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Does children's visual attention to specific objects affect their verb learning?

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Abstract
To learn a verb, children must attend to objects and relations, often within a dynamic scene. Several studies show that comparing varied events linked to a verb helps children learn verbs, but there is also controversy in this area. This study asks whether children benefit from seeing variation across events as they learn a new verb, and uses an eye tracker to test whether children adjust their visual attention to specific objects to better understand how they may be comparing events to each other. Children saw events in which the tool varied, the affected object varied, or there was no variation (control). No prior verb study has tested children's visual attention to specific objects under different variability conditions. We found 2½- and 3½-year-olds could extend verbs, and they were more successful with age. Analyses of the looking patterns in the learning phase show that children's attention to specific objects in events varied by condition, and that reduced looking to the tool was linked to less success at test. Eye tracking can provide a more detailed view of what children attend to while learning a new verb, which should help us better understand how children are learning from variation across examples.

Keywords
Eye tracking, memory, variability, verbs, word learning

Learning verbs, and being able to extend them to new contexts, is essential to becoming a native speaker. Verbs refer to events that must be parsed from a larger stream (e.g., Baldwin, Baird, Saylor, & Clark, 2001; Hespos, Saylor, & Grossman, 2009), and are

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perhaps more difficult to learn than are nouns (e.g., Bornstein et al., 2004; Gentner, 1982; Tardif, Shatz, & Naigles, 1997). Verb referents commonly include relations between multiple objects (e.g., Childers & Tomasello, 2002; Gentner, 1982; Haryu, Imai, & Okada, 2011), and there are few strategies a child could use to extend new verbs that would apply across different verbs. Thus, both learning a new verb and deducing how to extend it (e.g., to new objects, situations, and sentences) are difficult problems.

Children deducing the meaning of a new verb would benefit from comparing events linked to that verb. For example, children hearing the verb 'cook' and seeing a scene in which a mother stirs broccoli in a pan on one day (Event 1), and then a scene in which a father stirs spaghetti in a pot on another day (Event 2), could align these two events based on their common structure. In Gentner's structure mapping theory (e.g., Gentner, 1983, 1989, 2010), the perceptual similarity of objects across examples guides processing (e.g., between the spatula and the wooden spoon, and the mother and father), and helps children align objects across examples. This highlights the common relational structure between the instances (e.g., Loewenstein, Thompson, & Gentner, 2003) and leads to inferences. Inferences in verb meaning may include types of entities (e.g., agents, tools or affected objects) that may be commonly present when a particular verb is used.

Do children use variability information across multiple examples as they learn a new verb?

A growing number of studies have examined whether children benefit from comparing a set of events when learning verbs, and whether seeing varied events to compare is useful; as a whole, these findings are inconclusive. Specifically, there are studies that show that variation across events can help children learn verbs (e.g., Childers, 2011; Childers, Heard, Ring, Pai, & Sallquist, 2012; Childers & Paik, 2009). For example, in one study, 2½-year-olds shown varied events performed as well as a set of children who received direct instruction on a new verb's meaning (Childers, Hirshkowitz, & Benavides, 2014). Additionally, a study by Waxman, Lidz, Braun, and Levin (2009) shows that 2-year-olds who saw four comparison events and a contrast phase before test learned verbs, but it is unclear whether the comparison trials, the contrast trial, or both contributed to their performance at test. In Scott and Fisher (2012, Study 1), 2½-year-olds could attend to a link between a new verb and one of two novel events when that new verb and novel event recurred over trials. Together, this set of studies shows that young 2- to 2½-year-olds can learn from seeing varied events as they hear a verb.

However, there are also findings that suggest that variation may hurt children's verb learning. Two of these studies have focused on variability in agents in events, with one showing that 2½- to 3-year-olds were not as successful at extending new verbs when seeing four different agents in a learning phase as compared to a single agent (Maguire, Hirsh-Pasek, Golinkoff, & Brandone, 2008). In Childers, Paik, Flores, Lai, and Dolan (2017), children at these same ages in the US, China, Korea, and Singapore performed similarly when shown one or three agents when the actions were simple, overall body movements, but had difficulty when seeing three agents where the actions were complex (agent, tool, affected object).

More importantly, Haryu et al. (2011) showed that Japanese-speaking children are better at extending new verbs when objects are *similar* across the learning and test trial. Specifically, they found that 3- and 4-year-olds were more likely to extend a verb appropriately to a new Action Same event (showing the same action with a different object) when that event included an object that was similar to the object seen in the initial learning trial. Thus, these results also suggest that similarity, and not variability, in useful in verb learning. On the other hand, results from a study in Korean and English (Childers & Paik, 2009) suggests that if children are given a set of varied events to compare between the initial event and the test event, they can extend verbs to events with dissimilar objects at test.

In summary, as there is some controversy concerning whether variability in verb learning is helpful, and under which circumstances variability may be helpful, additional studies of verb learning from varied events are needed. Additionally, variability information is only useful if children actually attend to it; eye tracking data could reveal whether children are noticing which objects vary or stay the same as they see events.

Prior eye tracking studies examining verb learning in children

To our knowledge, only two studies with young children have used an eye tracker to examine children's attention to specific objects across events during verb learning. (Studies using eye tracking differ from studies using preferential looking or IPLP in that eye trackers can isolate fixations to specific parts of a video event.) In the first of these, 2½-, 3½-, and 4½-year-olds saw two pairs of events in a learning phase (Childers et al., 2016). Half of the children saw an initial pair of events in which the objects were the same size and shape (similar pair), and half saw an initial pair of events that varied (e.g., number of objects, shape of the objects, and/or the way the action unfolded). After this initial pair, children in both conditions saw the same events – a new pair of actions that differed from each other in several ways – and looking during this trial was tracked. Verb extensions were tested by asking children to point to one of two new events. Results showed 2½-year-olds looked significantly longer to two key objects in the events (the agent area of interest [AOI], and at the affected object AOI) only in the condition in which they initially saw a highly similar pair of events, and 3½-year-olds extended verbs only in the high similarity condition. Thus, being able to compare two similar events helped 2½-year-olds attend to important objects in varied events that appeared later, and this experience helped 3½-year-olds learn and extend the new verbs at test.

Valleau and Arunachalam (2017) also conducted a study with 2½-year-olds (31- to 36-month-olds) who heard novel verbs either in a full Determiner Phrase (noun) condition or in a Pronoun condition. During the learning phase, children saw trials with the same event (e.g., an agent waving an umbrella), and then saw a contrast trial with a different event. At test, they were asked to point to a scene with the same action shown with a new object (correct) or a new action shown with a familiar object (incorrect). They found that children who heard full noun phrases while learning a new verb, and were later correct at test, increased their looking to the Object AOI during the learning phase as compared to other children. Thus, increased looking to the moving object appeared to help children succeed in extending the new verb.

This is similar to the result in Childers et al. (2016), in which seeing a similar pair of events before a more varied one also led to an increase in looking to important objects in events. Although the events differed in complexity, and the sentences differed in form across these two studies, these results together show an increase in looking to important objects, which is fostered in different ways, could be one mechanism by which children learn and extend new verbs. Additionally, Valleau and Arunachalam's (2017) results suggest that hearing full noun phrases is helpful to 2½-year-olds, even though this is more linguistic information to process when compared to sentences with pronouns. This may have been why only the 3½-year-olds in Childers et al. (2016) could extend the verbs; perhaps children at the younger ages needed full noun phrases. Alternatively, Childers and Tomasello's (2001) results showed that hearing both pronoun and full noun sentences as opposed to only full noun phrases helped children produce new verbs creatively, which means that the effect of sentence type in verb learning needs more investigation.

In summary, only two prior studies have used eye tracking methodology to examine looking to specific objects over trials (Childers et al., 2016; Valleau & Arunachalam, 2017). One way we extend prior results is to examine children's looking when only a single event is shown (and not a pair of events), as is more typical in everyday life. We also examine children's looking to specific objects that varied over trials, asking whether children can adjust their looking to an object depending on whether that object varies or not. This allows us to ask two important questions about the comparison of events during verb learning: (1) what are children visually attending to when they see a set of dynamic events and hear a new verb, and (2) does a specific pattern of visual attention during learning help them learn new verbs?

Method

Participants

Thirty-six 2½-year-old children (*M* = 2;8, range = 2;4–2;11; 20 boys and 16 girls) and 34 3½-year-old children (*M* = 3;6, range = 3;0–3;11; 14 boys and 20 girls) participated in the study (see Table 1). Participants were recruited and data were collected at several local child care centers in San Antonio, Texas. In addition, families were contacted using a list of parent names obtained commercially, and through a lab website; in these cases, appointments were scheduled by email and by phone.

Of the families who provided ethnicity information, 59% reported their ethnicity as Caucasian, 16% were members of two or more ethnic groups, 6% identified as Hispanic, 1 was Asian, and 1 was African American. Children were included only if their parents reported exposure to English at least 80% of the time, and were excluded if teachers reported a speech delay. Some parents provided responses on the verb vocabulary section and the three longest sentences item on the MacArthur–Bates Communicative Development Inventory for Words and Sentences (Fenson et al., 1994). The 2½-year-old children's verb vocabulary was *M* = 92 verbs (range: 47–103, *n* = 19 reporting), and their mean length of the three longest sentences was 7 words (range: 4–13 words, *n* = 18 reporting). By chance, fewer checklists were returned in the older age group. The

Table 1. Demographic information by age group and condition.

Age group			
Condition	Mean age	Mean number of verbs (MacArthur CDI)	Gender
2½-year-olds			
Affected Object	32 months	89	m: 5, f: 5
Tool	31 months	92	m: 8, f: 6
Control	33 months	93	m: 7, f: 5
3½-year-olds			
Affected Object	42 months	101	m: 7, f: 2
Tool	43 months	95	m: 6, f: 7
Control	41 months	99	m: 6, f: 6

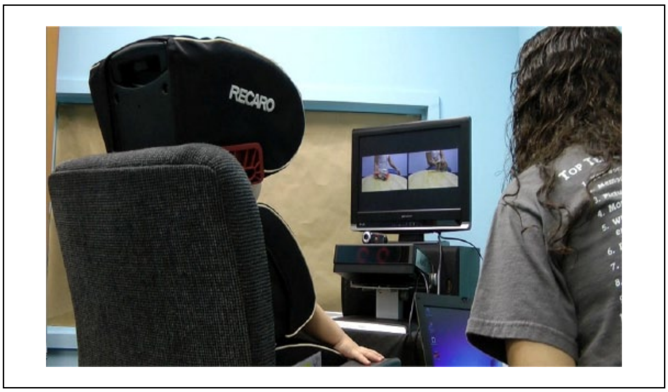

Figure 1. Experimental set-up.

3½-year-old children's verb vocabulary was $M = 97$ verbs (range: 78–103, $n = 9$ reporting), and their mean length of the three longest sentences was 9.4 words (range: 4–15 words, $n = 7$ reporting). Additional children participated but were excluded from the final sample because the child only pointed to one side of the screen (10) or he or she refused to point at test (18).

Experimental set-up

Participants were seated in front of a 21-inch flat screen video monitor. In order to minimize head movement and distractions, children sat in a car seat with stabilizing wings alongside the position of the head, which was attached to an adjustable office chair (see Figure 1). A Tobii X120 eye tracker device was placed below the video screen, which was connected to a laptop. Attached to the video screen was a webcam that recorded the child's pointing responses; this allowed an experimenter not present at the initial session to code the responses from tape. The distance between the table holding the video screen and tracker and the child's chair was approximately 16 inches, with some variation to maximize an individual participant's calibration. Eye movements were measured by the eye tracker using a corneal reflectance tracking technique. A near infrared light source was directed at the participant, undetectable to the naked eye, and the reflection of the light on the cornea was recorded as the participant watched the video stimulus on a monitor. If a parent was present, he or she sat in a chair behind the child, outside of the range of the eye tracker.

Design

There were two between-subjects factors: Age group (2½ or 3½ years) and Condition, or the object that was varied during the learning phase (tool, affected object, control). A within-subjects factor was looking to a specific object (AOI) type (agent, tool, affected object) in each event. There were also two dependent variables. As looking to each element is not independent (i.e., if children are looking at the tool, they cannot look at other objects), the first dependent variable was proportion looking to the tool = toolAOI/(toolAOI + affected object AOI + agent AOI). A second dependent variable was whether or not the participant pointed to the correct extension of the novel verb at test.

Materials

Sets of video clips were created for each of four novel verbs: *tam, jop, zim*, and *lorse* (see Appendix 1). However, as we were drawing AOIs, we realized that elements in the 'jop' event (stirring) could not be adequately spatially separated, so we excluded that set from the analyses.

All of the actions in the study were designed to be novel. All were causative actions and all were referred to using transitive sentences. In each of these events, the participant saw an agent (torso, arms, and hands visible) use an object (i.e., a tool) to manipulate a second object (i.e., the affected object) (see Appendix 1 for a complete list). Each verb set included three related events to be shown during a learning phase. Across the set of events, the events varied by condition.

For example, in the video events associated with the verb *lorse*, a woman used a tool to flip over a second object. In the Tool condition, videos depicted the action using three different tools across the set of events (see Figure 2, top: tongs, a spatula, a white scoop). In the Affected Object condition, the same action was shown using the spatula, but three different objects were affected across the set (see Figure 2, middle: lady bug toy, toy pizza, gold fish toy). For the Comparison Control condition, the first event seen in the other two conditions was shown three times so that there was no variation in the learning phase (see Figure 2, bottom).

In addition to the learning phase video events, sets of video clips for each test trial were created for each of the novel verbs (see Figure 3 and Appendix 1). Clips were designed to show a correct verb extension event and a distractor event. Test events depicted the same action and result as in the learning phase but were shown with new objects (correct verb extension) vs. a different action and result with those same new

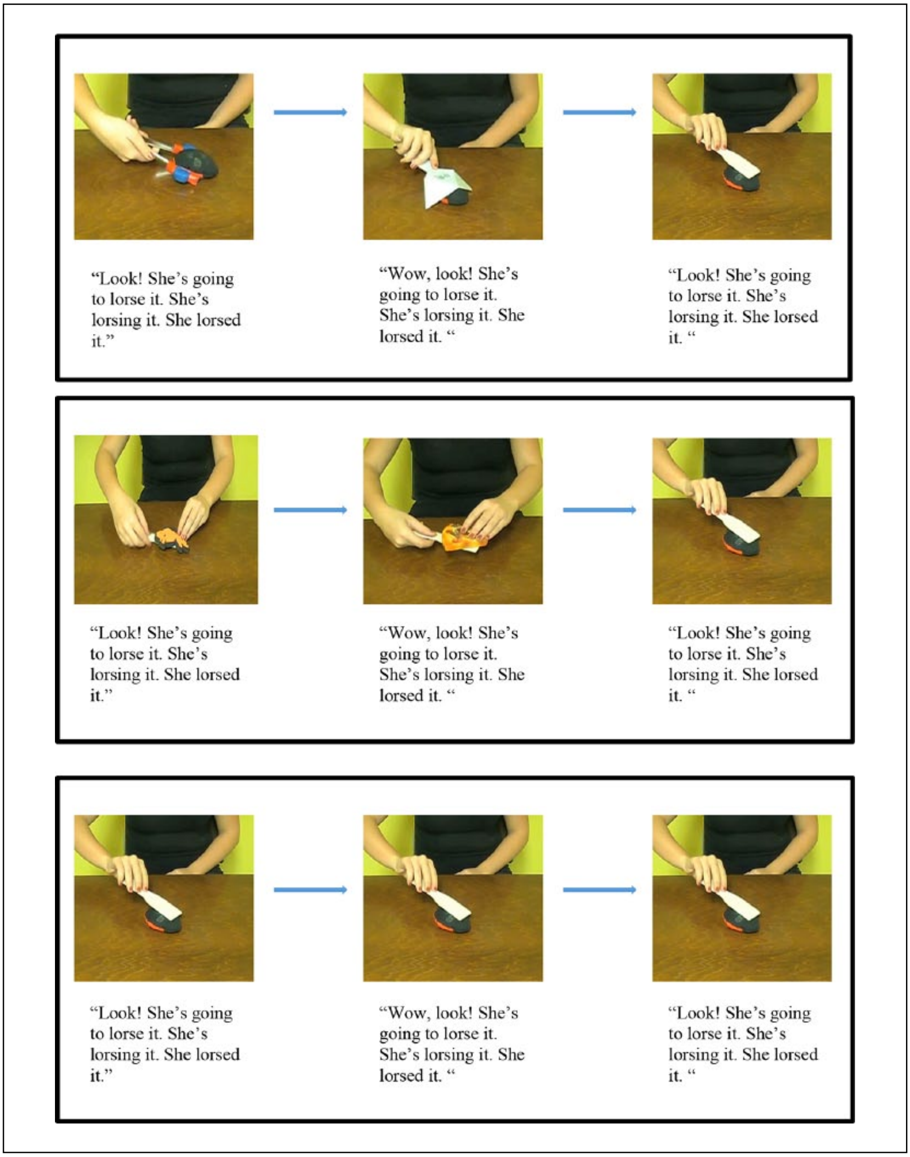

Figure 2. Tool condition (top), Affected Object condition (middle), Control condition (bottom).

objects (incorrect). For example, during the first *lorse* test trial, observers saw a video of the female actor using a green paint scraper to flip a toy hat over (correct) and saw her using the green paint scraper to lift and wave the toy hat in the air (incorrect). During the second *lorse* test trial, observers saw a video of the female actor on one side of the screen

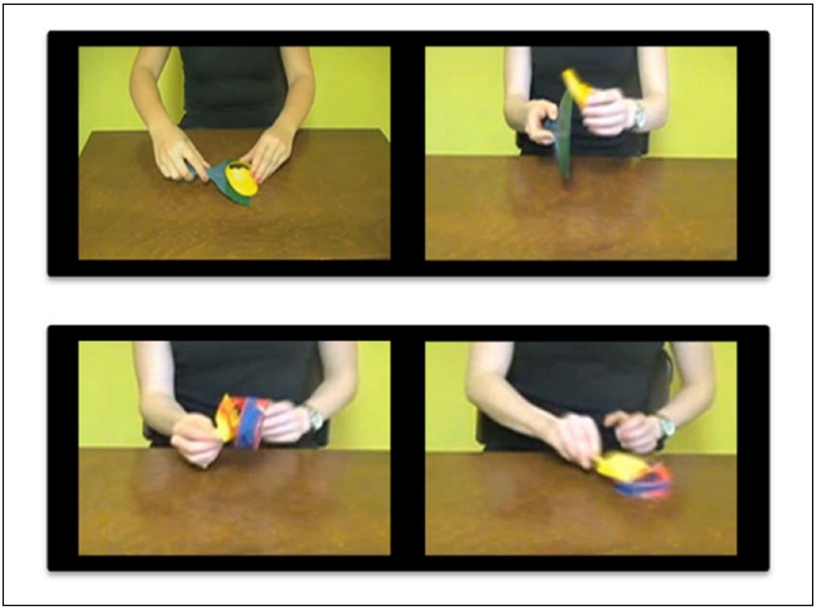

Figure 3. Test trials example.

using a toy shovel to flip a miniature backpack (correct) and saw her using the toy shovel to wave the miniature backpack in the air (incorrect) on the other side (see Figure 3).

Areas of interest

Areas of interest were drawn by hand using Tobii Studio software around the main object types (tool, affected object, agent) in all of the events in the learning phase. We used the 'dynamic AOI' feature in the software which uses keyframes corresponding to a particular point in the timeline. We defined multiple keyframes for each AOI frame by frame, and the software then allowed that AOI to move smoothly across multiple keyframes. AOIs were drawn only for scenes shown in the learning phase, and were drawn with spatial separation between each element in every frame (see Figure 4 for an example).

Procedure

Children participated in a quiet room in their child care center or in a room in an on campus laboratory. Before participating, the child's parent or guardian provided consent for the child's participation in the study, either by returning a signed consent form to the child's teacher at a child care center or by signing the form in the lab. At the child care center, researchers visited the center multiple times to build rapport before taking the child to a nearby room for the experimental session, while in the lab researchers played with the child while the parent completed forms to establish rapport with the child.

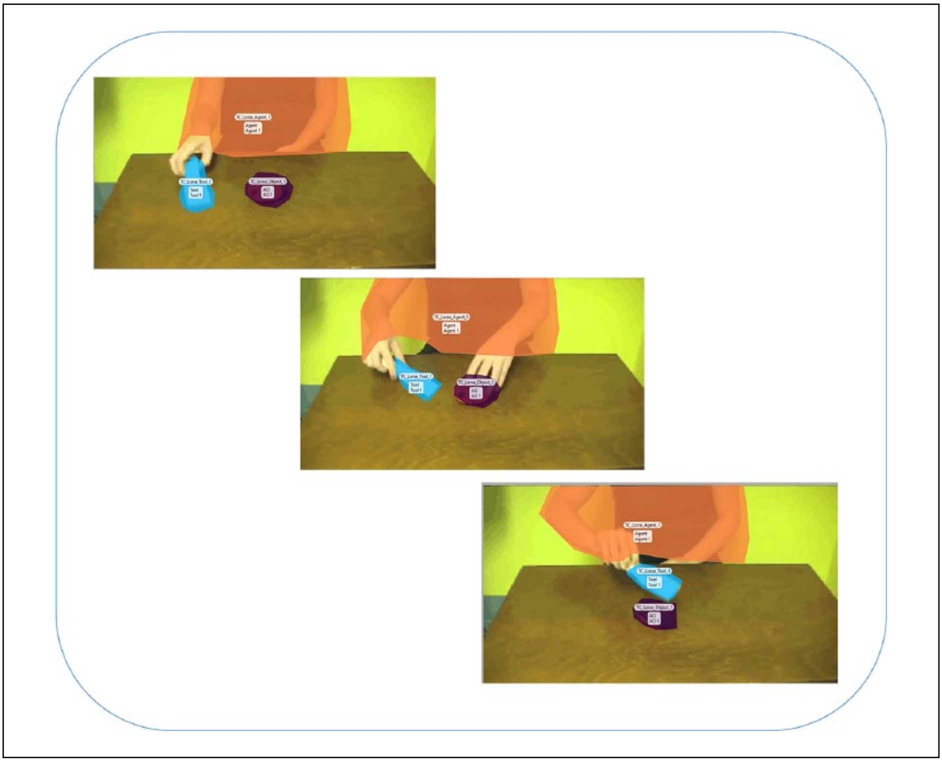

Figure 4. Example AOIs. Photos show beginning of the event (left), middle of the event (right) and end of the event (middle) for each verb set.

Two experimenters were present during the study; one controlled the eye tracker and presented the stimulus sentences using a script while the other coded the child's responses. After placing the child in a seat in front of the video monitor, the experimenter calibrated the Tobii X120 eye tracker using the Tobii 5 point calibration stimuli for infants. After calibration, the software displays a graphic of looking to each calibration area and we recalibrated one or more points if the results of the tracking did not cluster around a calibration point. We did not include a child's eye tracking data if his/her looking could not be calibrated ($n = 13$). The calibration procedure took approximately 1 minute before practice trials were initiated.

Next, the child saw three warm-up trials, each consisting of a split screen with one object on the left and a different object on the right. In the first warm-up pair, observers saw a video of a stuffed flower toy moving up and down on the left and a video of a person rolling a toy fire truck on the right while hearing 'Look at these things. Can you point to the dancing flower?' Second, they saw a video of a small spinning ball on the left and a video of a stuffed fish toy moving up and down on the right while hearing 'Look at these things. Can you point to the swimming fish?' Finally, participants saw a video of a person rolling a fire truck toy and a video of a person moving

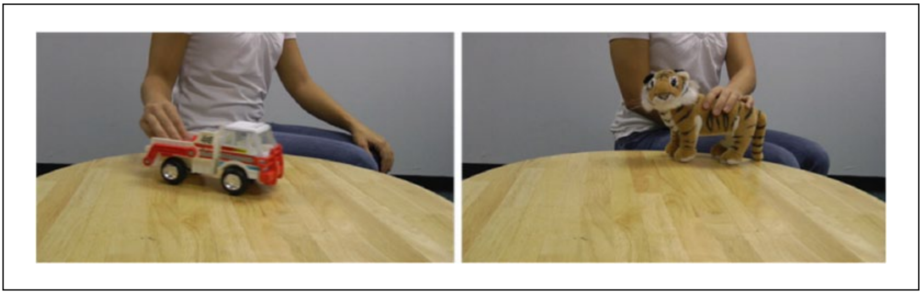

Figure 5. Practice trial example.

a stuffed tiger side-to-side while hearing, ‘Look at these things. Can you point to the rolling fire truck?’ (see Figure 5). The experimenter asked the child to point to one of the objects during each trial.

Then, each participant was exposed to a set of events for four novel verbs (*tam, jop, zim*, and *lorse*). Each verb set included a learning phase and a test phase. The learning phase included three events that co-occurred with a single new verb. In each trial, the child watched a novel action being performed while simultaneously hearing the experimenter label the action with the novel verb. For example, in the learning phase for the verb *lorse*, the experimenter would say ‘Look! She’s going to *lorse* it’ immediately before the action, ‘She’s *lorsing* it’ during the action, and ‘She *lorsed* it!’ immediately after the action in each event (see Figure 2). (We use live experimenters producing child directed speech because we have found that our youngest participants have difficulty attending and pointing at test if hearing recorded audio.) Between each learning trial, a black screen appeared for three seconds.

Following the learning phase, the participant was presented with two test trials (see Figure 3). In the first test trial, the child saw a split screen event that showed the novel action from the learning phase being performed on one side of the screen and a distractor action being performed on the other. All test events included both a new tool and new affected object not shown in the learning phase. The experimenter asked the child to point to the correct extension of the novel verb. For example, in the test phase for the verb *lorse*, the experimenter would say: ‘Where is she *lorsing* it? Can you show me? Can you point to it?’ Then the second test trial began including a different split screen event showing a target and distractor event. The target action switched to the other side of the screen in the second test trial to ensure the child was not pointing to one side of the screen for every test trial. This block of learning phase and test phase was repeated for three more verbs so that each child responded to eight test trials.

To assess whether the target and distractor test events were equally salient, a separate set of preschoolers (n = 10) were shown the practice trials, and then saw only the pairs of test trials while being asked to choose the event they liked best (e.g., ‘Which one do you like?’). We coded their responses as correct or incorrect as in the main dataset. We then compared that number (M = 4.5, SE = .34) to chance (4 of 8) using a one-sample *t*-test, $t(9) = 1.46$, *ns*. Thus, the correct events in the test trials were not simply more salient than were the distractor events.

Coding

Children's responses were coded as Correct (i.e., pointed to the correct extension of the verb at test) or Incorrect (i.e., did not point to the correct extension of the verb at test). We computed a mean proportion correct score (proportion correct = total correct/total number of responses) to capitalize on all of the test trials in which children pointed.[1]

Experimental sessions were initially coded by a live observer and recorded using a video camera. All sessions were later coded by a second observer from video. This second coding was the coding used in the final dataset because the second coder could pause the videotape and review pointing behavior if needed. A third independent coder who was not present in the original experimental session coded 25% of participants' pointing behaviors at test. These two coders agreed on 98% of the trials, with a Cohen's kappa = .96 ('very good').

Results

Eye tracking results

To examine children's looking during the learning phase, a repeated measures analysis of variance (ANOVA) was computed with Age group (2: 2½, 3½ years) and Condition (3: Tool, Affected Object, Control) as between-subjects factors, and Learning Trial (1, 2, 3) as a within-subjects factor. The dependent variable was proportion looking to the tool (= toolAOI/(toolAOI + affected objectAOI + agent AOI).[2,3] This analysis revealed a significant main effect of Learning Trial, $F(2, 64) = 3.51$, $p = .033$, $\eta_p^2 = .05$, and a Learning Trial × Condition interaction, $F(4, 64) = 5.96$, $p < .001$, $\eta_p^2 = .16$ (see Figure 6).

To further investigate the Learning Trial × Condition interaction, simple main effect tests were computed within each condition. These show that for the Affected Object condition, there was a significant effect of Learning Trial, $F(2, 63) = 12.47$, $p < .001$, such that participants in the Affected Object condition differed in looking between the first ($M = .58$, $SD = .19$) and second ($M = .44$, $SD = .28$) learning trials ($p = .01$) and the first and third ($M = .39$, $SD = .14$) trials ($p < .001$); children *decreased* in their looking to the tool in this condition. In the Tool condition, there was also a significant effect of Learning Trial, $F(2, 63) = 4.18$, $p = .02$, such that participants in the Tool condition differed in looking between the first ($M = .43$, $SD = .20$) and second ($M = .52$, $SD = .25$) trial ($p = .041$) and between the first and third ($M = .51$, $SD = .17$) trial ($p = .01$) but, in this case, looking to the tool *increased* over trials. In the Control condition, there was a significant effect of Learning Trial, $F(2, 63) = 3.99$, $p = .023$, such that children's looking to the tool significantly decreased between the first ($M = .57$, $SD = .21$) and third ($M = .47$, $SD = .21$) trials only ($p = .006$).

In sum, these analyses show that children increased their looking to the tool over trials in the Tool condition (in which the tool varied) and decreased their looking to the tool in the Affected Object and Control conditions (in which the tool did not vary).

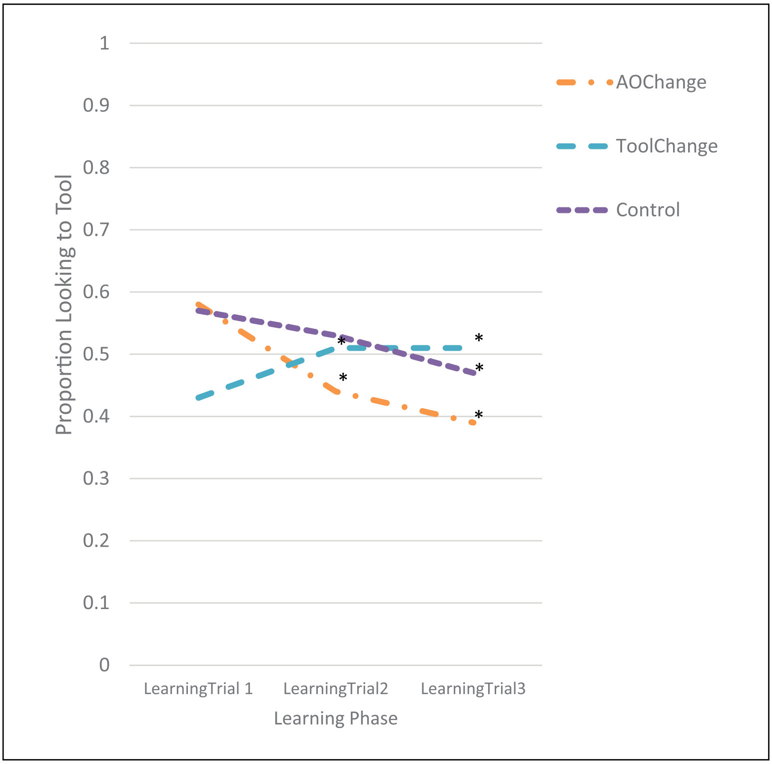

Figure 6. Looking data. Graph shows proportion looking to the tool AOI in each of the three learning trials by condition. Children increase looking to the tool in the Tool condition, and decrease looking to the tool in the AO and Control conditions.
*Trials differ from the first trial, $p < .05$.

Pointing data

To analyze the pointing data, a univariate ANOVA was computed with Age group (2: 2½, 3½ years) and Condition (3: Tool, Affected Object, Control) as between-subjects factors; the dependent variable was mean proportion correct verb extension at test (see Note 3). This analysis revealed a main effect of Age group with $F(1, 69) = 15.57$, $p < .001$, $\eta_p^2 = .20$; there was no main effect of Condition, and no significant Age group by Condition interaction ($p = .13$ and $p = .56$ respectively). To examine the main effect of Age group, one-sample t-tests were used to compare the overall mean proportion correct to chance (= .50); these showed that as a group, both 2½-year-olds ($t(35) = 3.46$, $p = .001$) and 3½-year-olds ($t(33) = 8.42$, $p < .001$) were extending verbs successfully at test.

A separate question is whether children in each condition were consistently succeeding at test, particularly in the younger age group (see Figure 7). To test this question, one-sample t-tests were computed comparing each proportion correct in each condition to chance, in the younger age group only. These showed that children in the Affected Object and Control

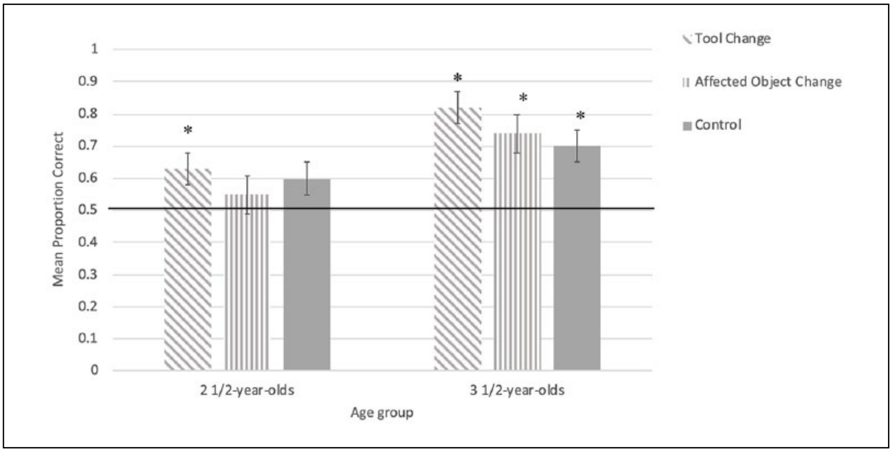

Figure 7. Pointing data.

condition did not exceed chance, with $t(9) = 1.40, p = .20$ and $t(11) = 1.93, p = .08$ respectively, while children in the Tool condition did exceed chance, $t(14) = 2.26, p = .04$.

Thus, the main analysis shows that across conditions, children were able to learn and extend the new verbs in this study, and there was development between 2½ and 3½ years. At the same time, 2½-year-olds' responses appeared to be especially influenced by the types of comparisons they saw, and they performed best in the condition in which the tool varied across events.

Analyses examining the links between looking and pointing data

A key question in eye tracking research is whether results from tracking eye movements can be used to predict children's responses at test. Although overall success in extending the new verbs did not differ by condition, it could still be that there are specific looking patterns during learning that are linked to more or less success at test. In this study, we collected children's proportion looking to the tool in the first learning trial, the second trial, and the third trial. As children have not had a chance to compare events in the first trial, we focused on analyzing looking patterns in the second and third trials, when children could be adjusting their looking to different elements in the scene based on the different learning conditions.

We conducted two hierarchical regression analyses to ask whether looking in the second and third learning trials predicted success at test. To do this, we entered participants' study condition in the first step (dummy coded to create three dichotomous variables: AO vs. other; Tool vs. other; Control vs. other), Age group (2: 2½, 3½) and proportion spent looking at the tool (ptool, as described in the prior analyses) in the second step, and the interactions of the condition variables and ptool in the third step. The dependent variable was proportion correct at test. The analysis of looking in the second learning trial showed that Age group was a significant positive predictor of success at test, with $\beta = .45$, $t(68) = 4.18, p < .001$, and there was a significant AO $\times$ ptool 2 interaction,

Table 2. Results of regression analysis for the second learning trial.

Model	Predictor	*B*	*SE B*	β	*t*	*p*
1	Affected Object	–.08	.06	–.19	−1.40	.17
	Control	–.07	.05	–.17	−1.29	.20
2	Affected Object	–.08	.05	–.18	−1.48	.14
	Control	–.08	.05	–.19	−1.58	.12
	Age group	.17	.04	.45	4.17	$<$ .001
	ptool 2	.06	.08	.08	.74	.46
3	Affected Object	.11	.10	.25	1.03	.31
	Control	.05	.12	.13	.42	.68
	Age group	.17	.04	.45	4.18	$<$ .001
	ptool 2	.26	.13	.33	1.98	.052
	Control × ptool 2	–.25	.21	–.36	−1.16	.25
	Affected Object × ptool 2	–.39	.19	–.49	–2.02	.048

Note. ptool 2 is the proportion of time spent looking at the tool during the second trial. Affected Object condition, dummy coded 0 = not AO condition, 1 = AO condition. Control = Control condition, dummy coded 0 = not Control condition, 1 = Control condition. Tool condition, dummy coded 0 = not Tool condition, 1 = Tool condition. Affected Object × ptool 2 and Control × ptool 2 refer to interactions between conditions and the proportion of time looking at the tool. The results for the Tool condition do not appear in the table because by default participants who are not in the Affected Object condition or the Control condition must be in the Tool condition.

$\beta = –.49$, $t(68) = –2.02$, $p = .048$. In the interaction, as the beta coefficient and t value are negative, and this interaction was only significant for the Affected Object condition, this suggests that looking to the tool during the second trial impaired children's performance at test only in the Affected Object condition (see Table 2). Thus, the regression shows more looking to the tool predicted worse performance at test in the Affected Object condition, while it was linked to better performance at test in the other conditions.

For the third learning trial, we found no significant interactions. However, at Step 2, Age group was a significant positive predictor of success at test, with $\beta = .42$, $t(68) = 3.92$, $p < .001$, and Affected Object condition was a significant negative predictor of success at test, $\beta = –.26$, $t(68) = –2.06$, $p = .044$ (see Table 3). As in the analysis of the second learning trial, experiencing the Affected Object variation was linked to worse performance at test. This could be because looking to the tool generally predicted success at test and, in this condition, by the third learning trial, the variation of the affected object drew children's attention away from the tool.

Discussion

We had two main goals for this study: to further examine whether variability across events is helpful during verb learning as there is controversy in this area, and to reveal what children are visually attending to across a set of events when they hear a new verb, asking whether a specific pattern of visual attention predicts successful verb extensions at test. To test these questions, children saw complex events in which an agent used a tool to create a change in an affected object. Some children saw three different affected

Table 3. Results of regression analysis for the third learning trial.

Model	Predictor	*B*	*SE B*	β	*t*	*p*
1	Affected Object	–.09	.06	–.22	–1.62	.11
	Control	–.08	.05	–.20	–1.52	.13
2	Affected Object	–.11	.05	–.26	–2.06	.044
	Control	–.09	.05	–.22	–1.86	.07
	Age group	.16	.04	.42	3.92	< .001
	ptool 3	–.15	.12	–.15	–1.29	.20
3	Affected Object	–.02	.16	–.04	–.12	.91
	Control	–.05	.14	–.12	–.35	.73
	Age group	.16	.04	.42	3.88	< .001
	ptool 3	–.08	.20	–.08	–.41	.69
	Control × ptool 3	–.08	.26	–.11	–.30	.77
	Affected Object × ptool 3	–.21	.35	–.21	–.59	.56

Note. ptool 3 is the proportion of time spent looking at the tool during the third trial. Affected Object condition, dummy coded 0 = not AO condition, 1 = AO condition. Control = Control condition, dummy coded 0 = not Control condition, 1 = Control condition. Tool condition, dummy coded 0 = not Tool condition, 1 = Tool condition. The results for the Tool condition do not appear in the table because by default participants who are not in the Affected Object condition or the Control condition must be in the Tool condition.

objects during a learning phase (AO condition), some saw events with three different tools (Tool condition), and some saw three identical events before test (Control). We then examined whether children's looking patterns during learning varied by condition, whether they were able to extend the verb at test (and whether this varied by condition), and whether we could predict whether children would be successful in extending the verb at test using their looking patterns in the learning phase.

Overall, our results show that children were able to learn and extend verbs across conditions as, as a group, both 2½- and 3½-year-olds were successful at test. At the same time, the main effect of Age shows there are developmental differences between 2½ and 3½ years. As there was not a main effect of Condition, we should be cautious in interpreting these results but, looking more closely within each age group, 2½-year-olds performed best in one of the varied event conditions – the Tool condition – and did not exceed chance in the single event Control condition or the Affected Object condition. This suggests that, especially in the younger age group, attending to the tool was helpful for verb learning and was supported by seeing varied tools during learning. Three-and-a-half-year-olds could learn the new verbs regardless of types of variation they were shown.

Thus, the results in the younger age group support prior studies in which variation has been shown to be helpful in verb learning (e.g., Childers, 2011; Childers & Paik, 2009; Waxman et al., 2009), while adding to this body of results by showing that the specific type of variation shown may be important. However, these results also highlight the difficulty we still have in this area of *predicting* when variability will be useful and when it will not. The usefulness of variability information likely depends on the age of the child (younger may have more difficulty), the experience they have with a particular task (with children likely being able to make more use of it as they gain more experience), and task demands (among other factors). It is important for researchers to continue to examine learning under different conditions to better understand how and when children use variation across examples as they learn verbs. The present results add to the set of studies showing variation is not always harmful in verb learning.

Recall that key research questions were: What are children attending to when they learn a new verb? Do they attend to specific elements in an event and, if so, do they modify their attention to specific objects based on prior examples they have seen? Focusing on the looking data, children did notice the variations that were present, as children's looking patterns in the learning phase differed by condition. Specifically, children increased their looking to the tool in the condition in which the tool varied across events (Tool condition) and decreased their looking to the tool in the conditions in which the tool did not vary (the Affected Object and Control conditions). Comparing our two experimental groups which saw varied events, there was a marked difference in their pattern of looking across the three learning trials, which is an exciting result (see Figure 6). No other study has shown (or tested) children's visual attention to objects under different variability conditions. We argue that the best explanation for the difference in looking patterns between the Affected Object and Tool conditions is that children were comparing the event they were seeing with the event they had just seen, and were able to use that comparison to notice which element varied. They also were adjusting their visual attention to look longer at a changing object than at unchanging ones. Because we found specific adjustments to elements in events that corresponded to whether that element varied or not, this is consistent with a comparison account in which observers align specific elements from one instance to another – Structural Alignment theory (e.g., Gentner & Namy, 2006). To our knowledge, this is the first experimental study providing eye tracking evidence consistent with this view, suggesting an object-by-object alignment across examples.

Our second research question was whether patterns of attention that children exhibit during learning are linked to more or less success at test. Does it help us to know what children are fixating on during the learning phase? Our results suggest it does. Focusing on the second learning trial, our regression analyses show that children in the Affected Object condition who looked more at the tool were less successful at test, while looking to the tool predicted more verb extensions in the other conditions. Why would this be? Children who are looking more at the tool in the Affected Object condition are ignoring the object type that is varying across trials, the affected object, and focusing on an unchanging tool. Thus, they appear to be failing to notice the important variation that is present in that condition. By the third learning trial, again, being in the Affected Object condition was linked to fewer verb extensions at test (Tables 2 and 3). So again, experiencing varied affected objects was not helpful in that group. Also, in both the second and the third learning trial, Age was a significant positive predictor of extensions at test, showing that looking patterns in older children were more beneficial to verb learning than those in younger children.

Why is looking to the tool helpful to children? It could be that in these complex events with an agent, tool and affected object, a key part of the action is what the agent is doing with the tool. By attending to this key part of the events, children were able to view test events with the new objects and quickly transfer their knowledge to the new event that preserved the action they had seen. Verbs can specify which tools are used in an event (e.g., staplers for 'staple' in English), so attending to tools could be useful.

This result showing attention to a particular object – in this study, the tool – was linked to children's ability to extend new verbs fits with the prior Childers et al. (2016) results showing that children in a progressive alignment (similar first) condition showed increased looking to specific objects at 2½ years, and better verb extensions at 3½ years. It also fits with Valleau and Arunachalam's (2017) results showing increased looking to a moving object may help children learn new verbs. Across all three studies, interestingly, it was not looking to the agent that was linked to better verb extensions, but looking to the tool or other object that helped children extend new verbs. Again, this makes intuitive sense as verbs do not specify particular individuals as agents (i.e., there are not proper verbs as there are proper nouns), but they can specify particular objects, particularly tools or instruments (as in the 'staple' example above). This also fits prior results from Imai showing that children learning verbs attend to objects (e.g., Imai & Childers, in press; Imai, Haryu, & Okada, 2005; Imai et al., 2008).

In sum, deducing the meaning of a new verb, and figuring out how to extend it or use it productively are difficult, important problems. Variation information should be useful to young children, if they can make use of it, because it can demonstrate at least a sample of acceptable extensions of that verb that the child could use to guide new extensions. Prior studies have shown that children can benefit from variation across examples in verb learning (e.g., Childers & Paik, 2009; Scott & Fisher, 2012), but a few verb studies also have shown that variation can be linked to fewer verb extensions (e.g., Maguire et al., 2008). In this study, we found that children could learn new verbs when given varied events perhaps because they were either at the right age or had the right amount of experience needed to process this varied information. Our study also shows that attention to particular objects, in this case the tool or instrument in events, helped children extend verbs, a finding that fits with two other prior eye tracking studies. Additional studies are needed to investigate these research questions with different types of events, different types of verbs, different types of extension trials (e.g., to different situations or sentences), and across different ages to more fully understand when and how comparison contributes to verb learning. As we gain a better understanding of how typically developing children learn and extend novel verbs, our results can inform the design of new interventions for children who find verb learning to be significantly more challenging.

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Notes

1. We conducted the same analyses using total number of trials correct as the dependent variable. The pattern of results was the same except that 2½-year-olds were at chance in their responding at test. We report the proportion correct data because it includes the number of correct responses children made out of their total responses; it does not count failing to respond on a trial as an error.
2. A preliminary analysis considering the order of events showed no main effect of order or interaction with any other factor.
3. Given that proportional data can be influenced by instability of error term variances, we computed analyses of the proportional data following arc-sine transformations (Neter, Wasserman, & Kutner, 1985). The analyses with arc-sine transformed data were not significantly different from the proportional analyses, thus the proportional analyses are reported.

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Appendix 1

Verb	*tam*	*jop*	*zim*	*lorse*
Associated action	A woman covers one object with another object.	A woman uses one object to stir objects in a transparent container.	A woman presses an object into a softer object, leaving an imprint.	A woman flips over an object using another object.
Learning phase	Tools: circular lid, small toy bucket, small plastic mat Affected objects: lion beanie baby, little ball, wooden wheel barrow	Tools: wooden mallet, wooden spoon, toy hammer Affected objects: ping pong balls in a measuring cup, plastic animals in a small suitcase, confetti paper in a clear box	Tools: small Elmo toy, toy wrench, pyramid shaped toy Affected objects: purple play-dough, pink play-dough, black play-dough	Tools: tongs, spatula, white scoop Affected objects: lady bug toy, toy pizza, gold fish toy
Test trial 1	Target action: A woman covers a small toy with a hollow can. Distractor action: A woman uses a hollow can to push around a small toy.	Target action: A woman uses a toy saw to stir toys contained inside of a plastic container. Distractor action: A woman taps a toy saw on the rim of a plastic container filled with toys.	Target action: A woman pushes the end of an arts-and-craft tool into play-dough. Distractor action: A woman takes play-dough and wraps it around an arts-and-crafts tool.	Target action: A woman uses a toy shovel to flip over a miniature backpack. Distractor action: A woman hooks a miniature backpack onto a toy shovel and shakes the backpack from side-to-side.
Test trial 2	Target action: A woman uses a cylindrical object to cover a pinecone. Distractor action: A woman pushes a pinecone around on a table using a cylindrical object.	Target action: A woman uses a foam poly brush to stir toys contained inside a graduated measuring cup. Distractor action: A woman taps a foam poly brush on the rim of a graduated measuring cup.	Target action: A woman pushes the end of a paint roller onto a piece of bread. Distractor action: A woman folds a piece of bread in half over a paint roller.	Target action: A woman uses a paint scraper to flip over a miniature hat. Distractor action: A woman hooks a miniature hat onto a paint scraper and shakes the hat from side-to-side.