantic knowledge and naming in 2;6 years old (see also Capone, 2007). In another study, co-speech shape gestures have been compared to an attention-getting gesture (Vogt & Kauschke, 2017). In Vogt and Kauschke, 4;0-year olds learned more rare animal names when taught with co-speech shape gestures than an attention-getting gesture.

In a follow-up study to Capone and McGregor (2005), we taught 2;8-year olds three experimental names with co-speech pointing, or a co-speech function gesture, or with a co-speech shape gesture (Capone Singleton, 2012). Pointing replaced the No gesture condition from Capone and McGregor (2005) to control for presence of a gesture. Pointing did not highlight a semantic feature. In addition, we tested generalization of taught names to two untaught generalization objects. Participants had exposure to the untaught generalization objects on teaching days, but the objects were never named. After 3 teaching sessions, 2;8-year olds were tested with taught objects, and the two untaught generalization objects. Children again named more taught objects in the SHP condition, but they also generalized more taught names to untaught generalization objects in the SHP condition than in the Function and Pointing conditions. These data highlighted retention of categorical information in the SHP condition. Testing generalization without the taught object in view was a departure from how the shape bias literature tested generalization because here children must rely on representations in memory. In experiments that test for a shape bias, an infant hears a novel object named, "this is a *dax.*". She sees other objects, with the *dax* in view, then chooses the same-shaped object as another *dax* if the shape bias has developed (e.g., Landau et al., 1988). The infant rejects an object that shares only color or texture.

In Capone Singleton (2012) the untaught generalization objects also varied in shape similarity to the taught objects. While both untaught generalization objects shared function with the taught object, one of the objects did not share exact perceptual features. The objects varied in perceptual similarity much like a cup category might vary with a sipper cup (lid, spout, handles), a coffee cup (a handle), and a commercial to-go cup (lid). The purpose of the shape-dissimilar objects was two-fold; the shape-dissimilar objects mimicked object variability we described above in the child's environment (i.e., improving external validity). From an experimental perspective, the shape-dissimilar object was also a rigorous test of semantic depth. Specifically, with no external cues to object category a child must first glean the function of the untaught generalization object; she would then need to link it to the semantic representation which must contain a shape to function relationship in memory. These 2;8-year olds generalized more names to the shape-dissimilar exemplars in the Shape condition over the other Function and Pointing conditions. In sum, the co-speech shape gesture appeared to aid retention of how the object functioned which supported our prior findings (Capone, 2007; Capone & McGregor, 2005).

A group of children who do not acquire a shape bias and maintain the smallest vocabulary for age is late talking toddlers (Jones, 2003; Jones & Smith, 2005; Perry & Kucker, 2019). Late talkers also do not generalize names and fail to show a vocabulary spurt (Colunga & Sims, 2017; Perry & Kucker, 2019). Late talking toddlers can persist into the preschool years with language impairment or with autism spectrum disorder; each of these groups of children persists with a lack of shape bias (Collison, Grela, Spaulding, Rueckl & Magnuson, 2015; Tek, Jeffery, Fein & Naigles, 2008). In a word learning study, Capone Singleton and Anderson (2020) provided co-speech shape gestures to four late talking toddlers ranging in age from 1;9 to 2;6 years. Late talkers learned more objects and generalized more taught words to a variety of untaught objects when compared to the control condition. In addition, late talkers said more phonemes in the word labels when naming objects in the Shape than Control condition. The latter result is noteworthy because small phonological repertoires are also characteristic of late talkers (Kehoe, Chaplin, Mudry & Friend, 2015). It would be therapeutically efficient if a semantic enrichment cue (i.e., the co-speech shape gesture) could improve both phonological and semantic learning. Theoretically, it would align with the semantic binding hypothesis and its relationship between phonological and semantic mapping.

In summary, highlighting object shape with co-speech shape gestures has led children as young as 2;6 years, and children under 2;6 years who are poor word learners, to retain details of object function and phonology without direct instruction, and to retrieve words so that the child can name taught words and generalize names to untaught objects. Co-speech shape gestures have outperformed co-speech function gestures (Capone & McGregor, 2005; Capone Singleton, 2012), pointing (Capone Singleton, 2012), attention-getting gestures (Vogt & Kauschke, 2017), or teaching words without gestures (Capone & McGregor, 2005).

The current study

The current study tested the effect of a shape cue (i.e., a co-speech shape gesture) on depth of lexical-semantic representation using various outcome measures. As in prior studies, we taught experimental objects and words to control exposure. We improved the experimental control of this study over past studies in several ways. We compared co-speech shape gestures (SHP condition) to novel co-speech indicator gestures (IND condition). Pointing in our prior study was familiar to children so we assigned a unique co-speech indicator gesture to each object just as each object had a unique SHP gesture. An IND gesture was not semantically related to the object. We made our generalization test more rigorous by only making the untaught objects available at the test. The taught object remained out of sight. Under these testing conditions, children needed to rely on retention of deep semantic representations to generalize names. Would children generalize more names to untaught exemplars in the SHP than the IND condition, particularly the shape-dissimilar exemplars that relied on function knowledge? Given the semantic binding theory, we also analyzed the number of phonemes said in naming responses. Would children say more phonemes when naming objects in the SHP condition than the IND condition? We anticipated more phonemes would be retained in the co-speech SHP condition given our prior study results and semantic binding theory (Capone Singleton & Anderson, 2020).

One way to examine the effect of shape on word depth was to examine how semantic representations changed over time. Error analysis on our naming test put a window onto word representations. To elicit many naming errors, we inserted an off-line primed naming paradigm (e.g., Gershkoff-Stowe et al., 2006). We compared circumlocution errors on taught words, between conditions. Would semantic knowledge be evident in circumlocution errors with more circumlocution errors in the SHP condition than the IND condition on each day?

We created the Naming test as a priming task to mislead children to believe the prime pictures (familiar objects) and taught pictures (novel to the children) were the same category. We used 1) prime pictures that were high in visual similarity to the taught pictures and 2) ordered the paired pictures in direct sequence. In this analysis we measured consistency of naming the PRIME words while children gained exposure to the taught words. Known words are subject to word retrieval errors when learning new words (Gershkoff-Stowe & Smith, 1997), and Gershkoff-Stowe et al. (2006) concluded that the

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word retrieval process for familiar and new words is the same. If taught words were misinterpreted as part of the prime word categories based on shape-similarity, the reverse could also be true because bidirectional links were forming in our local networks. The priming task could lead to a brief disruption in naming prime words. We expected FEWER of these in the SHP condition than the IND condition if an explicit cue to shape deepens the lexical-semantic representation. Would children demonstrate fewer disruptions in naming prime words as more inhibitory connections were potentially established in the SHP condition than in the IND condition?

Method

Participants

Participants were 23 preschoolers (13 girls, 10 boys) ranging in age from 2;8 to 4;5 years (mean age = 3;5 years, *SD* = 5.82; median = 3;5 years). We recruited from preschool settings, community advertisements, and word-of-mouth. Children were of African American (4%), White (79%), and mixed racial-ethnicity backgrounds (17%) that included African American-White, Hispanic-White, Asian-Indian-White, and Native American-White. Participants were included if (a) their vocabulary score fell above the 10^{th} percentile on the Expressive Vocabulary Test (EVT; Williams, 1997), and (b) they were monolingual English speakers. Participants' performance on the EVT ranged from the 34^{th} percentile to the 87^{th} percentile with a mean percentile of 63.54 (*SD* = 14.21), and median percentile at the 64^{th} percentile. Exclusion criteria was an EVT at or below the 10^{th} percentile and/or current enrollment in speech-language intervention. One child was excluded from participation because she was enrolled in speech-language therapy at the time of recruitment.

Experimental design and conditions

We used a within-subject, repeated measures, group design. Each child participated in both conditions and served as his or her own experimental control. Children learned words under two conditions that differed only in teaching gesture – a co-speech shape gesture (SHP condition) or a co-speech indicator gesture (IND condition). Gestures occurred simultaneously with the word model and were consistent with our prior studies (Capone & McGregor, 2005; Capone Singleton, 2012; Capone Singleton & Anderson, 2020).

Counterbalancing controls in the experiment

We counterbalanced between children for:

a) the order of presentation for condition, teaching objects, generalization objects, gestures
b) the indicator gestures across all the objects
c) the objects between both conditions

For example, in the Generalization test, presentation order of the shape-similar or the shape-dissimilar objects was counterbalanced between children so that half the participants named the shape-similar objects first, while the remaining children named the shape-dissimilar objects first. Each Teaching object occurred in the IND condition the same number of times as the SHP condition to counteract any potential item effects (e.g., a particular object might be more interesting or uninteresting). This method ensured the prime pictures were counterbalanced between conditions as well when teaching objects were tested in the Naming test.

Stimuli

Teaching stimuli were (a) teaching objects, (b) experimental words, and (c) gestures (IND, SHP). Testing stimuli were (d) digital pictures (teaching and prime picture), and (e) untaught generalization objects for each taught object. Table 1 shows a stimulus set for one object category. Table 2 shows select examples of the primed Naming Test.

Teaching objects

Four teaching objects were developed and validated in prior studies (Capone & McGregor, 2005; Capone Singleton, 2012). The object categories were distinct in shape and function from each other. Teaching objects were an apple corer, honey dipper, liquid jigger, and dumpling maker. Playdoh was used with all of the teaching objects to control for thematic referent between objects.

Teaching words

Four teaching words were selected from Storkel's (2013) nonce word database: /hig/, /pʌʤ/, /næf/, /wƐʧ/. In orthographic symbols these translate to *h-ee-g*, *p-uh-j*, *n-a-f* and *w-eh-ch.* Teaching words were controlled at mid-level phonotactic probability and neighborhood density (i.e., $0 \pm .35$; Storkel, 2013). Developmentally, the four teaching words were balanced for the early-8 developing phonemes and the mid-8 developing phonemes developed by Shriberg (1993). Each word had unique phonemes with no sound overlap between words. Teaching words remained paired with an individual object throughout the study.

Gesture cues

Each teaching object had a unique shape gesture to highlight its overall form or a salient feature (Table 1). Shape gestures were validated by adult raters and used in prior studies (Capone & McGregor, 2005). Each object had a unique gesture when assigned to the IND condition. Indicator gestures were (1) an upward-facing palm, extended toward the object or (2) a finger tap to the side of the object, within a 1 – 1½ inch spatial distance of the object.

Digital pictures

The Naming test consisted of eight digital color photographs presented on Apple iPAD (Model MC979LL-OS version 6.0.1). The photographs were the four teaching objects and four prime pictures. Each prime picture was a shape match to its teaching object (Table 2). A hammer preceded the jigger, a purse preceded the dumpling maker, a round hairbrush preceded the honey dipper, and a boat's steering wheel preceded the apple corer.

We had followed Gershkoff-Stowe et al. (2006)'s process for choosing digital pictures to serve as shape primes. Lab staff first compiled a list of overextension errors made when

Table 1. Stimuli set for /pʌʤ/ that includes the teaching object, the generalization objects, and the three possible gesture cues

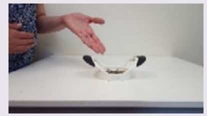
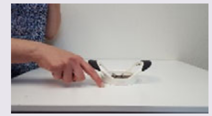
	/pʌʤ/	Gesture cue Shape	Gesture cue Extended hand	Gesture cue Table tap
Teaching Object				
Similar-object				
Dissimilar-object				

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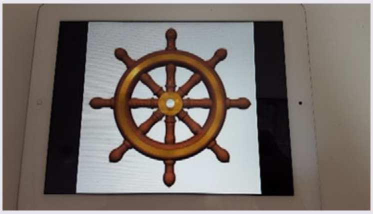
Table 2. Examples of iPAD presentations of shape-prime picture and teaching object picture in sequence.

Word label	Shape-Prime Picture	Teaching Object Picture
/pʌʤ/		
/hig/		

participants named objects in prior studies (Capone & McGregor, 2005; Capone Singleton, 2012). Second, we collected possible shape-prime pictures from the Google Images search engine (see Rogalski, Peelle & Reilly, 2001 for similar use of Google Images in a naming study). Five members of the Developmental Language and Cognition Lab at Seton Hall University then judged each image and reached a consensus on whether a particular image was a good shape match to the teaching object.

Generalization objects

Each teaching object was paired with two untaught generalization objects – a shape-similar object and a shape-dissimilar object (Table 1). Generalization objects were untaught objects, that were not seen until the generalization test. The three objects shared function but were differentiated by perceptual similarity. The shape-similar objects shared the same parts with the teaching object, but the shape-dissimilar object did not. For example, the apple corer /pʌʤ/was taught with a wide plastic version with two handles. Generalization was tested with a wide metal version and two handles (shape-similar) and a shape-dissimilar object that had one tall grip (see Table 1). Categorical membership of each generalization object (shape-similar, shape-dissimilar) was validated by adult raters in a prior study (Capone Singleton, 2012).

Naming test

The final picture sequence for the Naming test was the prime picture then the teaching object until the four pairs were presented. To keep the presentations random between

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days, we saved several possible random presentations of the four pairs on the iPAD. Saving the randomized pairs into files allowed the experimenter to arbitrarily choose a file at the start of each session. With this method, children saw a random order of test pictures each day.

Procedures

The Internal Review Board at Seton Hall University approved the study procedures. Children participated across three visits at their daycare setting, home, or in the lab after parents consented. There was a mode of 5 days between visit 1 and visit 3 ($M = 5.72$ days, $SD = 2.78$). The timing between visit 2 and visit 3 had a mode of 2 days ($M = 2.14$ days, $SD = .65$).

There were three types of study procedures: Naming test, Word Teaching, Generalization test. The sequence of study procedures within a visit (column) and across days (row) is illustrated in Table 3. Each visit began with a brief warm-up period for the experimenter and child. The warm-up period consisted of blowing bubbles and talk about the child's activity that day. The transition to the Naming test occurred when the experimenter removed the bubbles. At each visit the Naming test was administered first. Word teaching (visits one and two), or the Generalization test (visit three) followed an intervening task (the EVT or Verb generation task). The intervening task was identical between conditions and children. Children always received encouragement but there was no contingent responding by the experimenter on any task in this study.

Naming test

The experimenter introduced the Naming test by saying "I have some pictures here. I hope you can help me figure out what to call these things. Can you help me?". The iPad presentation started with a pictured circle which was followed by the sequence of prime pictures and teaching object pictures. The experimenter sat next to the child and transitioned from picture to picture with a finger swipe. At each picture, the experimenter prompted "this is a (pause)…" or "It's a (pause)…". Children named the prime pictures, and the teaching object pictures, alternating between the two. The child saw each picture until she named it, or for a maximum of 10 seconds before the experimenter swiped to the next picture. When all four prime and teaching pictures were presented, a pictured square indicated the Naming test was complete. Only at the last visit, the experimenter returned to the taught objects that the child did not name and gave a prompt to name with a gesture cue (i.e.,"It's an i*ndicator gesture*" or "It's a *shape gesture*"). The gesture cue matched the learning condition. Children were only exposed to the Naming test pictures at the test (prime pictures, teaching object pictures). Children never heard the experimenter name the prime pictures.

Word teaching

The transition to Word teaching occurred when the experimenter announced Playdoh was next. In addition to controlling for thematic referent, Playdoh marked the transition to Word Teaching. Each object was presented individually. The experimenter (1) showed the object then (2) demonstrated the function of the object. The experimenter would place the object in front of the child and say "Here, your turn. You try it.". The child then (3) enacted the function of the object for up to 20 to 30 seconds. Allowing the child to interact with the object ensured she or he was familiar with both the shape and function of

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Table 3. Administration sequence of study procedures within and across visits.

Visit 1	Visit 2	Visit 3
Naming test ↓	Naming test ↓	Naming test ↓ administered uncued naming trials before cued trials for misnamed pictures ↓
Expressive Vocabulary Test ↓	(intervening task) ↓	(intervening task) ↓
Word Teaching 1	Word Teaching 2	Generalization test: administered uncued similar or dissimilar objects ↓ administered cued trials for misnamed objects ↓ administered uncued dissimilar or similar objects ↓ administered cued trials for misnamed objects

the object. The experimenter and child continued to play with the object. During this play, (4) the experimenter labeled the object five times. Labels were co-speech indicator gestures in the IND condition (e.g., "it's a /næf/ + open hand extended toward the object") and co-speech shape gestures in the SHP condition (e.g., "it's a /hig/ + shape gesture"). Children heard each object labeled 10 times by the study's end at visit 2 (i.e., five co-speech gesture models per session).

Generalization test

At visit three, Playdoh and one set of Generalization objects (either the shape-similar or the shape-dissimilar) were put on the table to transition to play with generalization objects. The order of presentation for shape-similar and shape-dissimilar generalization objects was determined by a counterbalancing schedule between children. First, the

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experimenter showed the generalization objects and their functions. The experimenter then organized the four objects at the center of the table, flattened the Playdoh and said "Now, you try". The child enacted all the objects' functions before being asked to name the objects. These steps ensured participants were familiar with the shape and function of each generalization object.

Once the child was familiar with the four generalization objects, the experimenter placed each object in the center of the table and said, "what could we call this one?" If the child did not provide a name or the name was inaccurate, the experimenter re-presented the object after all objects in that naming block were queried. In this instance, a gesture cue was provided (i.e., "It's an i*ndicator gesture*" or "It's a *shape gesture*"). The gesture cue matched the learning condition for that object's category and was consistent with prior studies (Capone & McGregor, 2005; Capone Singleton, 2012; Lindsey et al., 2020). When the four generalization objects were tested, they were removed from the table, and the remaining generalization objects were presented (shape-dissimilar or shape-similar, respectively).

Naming and errors coding

Using broad International Phonetic Alphabet transcription, two levels of word form coding occurred:

1. Phonological-level coding: We tallied each phoneme the child produced in his or her naming response that matched a phoneme in the teaching word (e.g., "roller" in response to /næf/= 0 phonemes, /w/ in response to /wƸʧ/ , or /pɪg/ in response to /pʌʤ/ = 1 phoneme, /mæf/ in response to /næf/ = 2 phonemes). These were tallied from the Naming and Generalization Tests. There were rare instances when a child mapped 2 phonemes, but the response was not a transparent translation of the target word (e.g., /fæmr/ for /næf/. These responses were not included in the phoneme analyses.
2. Lexical-level (word) coding: We tallied responses containing at least two phonemes that were transparent to the teaching word in the Generalization test (e.g., /Ƹʧ/ produced for /wƸʧ/, /wɪʧ/ in response to /wƸʧ/, /pʌp/ produced for /pʌʤ/ were coded as accurate names).
3. Sound errors that were developmentally appropriate sound substitutions or distortions were scored as correct (e.g., /ʧ/ produced for /ʤ/).

Circumlocution naming errors

Circumlocution errors shared a functional (gestured, spoken) relationship to the teaching object. These were specific spoken or gestured descriptions of the object function such as "scoop it" or making a scooping motion for /hig/. General thematic relationships or attributes that were directly observed that gave no semantic detail from memory to differentiate the word representations were not tallied (e.g.,"we play with those", "that is your thing", "Playdoh"; saying "triangle" for /wɛʧ/).

Dependent variables

The dependent variables were: (1) accurate naming, (2) the number of circumlocution errors, (3) the number of generalization objects named, (4) the number of shape-

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dissimilar objects named, (5) the number of phonemes produced on the Naming test and Generalization test and (6) the number of prime objects with inconsistent naming across visits.

Treatment fidelity and dependent measure reliability

An independent researcher coded treatment fidelity for 15% of treatment sessions. Application of the treatment protocol was coded for (1) demonstrating the function of the object, (2) allowing the child to use the object function before the experimenter applied the co-speech gesture, (3) application of the correct co-speech gesture, and (4) application of the correct number of spoken labels. The experimenters applied the independent variables with 100% accuracy.

An independent judge coded inter-rater reliability for 20% of sessions. The following dependent variables were coded: (1) naming errors, (2) naming accuracy, and (3) phoneme coding. There was 100% agreement between independent judges for naming errors and naming accuracy. There was 99% agreement between independent judges for phoneme coding.

Results

The converging evidence of our prior studies led us to make one-tailed predictions in this study. Specifically, we predicted the SHP condition would be superior to the IND condition for naming taught objects (Capone & McGregor, 2005; Capone Singleton, 2012; Capone Singleton & Anderson, 2020; Vogt & Kauschke, 2017), expressing more circumlocution errors (Capone Singleton, 2012), naming more untaught generalization objects (Capone Singleton, 2012), and using more phonemes in words (Capone Singleton & Anderson, 2020). We predicted children would be less likely to disrupt prime picture naming in the SHP condition over the IND condition. We used planned comparisons, and a Bonferroni-corrected alpha level for multiple comparisons with post-hoc analyses.

Using a Spearman Rank Order Correlation, we found no relationship between age and any dependent variable. We found no relationship between expressive vocabulary size and the dependent variables. We will not discuss age or vocabulary analyses further.

Taught object naming and circumlocution errors

At visit 2, no taught objects were named in the IND condition and 1 taught object was named in the SHP condition. At visit 3, children named a mean of .17 (SD = .49) taught objects in the IND condition, and children named a mean of .48 (SD = .66) taught objects in the SHP condition. The between condition difference was significant (Z = 2.887, p = .004, one-tailed, r =.60), and gave us many errors to analyze between conditions. Cohen's r is the effect size measure for the Wilcoxon Signed Ranks Test. Cohen's r was calculated as r = Z / $\sqrt{N}$. A Cohen's r of this magnitude is considered a large effect (small = .10, medium = .30, large = .50; Cohen, 1988).

Figure 1 illustrates circumlocution errors, with standard error bars, produced at visit 2 and visit 3 between the IND and SHP conditions. After one teaching session (that occurred at visit 1), the mean number of circumlocution errors at visit 2 was .43 (SD = .72) in the IND condition and .56 (SD =.66) in the SHP condition. After the second teaching

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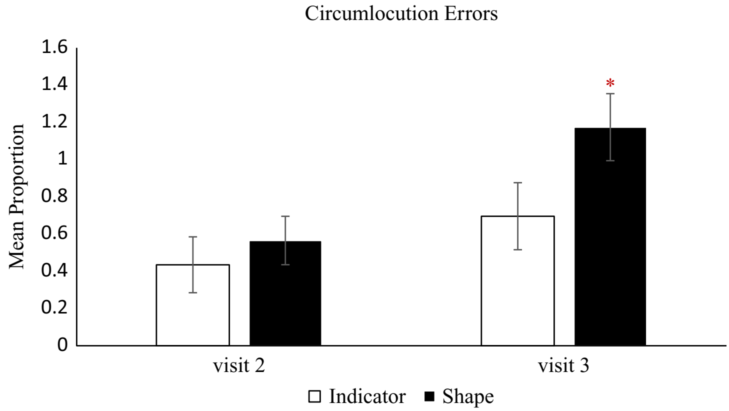

Figure 1. Mean proportion of circumlocution errors in each condition at visit 2 and visit 3. * indicates significant difference.

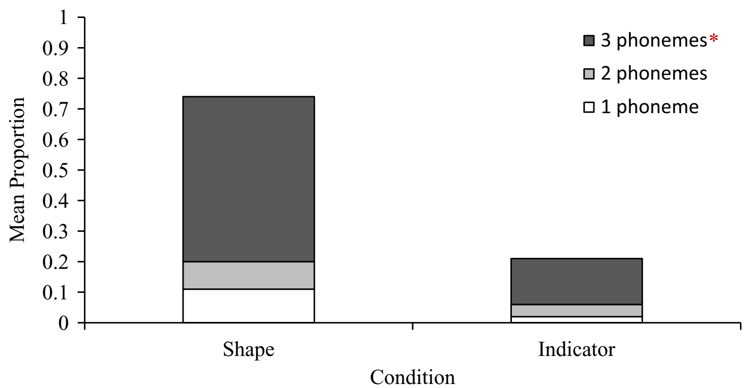

Figure 2. Mean proportion of words that contain the 1-, 2-, and 3- phonemes across the Naming test and Generalization test. * indicates significant difference.

session (that occurred at visit 2), the mean number of circumlocution errors was .69 (SD = .87) in the IND condition and 1.17 (SD = .88) in the SHP condition. A 2 (condition) x 2 (visit) Friedman analysis of variance (ANOVA) detected differences, $Fr(2,23) = 17.702$, $p < .001$. Post-hoc analysis using Wilcoxon Signed Ranks Test with Bonferroni-corrected alpha level (p = .033) revealed circumlocution errors at visit 3 in the SHP condition outweighed those in the IND condition (p = .017, one-tailed; r = .44). A Cohen's r of this magnitude is considered a medium effect.

Generalization test

At visit 3, we tested the generalization of each taught object by asking children to name two generalization objects. In the IND condition, children named a mean of .11 (SD = .38)

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of the generalization objects. In the SHP condition, children named a mean of .43 (*SD* = .72) of the generalization objects. A Wilcoxon Signed Rank Test detected a difference (Z = 2.579, p = .010, r = .38). A Cohen's r of this magnitude is considered a medium effect.

We were particularly interested in the context of the shape-dissimilar generalization objects because children relied on implicit function knowledge to generalize names from taught objects to the shape-dissimilar exemplars. We compared naming the shape-dissimilar exemplars. Children named .02 (*SD* = .15) of the shape-dissimilar exemplars in the IND condition. In the SHP condition, children named .15 (*SD* = .36) of the shape-dissimilar exemplars. A McNemar change Test detected a difference between conditions and the effect was large (p = .031, g = .50). Cohen's g is the effect size calculated for McNemar change Test (Cohen, 1988). Cohen's g is calculated as g = P - .5 where P = b/(b+c). A Cohen's g of this magnitude is considered a large effect (small = .05, medium = .15, large = .25; Cohen, 1988).

Naming prime pictures

Next, we measured accuracy of naming prime pictures in the Naming test. We conducted an item analysis for each prime object between visits by tallying inconsistent naming, by item over time. We took inconsistent naming over the three days, as a reflection of unstable inhibition between the prime and taught word. For example, if a participant accurately named the *brush* (i.e., a prime word) at visit 1 and visit 3 but named *brush* with a semantic error at visit 2 then we tallied this as an inconsistent naming pattern overall. Examples of errors that children produced when trying to name prime objects were "driver-thing" for wheel, "ship" for wheel, "headphones" for purse, "a toolbox" for hammer, "a light" for hairbrush, "a broom" for brush.

In the IND condition, children showed an inconsistent pattern with a mean of .28 (*SD* = .45) trials (i.e., visit 1 = "a brush", visit 2 = "a light", visit 3 = "a brush"). In the SHP condition, children showed an inconsistent pattern with a mean of .07 (*SD* = .25) trial. An exact McNemar change Test detected a statistically significant difference in the proportion of inconsistent naming patterns between conditions, (p = .021, g = .31). The effect size (g) was considered large (Cohen, 1988).

Phoneme production across naming test and generalization test at visit 3

We tallied the number of taught phonemes collapsed between the Naming test and Generalization test (similar, dissimilar). This analysis tallied partial word mapping with 1 phoneme productions (e.g., /nin/ said for /næf/), as well as 2 and 3 phoneme productions. Each participant could potentially produce 18 phonemes per condition. They produced 3 phonemes per object and there were 2 objects in each condition (6 phonemes x taught, untaught shape-similar, untaught shape-dissimilar = 18 phonemes per child).

In the IND condition, 26 phonemes were said in total across participants. In the SHP condition, 91 phonemes were said in total across participants. In the IND condition children produced a mean of .56 (*SD* = 1.65) phonemes, and in the SHP condition, children produced a mean of 1.87 (*SD* = 2.54) phonemes. A paired *t*-test found significantly more phonemes were said in the SHP condition than the IND condition, t (22) =-2.413, p = .012, d = .39. We reported Cohen's d as the effect size measure of the

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paired t-test. Cohen's d was calculated as d = M/SD. A Cohen's d of this magnitude is considered a small effect (small = .2, medium = .5, large = .8).

The next analysis compared the phonological composition of words when objects were named. Of the 23 children who participated in the study, 78% of the sample provided at least 1- but most often 2- and 3- phonemes in response to name queries. Figure 1 illustrates the mean proportion of words that contained 1-phoneme, 2-phonemes, and 3-phonemes by condition. The mean proportion of responses containing 1- phoneme, 2-phonemes, and 3-phonemes were .04 (SD = .20), .08 (SD =.28), .30 (SD =.92), respectively in the IND condition. The mean proportion of responses containing 1- phoneme, 2-phonemes, and 3-phonemes were .13 (SD = .45), .21 (SD = .42), 1.22 (SD = 1.27), respectively in the SHP condition. Data were subject to a 2 (condition) x 3 (phonemes) Friedman analysis of variance (ANOVA). Significant differences between phoneme categories were detected, Fr (5,23) = 29.115, p < .001. Post hoc analysis using the Wilcoxon matched pairs test with Bonferroni correction revealed significant differences. Bonferroni corrected alpha-level was p = .033. More 3-phoneme responses were provided in the SHP condition than the IND condition, Z = 2.198, p = .014, r = .46. A Cohen's r of this magnitude is considered medium (small = .10, medium = .30, large = .50). Planned comparisons for 1-phoneme (p = .207) and 2-phoneme (p = .090) comparisons were not different between conditions.

Discussion

The current study manipulated an explicit cue to object shape to learn more about the relationship between object, the feature of shape, and the word label in a word learning context. We examined the effect of the shape cue on depth of lexical-semantic representation using various outcome measures. We found deeper semantic knowledge (circumlocution errors, generalization to untaught objects, fewer disruptions to naming prime words) and better retention of the word form (number of phonemes, complete words) in the SHP condition relative to the IND condition. In no instance did the IND condition outperform the SHP condition. We replicated the finding of phonological retention that we previously observed in late talking toddlers (Capone Singleton & Anderson, 2020). The importance of shape to children's object cognition has traditionally focused on the shape bias literature (Kucker et al., 2019). Acquiring a shape bias is one important mechanism of word learning (Perry et al., 2021). Here, we leaned heavily into the shape bias literature to understand the origins of shape as a primary cue to object word learning (Kucker et al., 2019). Attending to shape makes it easier to learn new words for objects but here we extended that notion. The current results showed that shape continues to be an economical feature to hone into because our participants retained not only words, but more sounds in words and functions of objects neither of which were taught directly (i.e., no explicit cueing). It is possible that while the shape bias literature illustrates the importance of attention to shape in the earliest stages of language (e.g., Borgstrom et al., 2019), the current study speculates that attention to shape shifts toward the RELATIONSHIPS that shape shares with other aspects of the object representation so that it engages as part of a lexical-semantic network.

Capitalizing on statistical regularity economizes cognitive resources

Paying attention to object shape is economical when learning object names. Verbal and visual resources are limited in capacity. Taking advantage of statistical regularities is one

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source of efficiency (Saffran, Aslin & Newport, 1996). The shape bias is one example of a statistical regularity that children benefit from when learning object words. Here, the iconic gesture honed attention toward object shape, making it explicit; this may have lessened the word learning burden for the 3;5-year old. We speculate that resources redistributed to link shape with name, and to discern other semantic (i.e., function) and phonological (i.e., sound mapping) details of the word representation, including durable and binding links. In contrast, the indicating gesture narrowed down the referent but the child was left to extract shape and its relationships to other details implicitly.

The shape bias is a statistical regularity that emerges from social engagement, between infant and caregiver interacting with objects (Smith et al., 2002). Dyadic interactions tend to center around naming objects (Smith et al., 2002). The names of objects organize categorical membership too (Markman, 1990). Shape, name, and object categories are one of the earliest co-occurring regularities stored for infants. Once children have some experience with names and objects, it makes learning the shape bias possible (Samuelson, 2002). Samuelson (2002) showed that children must know words of a certain kind to extract patterns that are statistically consistent. Specifically, having rigid objects in the lexicon appears necessary to abstract shared shape as the organizing feature of object categories. Samuelson (2002) taught a precocious shape bias to infants under 1;6 year olds but could not stimulate a material bias in the infants. The fundamental difference between acquiring the two biases was composition of the infants' lexicons. The lexicons contained solid objects, but the 1;6-year olds did not know objects that could be categorized by material substance without material entities.

Compression of details in object representations

There is a high correlation between an object's shape and its functional affordances (Capone, 2007; Capone & McGregor, 2005; Capone Singleton, 2012; Fernandino, Binder, Desai, Pendl, Humphries, Gross, Conant & Seidenberg, 2016). Preschoolers in our study showed additional benefit from shape cues in that they mapped object function without direct teaching, above and beyond what hands-on experience provided them. This was reflected in circumlocution errors at visit 3 and more names generalized to shape-dissimilar exemplars. The current study replicated Capone Singleton (2012). In Capone and McGregor (2005; see also Capone, 2007) toddlers stated functions (i.e., verbs) when asked about them at comparable levels to the co-speech function gesture condition. As in the current study, experimenters did not say or teach functions in the SHP condition of that study. Drawing explicit attention to object shape appears to help the child interface with functional affordances of the object. One important method is that our 3;5-year olds manipulated objects in both the SHP and IND condition so the co-speech SHP gesture was the key difference. Wakefield, Hall, C., James, and Goldin-Meadow (2018) also found that co-speech gestures promoted generalization of verbs over hands-on experience with novel objects. Fernandino et al. (2016) found that both haptic and visual brain regions are active when adults process shape-related information. Shape processing was triggered from listening to object labels in that study.

Highly correlated semantic features (shape, name, and function) are overlapping. We showed above that name and shape both organize categories. Shape and function are also physically overlapping (Chaigneau, Barsalou & Sloman, 2004). Memory capacity is maximized through a process of compressing the redundancy in overlapping features (Brady, Konkle & Alvarez, 2009; O'Donnell, Clement & Brockmole, 2018). Compression occurs when information is linked together. The linking of information prunes redundancy in memory. In the case of solid objects, overlapping knowledge between shape and name, and shape and function may get compressed in memory. Compression of redundancy also frees neural resources because associated items take up less space in memory (O'Donnell et al., 2018). We speculate that shape may compress phonological and function details within the object representation. It is interesting to consider that like shape's primacy in the formation of categories, shape may take primacy in this role of compression (Gentner, 1978; Kemler-Nelson, 1999). In previous studies that compared co-speech function gestures with a SHP condition, lexical-semantic representations were more robust under SHP conditions than when learned with function gestures (Capone & McGregor, 2005; Capone Singleton, 2012). It is possible that certain connections within the lexical-semantic representation are more robust given how these early relationships are built in infancy (i.e., the connection between name and shape, the connection between shape to function).

Inhibiting words in the lexicon

The concept of depth goes beyond the details of a single referent. A healthy lexicon engages and inhibits within a well-connected network of lexical-semantic representations (Kapnoula, Packard, Gupta & McMurray, 2015; Leach & Samuel, 2007). The network is teaming with excitation and inhibition. Inhibitory connections develop as part of the semantic representation. Although our main aim for the primed Naming Test was to elicit naming errors on taught words, we took the opportunity to analyze accuracy in naming prime pictures too. Naming of prime pictures could reflect inhibition in the local networks we were creating over time. Differences between the SHP and IND conditions reflected the experimental manipulation because prime words were counterbalanced between conditions.

When asked to name prime and taught words in sequence, we found an effect on the consistency of retrieving PRIME words over time. Specifically, there were fewer disruptions in the SHP condition than the IND condition. In a lexical-semantic network, a new word (i.e., our taught word) begins to fit itself within established words. Our priming paradigm was developed for the 3;5-year olds to assume each prime picture and taught object were the same category, that of the prime picture. Word retrieval is competitive and in the current study, the prime picture and taught object were competing for activation (Dell, 1986; Gershkoff-Stowe et al., 2006). Also, errors in retrieving known words are not uncommon when learning new words (Gershkoff-Stowe & Smith, 1997). As new words are integrated into the lexicon, new connections develop to and from established words. Inhibitory connections develop to inhibit activation of the taught words while naming prime words because the two words share perceptual similarity. As taught words secured more details, we interpret fewer errors on prime picture to mean more inhibitory connections and less overlap with the teaching words, than the IND condition. We speculate that the taught words in the IND condition remained shallow and highly overlapping with prime words yielding more bidirectional activation to disrupt naming in that local network.

The role of gesture in making shape explicit

A gesture is a word learning cue always at our fingertips (p.760, Capone Singleton & Anderson, 2020). Young children are acquainted with gesturing by caregivers in the context of word learning. Caregivers often show and point but parents create iconic gestures too (Butterworth & Grover, 1990; Zammit & Schafer, 2010). Providing a co-speech gesture may help in the moment of learning when the lexicon is sparse, or strategies are few in the child's repertoire. Co-speech iconic gesture, such as one that mimics object shape, can make semantic features explicit. For our preschoolers, a co-speech shape gesture seemed to support evolving representations while they were shallow. The 3;5-year old categorized new objects in the moment by drawing on mental representations that were retained. Co-speech shape gestures do more than act as a reminder because both the SHP and IND conditions had unique gestures for each object. Instead, co-speech shape gestures seem to help children encode and store the original object, and/or retrieve the semantic representation from memory when trying to make sense of the untaught objects presented to them for generalization (Jones & Smith, 1993).

Our findings contrast with other studies that fail to find children under 3;0 years can interpret shape gestures (e.g., Hodges, Özçalişan & Williamson, 2018; Magid & Pyers, 2017). In Magid & Pyers, (2017) 3;0-, and 4;0-year olds were exposed to shape and arbitrary gestures but only 4;0 year olds recognized shape gestures after teaching. Hodges et al. (2018) examined developmental changes from 2;0- years to 4;0-years in comprehending shape gestures (i.e., referred to as attribute gestures). At 2;0 years few children chose the correct referent of the shape gesture. Only at 3;0 and 4;0-years did children perform at above chance levels of responding on a forced-choice picture recognition task. The difference between studies that fail to find shape gestures are comprehended by children under 3;0-years and studies such as this one, is that the current study used co-speech gestures. Co-speech gestures in this study simultaneously said the semantic referent while gesturing the shape cue whereas studies that fail to find children comprehending shape gestures do not pair gestures with content words. We suspect that shape gestures work in concert with nouns to cue object categories. When children hear a noun, they may make hypotheses about what is important to the current word learning (or play) context. Our co-speech shape gestures may be confirming those hypotheses by bolstering the learning context with a second cue (Hollich, Hirsh-Pasek, Golinkoff, Brand, Brown, Chung, Hennon & Rocroi, 2000).

Conclusion

We set out to examine the role object shape plays in word depth. We showed that explicit attention to object shape continues to be important while deepening word representations over the first few exposures. In the SHP condition, 3;5 year olds (a) expressed semantic knowledge about objects when they failed word retrieval, (b) said more sounds in the names they did retrieve, and (c) named more untaught objects in a Generalization test, than in the IND condition. There were also fewer disruptions when naming prime picture in the SHP condition; we interpreted this as better inhibition of taught words due to more detailed semantic representations. Because the relationship between name and object shape is one of the first built into semantic memory, we suggest that several mechanisms in learning may continue to benefit from attention to shape including memory compression.

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