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How does a blind person see? Developmental change in applying visual verbs to agents with disabilities

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ABSTRACT

Classic theories emphasize the primacy of first-person sensory experience for learning meanings of words: to know what "see" means, one must be able to use the eyes to perceive. Contrary to this idea, blind adults and children acquire normative meanings of "visual" verbs, e.g., interpreting "see" and "look" to mean with the eyes for sighted agents. Here we ask the flip side of this question: how easily do sighted children acquire the meanings of "visual" verbs as they apply to blind agents? We asked sighted 4-, 6- and 9-year-olds to tell us what part of the body a blind or a sighted agent would use to "see", "look" (and other visual verbs, $n = 5$), vs. "listen", "smell" (and other non-visual verbs, $n = 10$). Even the youngest children consistently reported the correct body parts for sighted agents (eyes for "look", ears for "listen"). By contrast, there was striking developmental change in applying "visual" verbs to blind agents. Adults, 9- and 6-year-olds, either extended visual verbs to other modalities for blind agents (e.g., "seeing" with hands or a cane) or stated that the blind agent "cannot" "look" or "see". By contrast, 4-year-olds said that a blind agent would use her eyes to "see", "look", etc., even while explicitly acknowledging that the agent's "eyes don't work". Young children also endorsed "she is looking at the dax" descriptions of photographs where the blind agent had the object in her "line of sight", irrespective of whether she had physical contact with the object. This pattern held for leg-motion verbs ("walk", "run") applied to wheelchair users. The ability to modify verb modality for agents with disabilities undergoes developmental change between 4 and 6. Despite this, we find that 4-year-olds are sensitive to the semantic distinction between active ("look") and stative ("see"), even when applied to blind agents. These results challenge the primacy of first-person sensory experience and highlight the importance of linguistic input and social interaction in the acquisition of verb meaning.

1. Introduction

Locke (1690) famously claimed that blind individuals could never understand concepts reflecting visual experience. For example, the learner who does not have the relevant sensory experience for terms such as *"look"* and *"see"* could never develop the corresponding meanings (Locke, 1690; see also Cutsforth, 1932; Cutsforth, 1951). In recent decades, this strong view of the necessary conditions for learning word meanings has been challenged by evidence that blind individuals develop meanings for visual verbs that are remarkably similar to those of sighted individuals. For example, similar to sighted adults, blind adults distinguish among verbs of visual perception (e.g., "*see", "look", "peek", "stare*"), and distinguish all "visual" verbs from verbs of tactile perception (e.g., "*touch", "feel*"), and modality-neutral verbs when making semantic similarity judgments or writing definitions (e.g., "perceive", "notice"; Lenci, Baroni, Cazzolli, & Marotta, 2013; Bedny, Koster-Hale, Elli, Yazzolino, & Saxe, 2019). Blind adults infer how sighted people will feel based on visual experiences they themselves have never had, such as recognizing a loved one's handwriting, and activate similar cortical systems when doing so (Bedny, Pascual-Leone, & Saxe, 2009; Koster-Hale, Bedny, & Saxe, 2014). Moreover, Landau and Gleitman (1985) showed that a young congenitally and totally blind child developed coherent meanings for visual verbs (look vs. see) and that by 4-years-of-age she applied them accurately to both blind and sighted agents. As a whole, such findings argue against the idea that first-person experience is necessary for learning the meanings of "visual" words or understanding the perceptual experiences of others.

The challenge of thinking and talking about experiences that are not

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like our own is not unique to children who are blind, however. All children and adults routinely apply verbs to agents who differ from themselves and each other in a one way or another, in age, gender, or bodily capacities. In this paper, we ask the flip side of Locke's question: rather than asking how someone born blind acquires the meanings of visual verbs in reference to a sighted agent, we ask how sighted children (and adults) apply visual verbs to agents who are blind. As a point of comparison, we also examine how leg-related motion verbs (e.g., walk) are applied to agents who use a wheelchair. For adult speakers, the inferences that follow from sentences that contain verbs that refer to perception and action depend on the agent to whom the verbs are applied. For example, the sentence "Lisa saw the mug" licenses the inference that Lisa knows the color of the mug. If Lisa is blind, however, the inference might be quite different. Upon discovering that Lisa is blind, the listener could judge that *seeing* cannot be applied to Lisa at all and that the sentence is necessarily false. Alternatively, the listener might infer that Lisa saw the mug with her hands and therefore that she would know whether the mug is warm or cold, but not whether it is yellow or red. Thus, components of the verb's meaning (i.e., the sensory modality of visual verbs) interact with the capacities of the agent performing the action. If the canonical modality of the perception verb is visual (e.g., for the verb "see"), but the agent's eyes do not support such information gathering, the listener modifies their interpretation accordingly. The goal of the present paper was to examine how sighted children (and adults) apply verbs to agents whose capacities conflict with the normative properties of the verb's meaning (i.e., applying *seeing* to blind agents or *walking* to a wheelchair user). Although the primary focus of the current paper is on verbs of perception, comparing perception and motion verbs enables us to test whether developmental patterns are specific to verbs that intersect with mental phenomena, such as seeing, or more broadly relate to the integration of verb meaning with the physical and mental capacities of agents.

By age 2, sighted children use visual verbs to describe both their own and other sighted people's visual experiences (Bretherton & Beeghly, 1982; Frank, Braginsky, Yurovsky, & Marchman, 2017). Visual and other perception verbs (e.g., touch, smell) are correctly distinguished by modality (Bretherton & Beeghly, 1982; Davis & Landau, 2020; Frank et al., 2017). Thus, early in the preschool years children have mastered an important aspect of the so called "root" meaning of the verb, i.e., that aspect of word meaning which intuitively gives each verb it's unique semantic content, for example, that "walk" means moving through space with a particular manner of motion, and that "give" means transferring something from one person to another. For perception verbs, the root meaning includes their specific modality, e.g., that "see" and "look" are tied to vision, that "touch" and "feel" are tied to haptics, etc. (Jackendoff, 1983, 1992; Levin, 1993; Miller & Johnson-Laird, 1976).

By 4-years-of-age, children also know the set of syntactic frames in which a verb participates, and they can use these frames to infer additional aspects of the verb's meaning, using the number and type of arguments that a verb requires, via syntactic bootstrapping (Gleitman, 1990; Gleitman, Cassidy, Nappa, Papafragou, & Trueswell, 2005; Landau & Gleitman, 1985; Papafragou, Cassidy, & Gleitman, 2007; Snedeker & Gleitman, 2004). For example, perception verbs across all modalities have two required arguments, the "perceiver" and the "perceived", hence these two arguments are expressed in the syntax (e.g., "*He looked (at)/touched/smelled the object*"). Modality itself is not mapped to different syntactic frames (i.e., the same basic set of frames applies to verbs of vision, touch, audition, etc.).

Within each modality, however, perception verbs distinguish syntactically between active forms such as *"look"* and *"listen"*, which encode the action of directing one's eyes/ears towards something in order to achieve perception, and stative forms such as "*see"* and "*hear",* which encode the resulting state of modality-specific perception – i.e., the perceiver's internal knowledge state (Jackendoff, 2007; Viberg, 1983). A consequence of this difference in meaning is that we can easily conceive of situations in which one can *look* but not *see,* or *listen* but not *hear* (Jackendoff, 2007). For example, active verbs can occur as imperatives (*Look! Listen!)* but statives cannot (**See! *Hear!)*; one can command another person to direct their eyes or orient their ears to *look* or *listen*, but not to reach the corresponding mental state of *seeing* or *hearing*. By contrast, stative verbs can be queried (*See? Hear?)* but active verbs cannot (*Look? *Listen?)[1]

In sum, prior evidence suggests that 4-year-old sighted and blind children have mastered both the root and the syntax-related aspect of visual verb meaning. However, all prior studies with sighted children have focused on application of visual verbs to canonical sighted agents. One possibility is that sighted children have full mastery of both aspects of verb meaning even this context. That is, that the verb meanings of sighted children are by 4-years-of-age similar to those of adults. This possibility is consistent with the case-study of the blind child Kelli, discussed above (Landau & Gleitman, 1985). Kelli used visual verbs such as "look" and "see" to refer to haptic perception when they were applied to herself (e.g., *"I see with my hands"*), but to perception with the eyes for sighted people, including cases that do not apply to tactile perception, such as perception at a distance of objects in the line-of-sight. Kelli also made distinctions between active and stative visual verbs (i.e., "look" vs. "see"), showing that she understood that the first refers to perceptual activity but the second to mental states that are produced through this activity. Moreover, she made this distinction when applying "*see*" and "*look*" to both blind and sighted agents. On this view, applying visual verbs to agents whose perceptual capacities are in conflict with the canonical interpretation of "visual" verbs presents no special cognitive challenge.

On the other hand, blind children might have the advantage of relevant experience over sighted children when it comes to applying visual verbs to agents who have different bodily capacities from oneself. Most blind children, including Kelli, live among sighted people and routinely hear visual verbs applied to sighted agents. Kelli spent years interacting with her sighted mother and sister, which could have provided the circumstances for learning about the relevant similarities (and differences) between haptic and visual perception. By contrast, most sighted children have never encountered a blind person. They have had no opportunity to reason through what perception is like for agents whose eyes "don't work" and have little or no experience hearing visual verbs applied to blind agents. Previous evidence suggests that sighted children of this age do have some undersatnding of visual disabilities. For example, children correctly predict that a blind agent would have more trouble with visual than motor tasks (Diamond & Hestenes, 1996; Diamond & Kensinger, 2002). However, the depth of this knowledge and whether it can be fruitfully combined with the modality specific aspects of verb meaning is an open question. If experiences of talking and thinking about perception by agents different from oneself is more relevant to verb usage than one's own first-person sensory experience, then sighted children might experience a protracted development in applying visual verbs to agents who are blind, despite the fact that, unlike children born blind, they can readily experience what it is like to "not see" by closing the eyes.

In the following experiments, we tested how young sighted children come to apply both aspects of visual verb meanings (modality and the active/stative distinction) to a blind (vs. sighted) agent. In Experiments 1 and 2, we asked sighted children between the ages of 4 and 9 what body part a blind/sighted agent would use to perform visual actions. To foreshadow, the results of Experiment 1 suggest that sighted children are unable to modify their interpretation of visual verbs in accord with a blind agent's bodily capacities. In Experiment 2, we replicate and extend this finding by asking whether the protracted development is specific to

[1] Stative verbs can also be used like attitude verbs to refer to someone's mental states in sentences with "that"-complement clauses (*John saw/heard/knew that Mary left),* whereas active verbs cannot (**Look? *Listen?*; **John looked/listened that Mary left).*

verbs that refer to mental experiences (i.e., coming to know something via looking). We test children's ability to integrate the meanings of leg-related motion verbs (e.g., run) with agents who are wheelchair users. Finally, in Experiment 3, we asked sighted children to evaluate whether a blind agent, a sighted agent and a blindfolded agent is *looking* and *sees* an object in their direct line of sight. This last study enabled us to ask whether children in this age range are sensitive to the active/stative distinction within visual verbs when these are applied to agents who are blind; we also ask whether any immaturity among sighted children in verb extension is specific to their understanding of blind as opposed to blindfolded agents.

We hypothesized that, like Kelli, sighted 4-year-olds would have no trouble making the active/stative distinction, even when applied to blind agents, since this distinction can be acquired independently of understanding an agent's modality-specific perceptual capabilities. That is, whether a child understands *how* the blind agent perceives the world, they still might understand the distinction between being in an active or stative mode of perceiving. By contrast, sighted children might have trouble modifying their interpretation of the modality-specific aspect of visual verbs' meanings in accordance with the sensory capacities of the agent. If so, we might expect young children to simply deny that a blind agent could ever *see* or *look*, perhaps treating the blind agent as though they were a sighted agent who had their eyes closed. An alternative possilbity is that children revert to the "visual" interpretation of *seeing* and *looking*, even for blind agents. If so, they might claim that a blind agent would nevertheless use their eyes to "see" and describe them as "looking" even when they are not in physical contact with the object, as long as they are directing their eyes towards it.

2. Experiment 1

2.1. Methods

2.1.1. Participants

Twelve 4-year-olds (8 girls; mean age = 4;6, range = 4;1–4;11), fourteen 6–7-year-olds (7 girls; mean age = 6;10, range = 6;0–7;9), and twelve 9-year-olds (8 girls; mean age = 9;4, range = 9;0–9;10) were tested in the Language and Cognition Lab at Johns Hopkins University. In addition, 51 adults were tested online through Amazon Mechanical Turk (AMT; 25 women; mean age = 36;1). Two additional 4-year-olds were tested but excluded from the analysis because they did not complete the entire procedure. Three adults were also excluded as they missed two catch trials (n = 2) or reported not being a native English speaker (n = 1). A parent/legal guardian provided written informed consent for the children, who also gave their oral assent to participate. Children received a toy for participating. Adult participants provided their written consent by ticking a checkbox and received monetary compensation for completing the online survey. The experimental protocols for both children and adults were approved by the Johns Hopkins Homewood Institutional Review Board.

2.1.2. Design, stimuli and procedure

The age at which children master the meanings of various perception verbs as they apply to canonical agents is not known. We therefore began by querying children on a large set of 25 perception verbs, including 9 visual verbs, 9 tactile verbs, and 7 auditory, gustatory, olfactory verbs (see Table 1). The following experiments (1 and 2) focus on the subset of these verbs that were mastered by the majority (>80% of 4-year-olds). Each verb was applied to three agents: first to the participants themselves, and then to two fictional agents, one sighted and one blind. For each agent, participants were asked which part of their body that agent would use to carry out the 25 different perceptual acts (e.g., "*What part of your/her body would you/Lisa use to* [verb] *something?*") and were then offered five different response options (e.g., "*Would you/she use your/her eyes, ears, nose, mouth, or hands?*").

The task was explained to the children in a brief warm-up by giving an example and 2 questions about how different body parts could be used for different actions, using verbs other than those included in the experiment ("*I can use my legs to run! What part of your body would you use to clap? …and to eat?*"). Children had no problem producing the relevant body parts (i.e., hands, mouth). Then, the experimenter explained that they would play a game about what you do with the eyes, ears, nose, mouth, and hands, and asked the children to point at each on their own body (e.g., "*Where is your nose? Can you show me your hands?*").

Children then began the main procedure. They were first asked what body part they themselves would use "*to* [verb]". This question was repeated for each of the 25 verbs, which were presented in one of two fixed orders, randomly assigned to participants. Response choices (i.e., body parts) were listed randomly for each query. After asking about the participants themselves, the experimenter introduced both fictional agents (as below), and then queried all 25 verbs for each agent, one agent at a time, in counterbalanced order across participants.

To introduce the fictional agents and make clear that one was sighted and one was blind, the children were read a brief description of each (see Table 2); adults read the descriptions themselves. Each description included the agent's name, where s/he lived, their hobbies, and the fact that the agent was either sighted or blind. Two pertinent facts were then given to illustrate the difference: that the agent reads (either using Braille or printed text) and that s/he can use a watch (either a talking watch or a standard watch). The children were also shown actual examples of the books and watches. The additional details were used to help the children distinguish and remember the two agents, while at the same time conveying that they are similar to each other and to other typical agents in respects besides blindness (e.g., they both had hobbies).

Table 1
Complete list of perception verbs in Experiment 1 by modality in alphabetical order.

Visual verbs	Tactile verbs	Verbs of other modalities (auditory, gustatory, olfactory)		
Gawk	Caress	Eavesdrop	**Smell**	**Taste**
Gaze	**Feel**	**Hear**	**Sniff**	Savor
Glance	Nudge	**Listen**		
Look	**Pat**			
Peek	Prod			
Peer	**Rub**			
See	Stroke			
Stare	**Tap**			
Watch	**Touch**			

Note: **Bolded** verbs were used in both Experiment 1 and 2.

Table 2
Blind and Sighted fictional agent descriptions, narrated by the experimenter to children or read by adult participants. Critical information about each agent is in italics below but was not italicized in the text presented to adults.

Lisa – Blind agent
I'm going to tell you something about my friend Lisa.
Lisa lives in an apartment downtown. She likes music and playing with computers.
Lisa has a cat whose name is Snowball, who spends most of the day sleeping.
Lisa is blind, her eyes don't work.
This is one of her favorite books, and it's written in Braille [showing the book to the child]. These raised dots here are letters, and Lisa uses her fingers to read [demonstrating how to read Braille].
Lisa also has a talking watch, that tells her what time it is aloud when she presses this button [demonstrating how the watch operates].
Tommy – Sighted agent
I'm going to tell you something about my friend Tommy.
Tommy lives in a farm in the County. He likes playing outside and hiking. Tommy has a dog named Jack, who runs and barks a lot.
Tommy's eyes work just fine, he is not blind.
He reads books with printed letters, like this one [showing the book to the child]. This is one of his favorite books, it's about colors [directing the attention of the child to the book content].
This is Tommy's kid watch, and he can tell the time by the position of the hands on the screen [pointing the child attention to the time on the screen].

When children were then asked about the target verbs, they were reminded every 5 verbs that the sighted agent's eyes "*work just fine*" whereas the blind agent's eyes "*don't work*". Children received a sticker at the end of each third of the experiment to keep attention and motivation high. All procedures with children were videotaped for later coding.

The online survey completed by the adult participants used the same stimuli and procedures with the following exceptions. Participants read the text descriptions of the agents and used radio buttons to indicate their response, choosing from the five main perceptual body parts (i.e., eyes, hands, nose, mouth, ears) and "*other*". If participants chose "*other*", they were prompted to leave a comment. This option was included because piloting showed that adults often (sensibly) said that the Blind agent "*could not*" "*see", "look",* etc. Indeed, every time participants chose "*other*", they specified in the comment that the Blind agent "*could not [verb]*".

2.1.3. Data coding and analysis

Children and adults' responses were coded in three main categories: "Canonical", "Cannot", and "Extension". Responses were coded as "Canonical" if the body part produced was the one that a typical agent would use to perform the action (e.g., eyes for "*see", "look", "glance"*, etc.; ears for "*listen*" and "*hear*"; mouth for "*taste"*, etc.). The two other response categories emerged from a preliminary review of the data. In "Cannot", participants said the agent "*could not* [verb]"; in "Extension" responses, they provided a different body part from the canonical one (e.g., hands or ears for the Blind agent to "*see*"). Note that whether a body part was "Canonical" depended on the verb, not the agent. Thus, the eyes were considered the "Canonical" body part for visual verbs even when referring to the Blind agent. Even though participants could choose more than one body part for a given verb-character pair (e.g., both hand and ears for "look" applied to the blind character), no one provided more than one response. On occasion, children said they did not know a verb; these responses were coded accordingly (percentage of "Word not known" responses in each age group: 4-year-olds 21.3%; 6-year-olds 11.2%; 9-year-olds 8%).

In this experiment and all others, our general analytic approach was to analyze the data using Bayesian mixed-effects logistic regressions (Gelman & Hill, 2006; Kruschke, 2011, 2018). The models were fit in R Stan with the brms package (Bürkner, 2017; Carpenter et al., 2017). We specified weakly informative, normally distributed priors N(0,10) on all fixed effects and intercepts. The Hamiltonian Monte Carlo (HMC) sampling adaptation parameter was set to $\Delta = 0.99$ to ensure convergence, assessed as a Rhat value not greater than 1 (Gelman & Rubin, 1992). The other options were left to brms default settings.

Adopting a Bayesian framework has some practical advantages: it is robust to small sample sizes, asymmetric distributions, and outliers. Moreover, since the estimated coefficients (β estimates) are centered around zero, their 95% highest density intervals (HDI) have a straightforward interpretation: according to the model, the coefficient value lies within the interval with 0.95 probability. Hence, if the interval does not contain zero, the probability of observing a given effect is $p < 0.05$. We report an effect to be significant when the 95% HDI intervals of the β estimates do not include zero (Kruschke, 2011, 2018). We provide in text the β estimate, 95% HDIs, and posterior predictive *p*-values for the relevant main effects and interactions. Further details on all models are reported as Supplementary Information.

In our specific analytic approach for Experiment 1, we fit 3 separate models, one for each agent (i.e., the participant him/herself, the Sighted agent, the Blind agent). All models included participants as random-effect and tested for an effect of age, modeled using effect coding (i.e., comparing each level of a categorical variable to the grand mean, equivalent to ANOVA; effect levels: 4, 6, 9, adults). The analyses for the Self model were intended to establish a baseline of which verbs the children knew, and hence would be good candidates for querying about the fictional agents. We assumed that a "Canonical" response for a verb when querying about participants themselves would establish that they knew that verb, allowing us to then move on to test those "known" verbs relative to the Sighted and Blind agents. The analyses for these two fictional agents were intended to probe participants' use of the "known" verbs as applied to agents with similar experiences to their own (Sighted agent) and different experiences (Blind agent). In these analyses, we again tested for effects of age, but also tested for effects of verb modality, modeled using either effect coding or Helmert coding (see below) focusing on how children treated visual verbs compared to tactile and auditory/gustatory/olfactory verbs for each agent.[2]

2.2. Results

2.2.1. Verbs of perception applied to the Self

In order to determine which of the 25 verbs were most familiar to the children (and adults), we coded responses binarily as "Canonical" vs. "Non-canonical" responses; for the latter, "Cannot", "Extensions", and "Word not known" responses were grouped together. The data were fit with a binomial logistic regression model that tested for an effect of age (effect coding, 4, 6, 9, adults vs. grand mean). Since we suspected that verb frequency would play a role in children's familiarity with the verbs, we also tested for an effect of verb frequency (standardized to mean = 0, SD = 1; shown in bottom panel of Fig. 1). Frequencies were the log10 per-million frequency of each verb in the 4 year-olds' corpora of the American and British parts of CHILDES, extracted using ChildFreq (Bååth, 2010; MacWhinney, 2014).

As can be seen in Fig. 1 (top panel), when queried about themselves, adults produced "Canonical" body parts on 97% of trials across all verbs (98% visual; 98% tactile; 96% other verbs), whereas children's responses varied significantly over verbs, with 15 verbs eliciting over 80% canonical responses by children of all ages (shown in the shaded panel). As we predicted, children's performance varied with verb frequency (main effect of frequency: β = 7.40, 95% HDI = [4.91, 10.33], $p < 0.0001$), with 4-year-olds knowing fewer verbs than the average and rarely answering with the "Canonical" body part (<20%) to the lowest frequency verbs (4-year-olds vs. age grand mean: β = −5.36, 95% HDI = [−8.25, −2.78], $p < 0.002$; interaction with frequency: β = −3.59, 95% HDI = [−6.55, −0.91], $p < 0.006$). These data show that children as young as 4 years of age know the canonical modality for a wide range of perception verbs across all five modalities as applied to their own perception. Our next question is whether and how their judgments will vary for the two fictional agents whose perception should be similar to their own (Sighted) or quite different (Blind).

2.2.2. Verbs of perception applied to fictional sighted and blind agents

Children's production of "Canonical" responses about the Self varied significantly with verb frequency, with the youngest children producing these responses less than 50% of the time for 10 of the lowest frequency verbs. Since our interest here was specifically in how children extend verbs to blind agents when they do know the modality as it applies to themselves, we limited further analyses of responses to the Sighted and Blind agents to those 15 verbs (5 visual, 5 tactile, 5 other modalities) for which at least 80% of the children in each age group provided the "Canonical" body part.[3] For each individual child, we further excluded verbs if that child did not provide the "Canonical" (i.e., correct) body part when asked about themselves, even if this verb met the 80% criterion for the group. Applying these criteria also eliminated all verbs for

[2] We tested item-wise models analyzing participants' responses to each visual verb applied to the blind agent (Experiment 1 and Experiment 2) and to each motion verb applied to the wheelchair-using agent (Experiment 2) but did not find significant differences among the age groups for specific verbs (see Supplementary Information for details on the item-wise analyses).

[3] Frequencies for the retained verbs only: CHILDES $\log_{10}$ mean = 2.03, SD = 1.03, range 0.48–3.79.

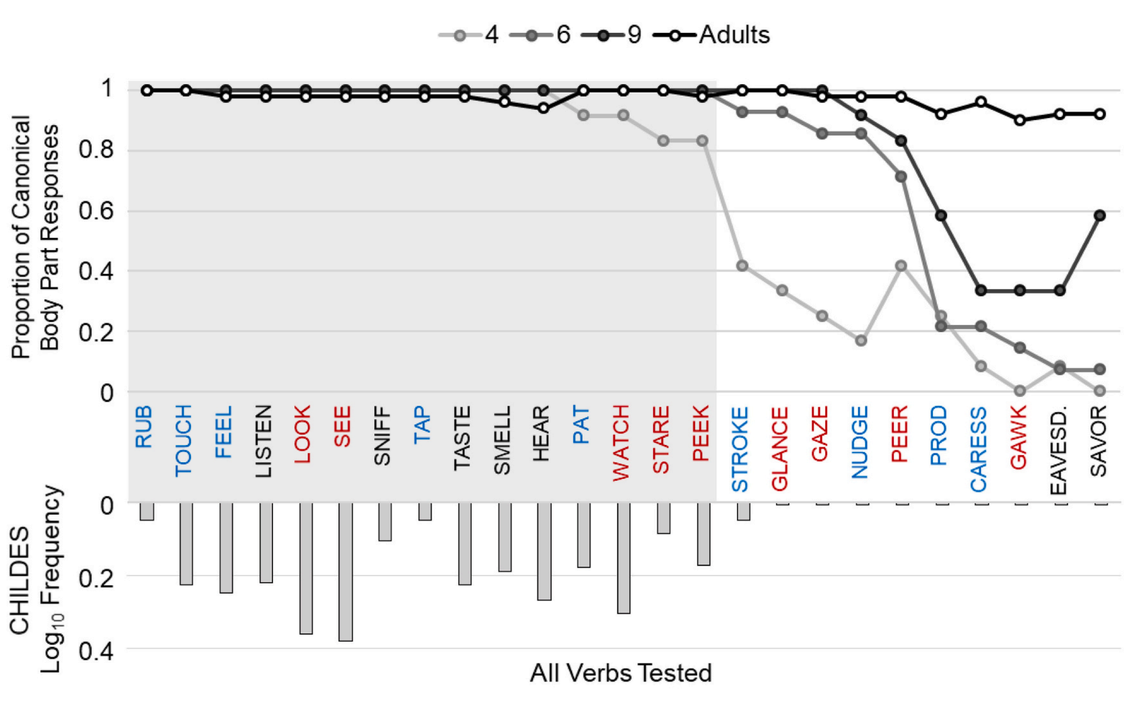

Fig. 1. Proportion of "Canonical" body part responses by verb for the Self condition (ordered according to increasing probability of canonical body part response among 6-year-olds). Red: visual verbs; blue: tactile verbs; black: auditory/gustatory/olfactory verbs. The bars below the chart indicate each verb's CHILDES per-million $\log_{10}$ frequencies (mean = 1.5, SD = 0.87, range 0–3.79). The shaded area highlights the verbs for which at least 80% of 4-year-old children provided the "Canonical" body part response. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

which children explicitly said they did not know the word.

The responses to each fictional agent were separately modeled using multinomial logistic regressions fit to the "Canonical", "Cannot", and "Extension" responses. Both models tested for an effect of age as well as an effect of verb modality. For the Sighted agent model, given our findings for the Self model, we expected participants to respond with similar numbers of "Canonical" body parts for the different modalities. We therefore used effect coding, which tests the effect of verb modality by comparing responses in each of the modality categories (Visual, Tactile, Other) to the mean of all categories.

For the Blind agent model, our main question was whether visual verbs differed from non-visual verbs, but we also wanted to know whether there were differences among the non-visual verbs. For example, people might treat tactile verbs for a Blind agent differently from auditory, gustatory, or olfactory verbs. We therefore evaluated the effect of verb modality using Helmert coding, which compares each level of a categorical variable to the mean of the subsequent levels (Jaeger, 2008). We first compared the responses for tactile verbs to those for other non-visual verbs (auditory, olfactory, gustatory); then, we compared the mean of all non-visual verbs to the visual verbs.

For the Sighted agent, both children and adults produced "Canonical" body parts at ceiling levels for the 15 perception verbs (4-year-olds: 99.3%; 6- and 9-year-olds: 100%; adults: 98.3%), with no effects of age or verb modality, nor interactions between the two. Data for the visual verbs only are shown in Fig. 2 (leftmost panel). These data show that even young children can readily judge the modality of the target

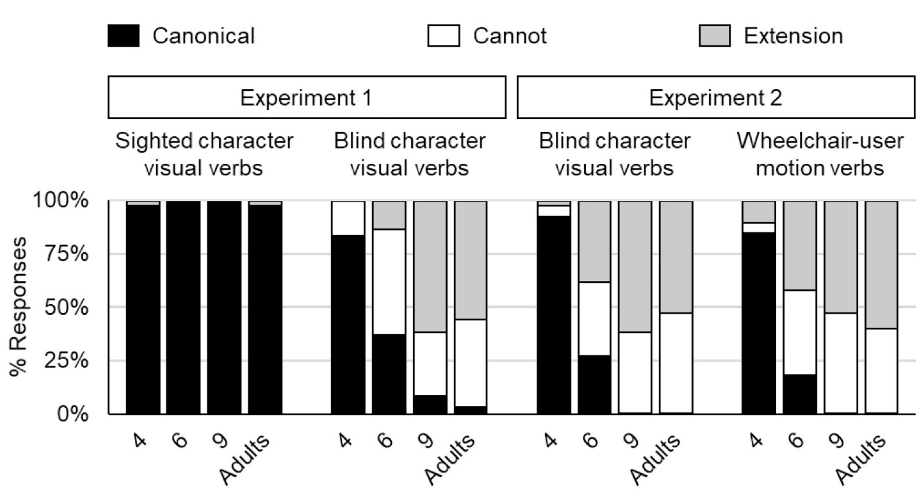

Fig. 2. Left two panels: Experiment 1. Percentage of response types produced by children and adults when queried about visual verbs applied to the Sighted and Blind agents. Right two panels: Experiment 2. Percentage of response types produced by children and adults when queried about visual verbs for the Blind agent and motion verbs for the Wheelchair agent.

perception verbs when applied to a sighted fictional agent.

By contrast, the responses for the Blind agent varied over both age and verb modality. Across all *non-visual verbs* (not shown in Figures), both adults and children produced "Canonical" body parts at ceiling levels (4-year-olds: 94%; 6-year-olds: 100%; 9-year-olds: 92.5%; adults: 98%), showing that they knew which body part would be used by a Blind agent for tactile, auditory, gustatory, and olfactory verbs. However, as shown in Fig. 2 (second panel from left), responses for *visual verbs* varied strikingly over age. Four-year-olds largely continued to produce "Canonical" responses for these verbs, saying that the Blind agent would use the eyes (84%; "Canonical" responses interaction 4-year-olds vs. age grand mean by all non-visual vs. visual verbs: $\beta = 11.19$, 95% HDI = [3.62, 19.66], $p < 0.02$). Older children and adults were significantly less likely to provide these "Canonical" (i.e., eyes) responses (6-year-olds: 37%; 9-year-olds: 8%; adults: 3%; main effect of "Canonical" responses for non-visual vs. visual verbs: $\beta = -24.93$, 95% HDI = [−33.07, −18.03], $p < 0.001$). Moreover, while older children and adults often responded with "Extensions" for the visual verbs (i.e., saying the Blind agent would use her hands/ears; 4-year-olds 0%, 6-year-olds: 13%; 9-year-olds: 60%; adults: 56%), 4-year-olds never extended the visual verbs ("Extension" responses interaction 4-year-olds vs. age grand mean by all non-visual vs. visual verbs: $\beta = -16.2$, 95% HDI = [−26.74, −6.31], $p < 0.002$).

2.3. Discussion

The early modality-specific restriction of the visual verbs among 4-year-olds when judging the blind agent was particularly striking in view of the children's apparent understanding – at least according to their report – that the blind agent's "*eyes don't work*". Children quickly picked up on this fact about this agent, often interrupting us to say, *"Yes I know, her eyes don't work"*, then immediately judging that this agent would "*see with her eyes*". The children's apparent understanding of the blind agent's visual status is consistent with previous work showing that preschoolers have some understanding of how children with disabilities, including visual impairments, differ from typically developing children (Diamond & Hestenes, 1996; Diamond, Hestenes, Carpenter, & Innes, 1997). Children correctly judge that blind agents are more likely to have difficulty with activities requiring vision than activities requiring movement or hearing (Diamond et al., 1997; Diamond & Hestenes, 1996). Yet the difference between this state of understanding and the children's judgments about how the blind agent would "*see*" suggests a striking dissociation between their understanding of what the eyes actually do (or fail to do, in blind agents) and their inability to combine this understanding with the meanings for visual verbs.

The results from Experiment 1 suggest that 4-year-old children do not modulate their interpretation of visual perception verbs according to the perceptual capabilities of the agent. Even when an agent's eyes "*don't work*" children continue to say that the agent would "*see*" with their eyes. Thus, children respond as though the agent were sighted with their eyes open, failing to integrate visual verb meanings with the blind agent's actual capabilities (e.g., by interpreting looking as applying to the hands or ears). Is this failure specific to perception verbs? If not, 4-year-old children might have more general difficulty integrating the verb modality with their understanding of the sensory/physical capabilities of the agent to which the verb is being applied. If the latter, then the apparent restriction in verb meaning should generalize beyond the domain of visual verbs. To distinguish between these possibilities, in Experiment 2 we asked children to make judgments about three different agents —Sighted, Blind, and Wheelchair user, whose legs "*don't work*". Children were queried again about visual and non-visual perception verbs, and about motion verbs, e.g., *"run", "hop"*, etc. If children have difficulty integrating verb modality and agent capabilities, they should similarly fail to modulate their interpretation of leg-related motion verbs according to the motor capabilities of the agent (i.e., whether or not they are a Wheelchair user). In Experiment 2, we also enriched our presentation of the fictional agents by using video-taped introductions of a Sighted agent, a Blind agent, and an agent in a Wheelchair. This modification was intended to help children more fully encode information about the agents.

3. Experiment 2

3.1. Methods

3.1.1. Participants

In Experiment 2 we tested a new group of participants consisting of twelve 4-year-olds (7 girls; mean age = 4;6, range = 4–4;10), twelve 6-year-olds (9 girls; mean age = 6;7, range = 6–6;11), twelve 9-year-olds (5 girls; mean age = 9;6, range = 9;1–9;11), and twelve adults (7 women; mean age = 20). Children received a toy as compensation for participating and adults, who were undergraduates recruited on the Johns Hopkins University campus, received class credit. The parents/legal guardians provided their written consent, and the children gave their oral assent to participate. The experimental protocol was approved by the Johns Hopkins Homewood Institutional Review Board.

3.1.2. Design, stimuli, and procedure

The experimental design, stimuli, and procedure were the same as in Experiment 1, with the following exceptions. First, there were three agents, a Sighted agent, a congenitally Blind agent, and an agent (who was sighted) in a Wheelchair. Each agent was portrayed by a woman who introduced herself in a video telling a brief story and giving examples of everyday activities that exemplified what was special about her (see Fig. 3 and Table 3; the introductory videos are provided as Supplementary Information). A still frame of each fictional agent remained visible to participants after the introduction. Stimuli included 20 verbs: the same ($N = 15$) perception verbs that were fully analyzed in Experiment 1 plus 5 manner of motion verbs whose meanings involved leg movement (*"hop", "jump", "run", "skip", "walk*"; hereafter "motion verbs"). The motion verbs were added to test whether young children would show a similar pattern of responding for the Wheelchair agent/motion verbs as they did for the Blind agent/visual verbs, i.e., whether they would say she uses her legs to "*run", "hop*", etc., even though they were told that her *"legs don't work"*. Each participant was queried on each verb once for each of the three fictional agents.

As in Experiment 1, there was a brief warm-up in which children were asked which body part they themselves would use to "*see", "feel", "hear", "taste", and "smell*". They were also queried on "*kick*" as pre-training for the motion verbs. After the warm-up, each agent was introduced with a video to the participants, who were then asked which body part (eyes, ears, hands, nose, mouth or legs, offered as possible answers on every trial in a random order) they would use "*to* [verb]" for each of the perception and motion verbs. Participants were always queried first for the Sighted agent while looking at her picture. The entire procedure was then repeated for both the Blind and the Wheelchair agents, in counterbalanced order across participants. Children were reminded of each agent's special characteristic after every 4 verbs. As in Experiment 1, the children quickly picked up on the idea of what was special about each agent (including that one had eyes that "*don't work*" and one had legs that "*don't work*").

3.1.3. Coding and analyses

Children's and adults' responses were coded as in Experiment 1 ("Canonical", "Cannot", "Extensions"). Children never reported not knowing any of the queried verbs.

We analyzed the data using Bayesian mixed-effects logistic regressions in R as in Experiment 1. We tested 3 separate logistic regression models, one for each fictional agent. All models included participants as random-effect and tested the effect of age (effect coding, comparing each group to the grand mean: 4, 6, 9, adults) and verb modality, with the latter coding varying according to agent type, as

Fig. 3. Picture of the three fictional agents from the introductory video. From left to right: Sighted agent, Blind agent, and Wheelchair agent. The introductory videos are provided as Supplementary Information.

Table 3
Sighted, Blind and Wheelchair agents' descriptions, narrated by the individuals in the videos. Critical information about the agents appears in italics.

Jenny – Sighted agent
Hi, I'm Jenny.
I live in a small house near the sea. I like cooking, and I bake yummy cupcakes. I have a bunny named Puff, who eats a lot of carrots.
There's something special about me: I'm from Japan, and I can speak Japanese. I was born there, and I started to learn Japanese when I was a baby.
I love to go out for a jog in the morning. *I run almost every day* in the park, that's how I exercise.
This is my favorite book, and it's written in Japanese. These symbols are letters [pointing]. I read from top to bottom, and right to left [moving fingertip along the sentence]. See? This is how I read!
Lisa – Blind agent
Hi, I'm Lisa.
I live in the city in an apartment downtown. I like music and I know how to play the guitar. I have a cat whose name is Snowball, and he spends most of the day sleeping.
There's something special about me: I'm blind and my eyes don't work. I was born blind and my eyes never worked, not even when I was a baby.
I use a white cane when I walk around. When walking, I sweep my cane from side to side, like this, to find out if there's anything in my way [demonstrating cane use]. That's how I get around!
This is my favorite book. It is written in Braille. These raised dots here are letters, and I use my fingers to read. I pass my fingers over the dots, like this [passing finger over Braille]. See? This is how I read!
Sarah – Wheelchair agent
Hi, I'm Sarah!
I live in a farm in the countryside. I like playing outside and I know a lot about plants. I have a big dog whose name is Jack, and he runs and barks a lot.
There is something special about me: I'm in a wheelchair and my legs don't work. I was born this way, and my legs never worked, not even when I was a baby.
I use my arms and hands to move my wheelchair. I put my hands on the wheels, and I move my arms forwards and backwards, like this [demonstrating wheelchair use]. You see? This is how I get around!
This is my favorite book. It's about magic, and *it's written in English* [showing book's page].

discussed below.

3.2. Results

3.2.1. Sighted agent

As expected, there were no "Cannot" responses for the Sighted agent (i.e., no one said the sighted agent "*cannot [verb]*" for any tested verb). Since the data for this agent were effectively binary ("Canonical" or "Extensions"), we analyzed them using a binomial logistic regression model. As in Experiment 1, this model tested for an effect of age (effect coding) as well as for the effect of verb modality by comparing each verb category to the grand mean (effect coding). This was done because, based on the results of Experiment 1, we did not expect significant differences in how verbs of different modalities were applied to this agent. Results showed that both children and adults produced the "Canonical" body parts for all verbs at ceiling levels (adults: 100%; children: >98%), although 4-year-olds did so less often (>93%; 4-year-olds vs. age grand mean: $\beta = -14.13$, 95% HDI = $[-24.27, -5.73]$, $p < 0.003$). These results showed that, as we found in Experiment 1, even the youngest children could extend the queried verbs to a fictional sighted character.

3.2.2. Blind agent

For the Blind agent, participants produced all three types of responses ("Canonical", "Cannot", "Extension"). These responses were thus analyzed with a multinomial logistic regression model paralleling the one we used in Experiment 1, evaluating the effect of age (effect coding) and the effect of verb modality first among non-visual verbs (tactile vs. auditory/gustatory/olfactory, then the mean of all these vs. motion verbs), and then comparing the mean of all the non-visual verbs to that of the visual verbs (Helmert coding).

As in Experiment 1, responses for the Blind agent varied significantly across both age and verb modality. For the non-visual perception and motion verbs, adults and children in all age groups consistently produced the "Canonical" body parts at ceiling levels (4-year-olds: 99%; 6-, 9-year-olds, adults: 100%). However, responses for the visual verbs varied significantly over age (see Fig. 2, Experiment 2, left panel). Four-year-olds overwhelmingly produced the "Canonical" body part for the visual verbs, saying that the Blind agent would use her eyes (93%; shown by an interaction of 4-year-olds vs. age grand mean by all non-visual vs. visual verbs: $\beta = 15.06$, 95% HDI = $[5.11, 25.33]$, $p < 0.007$). "Canonical" responses for the visual verbs were otherwise infrequent (6-year-olds: 27%; none by 9-year-olds and adults; main effect of visual vs. non-visual verbs: $\beta = -29.35$, 95% HDI = $[-39.13, -20.15]$, $p < 0.002$), Other common responses among the participants were that the Blind agent "Cannot" "*look", "see"*, etc. (4-year-olds: 5%; 6-year-olds: 35%; 9-year-olds: 38%; adults: 47%) and "Extensions" to the hands/ears, or even the cane (4-year-olds: 2%; 6-year-olds: 38%; 9-year-olds: 62%; adults: 53%). The overall pattern of responses for the Blind agent was remarkably similar to that from Experiment 1, providing a replication of the basic finding that 4-year-olds respond with "eyes" for the Blind agent and visual verbs, and that this pattern declines over age, replaced with "Cannot" or "Extensions".

3.2.3. Wheelchair agent

The responses for the Wheelchair agent (also coded as "Canonical", "Cannot", and "Extension") were analyzed with a multinomial logistic regression model similar to the one fit to the Blind agent. This model, too, tested for an effect of age (effect coding) and an effect of verb modality (Helmert coding), this time using the motion verbs as the critical modality to be compared with other modalities. Thus, this model first tested the effect of modality among the three categories of perception verbs (visual, tactile, auditory/gustatory/olfactory), and then compared the mean of all these perception verbs to that of the motion verbs.

The pattern of responses for the motion verbs applied to the Wheelchair agent was parallel to the one observed for the visual verbs applied to the Blind agent (Fig. 2, Experiment 2, right panel). For the Wheelchair agent, adults and children of all ages correctly produced the "Canonical" body part for all perception verbs (4-year-olds:97%; 6- and 9-year-olds: 99%; adults: 100%). However, responses for the motion verbs varied over age. Only 4-year-olds consistently produced the "Canonical" body part (i.e., the legs) for the motion verbs (85%; interaction 4-year-olds vs. age grand mean by perception vs. motion: $\beta = 14.14$, 95% HDI = [4.48, 23.77], $p < 0.008$), whereas older children and adults almost never did (6-year-olds: 18%; none for 9-year-olds and adults; main effect of "Canonical" responses for motion vs. perception verbs: $\beta = -26.58$, 95% HDI = [−35.69, −18.34], $p < 0.002$). The more common responses for older children and adults were either that the Wheelchair agent "Cannot" "*walk", "jump",* etc. (4-year-olds: 5%; 6-year-olds: 40%; 6-year-olds: 47%; adults: 40%) or that she used hands or the wheelchair to carry out these actions, i.e., "Extensions" (4-year-olds: 10%; 6-year-olds: 42%; 6-year-olds: 53%; adults: 60%).

3.3. Discussion

The results of Experiment 2 replicated and extended the findings of Experiment 1. Four-year-old children again said that the Blind agent would use her eyes to "*see", "look",* etc., despite affirming during the experiment that her eyes "*do not work*". They also said that the Wheelchair agent would use her legs to "*run", "jump",* etc., despite acknowledging during the procedure that she had legs that "*do not work*". This suggests that young children's difficulties in applying visual verbs to a blind person were not specific to the case of visual verbs and blindness, as the same pattern emerged when children were asked to apply motion verbs to the Wheelchair agent. Six- and 9-year-old children often judged that the Blind agent "Cannot" "*see", "look",* etc., and that the Wheelchair agent "Cannot" "*run", "jump",* etc. They also provided "Extensions" of visual and motion verbs, saying that the agents could use either other body parts (i.e., hands) or their cane/wheelchair – special tools owned only by the Blind and Wheelchair agents, respectively, which could have represented a better proxy for perceiving/moving than other body parts.

In Experiments 1 and 2, we focused on children's knowledge of the modality-specific aspect of visual verbs' meanings, and their ability to combine these elements of meaning with a representation of non-canonical (i.e., blind, wheelchair user) agents. The data show definite limits in young children's understanding of what modality should be used by a blind agent to "*look", "see*", etc. But do these limits also extend to young children's understanding of other semantic components of visual verbs that do not involve modality per se when these verbs are applied to a non-canonical agent? In Experiment 3, we pursue this question by asking whether young children understand the distinction between active and stative visual verbs ("*look*" vs. "*see*") as applied to a Sighted and Blind agent.

In Experiment 3, we presented children with photographs of Blind and Sighted agents pointing their heads (and eyes) in the direction of objects and asked them to evaluate whether the agents were *looking* and whether they did *see* the objects in their direct line of sight. Experiment 3 tested children's application of "visual" verbs to non-canonical (blind) agents in a paradigm where they were not required to produce a body part or give a "cannot" response. Will children endorse the idea that a blind person is *seeing* or *looking* when they are not in physical contact with an object?

Given young children's limits in understanding the modality of visual verbs as applied to a Blind agent, one possibility is that they would also fail to appreciate the distinction between *looking* and *seeing* when these verbs are applied to agents who are blind. As we discussed in the introduction, the meaning of the verb *look* entails that one direct one's eyes in order to perceive through vision, whereas *see* entails that one achieves a mental state in which visual perception has occurred. If 4-year-olds fail to appreciate this distinction, they should be equally likely to endorse that a Blind agent (as well as a Sighted one) is *looking* and *seeing* an object if their eyes are directed towards it. Alternatively, since the active/stative distinction does not interact with the agents' perceptual capacities, we might expect children to endorse the statement that a blind agent whose eyes are directed towards an object is *looking* more so than *seeing*, even though overall they endorse both of these more so than older children and adults. If so, this would provide further evidence for the specificity of the originally observed effect: that children are having trouble combining the modality-specific aspect of the verb's meaning with the agent's capabilities.

Finally, Experiment 3 also tested children's ability to reason about blindfolded agents as a control. We predicted that although 4-year-old children would endorse that a blind person is *looking* and *seeing* when their gaze is directed towards an object, they would not do so for a sighted agent wearing a blindfold. Previous studies suggest that children are able to reason about occlusion quite early on, inferring that an agent whose vision is obstructed does not gain knowledge based on their visual experience (e.g., Brooks & Meltzoff, 2007). We therefore predicted that children's inability to integrate the semantics of the verb would be specific to blind agents.

4. Experiment 3

4.1. Methods

4.1.1. Participants

This task was carried out directly after Experiment 2, with the same participants (children aged 4 to 9 and adults) completing both experiments. Thus, participants were already familiar with both the experimenter and the fictional agents.

4.1.2. Design, stimuli, and procedure

Our main question was whether participants would judge the Sighted and Blind agents to be "*looking*" and to "*see*" two toys when they were directly in the agents' line of sight. To illustrate this situation, we created six pictures including the Blind and Sighted agents from Experiment 2 (see Fig. 4 and Supplementary Fig. 1). In each picture, two agents seated at a small table and positioned their head/eyes so that the toys (called "daxes") were in their direct line of sight.

Three pictures showed the Blind and one of the Sighted agents with their hands in their laps (i.e., not touching the toys; one shown in Panel A of Fig. 4, two shown in Supplementary Fig. 1) and one picture showed them with their hands touching the toy (Panel B of Fig. 4). This manipulation of not touching vs. touching the objects was designed to determine whether *looking* and *seeing* would be accepted more often for the Blind agent when she was touching the objects.

Two more pictures (one shown as example in Panel C of Fig. 4) were used to assess whether children understood that a sighted person who was temporarily unable to use her eyes due to a familiar occluder —a blindfold— could not be said to either "*look*" or "*see*". Each of the two pictures showed the Sighted and Wheelchair agents, both seated at the small table with the toys resting on it, and the angle of their heads tilted to show that the toys were potentially in their line of sight. In each picture, one of the agents was blindfolded, thus effectively preventing any vision.

The six pictures were shown to the participants one at a time, in one of two fixed orders. The two blindfold pictures (one shown as example in Panel C of Fig. 4) were always shown last. For each picture, the participants were first reminded of the agents' special features (e.g., "*Look, here are Lisa the blind girl and Sarah in the wheelchair…*"). Then they were asked the two critical questions for each agent, i.e., "*Right now, is [agent] looking at the daxes?", "Does she see the daxes?"*. The combination of six pictures, two agents and two queries resulted in a total of 24 yes/no queries.

Immediately after these critical questions, for each picture and agent,

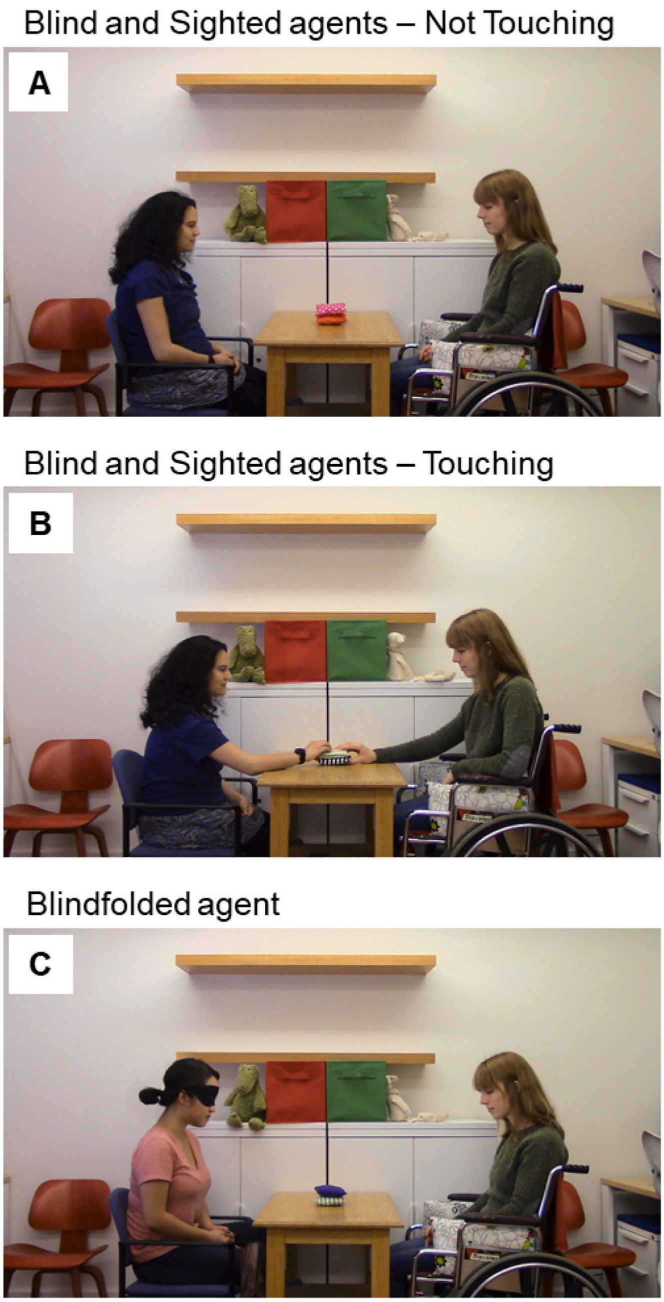

Fig. 4. Picture stimuli used in Experiment 3. Panels A and B: Pictures showing the Blind and Sighted agents, both of whom had their eyes directed towards the target objects and their hands either in their laps (A – Not Touching condition) or on the objects (B – Touching condition). Panel C: one of the two blindfold pictures with two sighted characters (one blindfolded) pointing their eyes towards the target.

participants were asked two control questions using the verbs "*touch*" and "*feel*", i.e., "*Right now, is [agent] touching the daxes?*" and "*Does she feel the daxes?*", for a total of 24 questions. Every participant answered all of these questions correctly across the pictures, i.e., saying that the agents were touching and could feel the objects only when their hands were resting on them.

Before starting the task, the experimenter explained to the participants that she would show them pictures of the agents and a pair of objects and ask them questions about what the agents were doing. The participants were then given three warm-up trials featuring pictures of two agents who were either engaged or not engaged in activities other than perception (e.g., talking on the phone, drinking a cup of tea, brushing her hair). For each agent, participants were asked "*Is [agent] (doing the activity)?*". All participants answered these correctly.

4.1.3. *Coding and analyses*

Participants' responses were coded binarily (yes = 1, no = 0) and analyzed using binomial mixed-effects logistic regression, as in the previous experiments. We tested two separate models: one on the blindfold trials, and one on the responses to the blind agent. All models included participants as random effect and age as fixed effect (effect coding comparing each group to the grand mean, unless otherwise noted).

4.2. *Results*

4.2.1. *Do children think that a blindfolded agent can "see"?*

All participants endorsed that the Sighted non-blindfolded agents were both *looking* and did *see* 100% of the time. By contrast, only one 6-year-old affirmed that the blindfolded agent was *looking* (8% "yes" responses; all other age groups: 0%) and no child endorsed *seeing* for the blindfolded agent (0% "yes" responses in all age groups; Blindfold vs No-blindfold: $\beta = 42.63$, 95% HPD = [31.88, 54.23], $p < 0.001$). Children thus had no difficulties in judging the visual experience of a blindfolded person, confirming that they have no issues with a temporary lack of vision nor a yes/no bias.

4.2.2. *Are the blind agents looking? Do they see?*

All participants except for one 6-year-old child said that both Sighted agents were *looking* and did *see* (6-year-old "yes" responses: "looking" 98%, "see" 94%; all other age groups were 100% for both verbs).[4] Therefore, we focused our analyses by modeling the responses to the Blind agent in isolation. This model tested for an effect of age, an effect of verb prompt (look vs. see), and an effect of tactile access (not touching vs. touching). Since we had specific predictions about the effect of age on the responses for the Blind agent (i.e., that younger children, and especially 4-year-olds, would be more likely to say the Blind agent was *looking* and did *see*), in this analysis age groups were compared to each other in turn, rather than against the grand mean as in the previous models (Helmert coding: 4- vs 6-year-olds; 4- and 6- vs. 9-years old; all children vs. adults).

As Fig. 5 shows, the responses for the Blind agent varied over age and echoed the developmental pattern observed in Experiments 1 and 2. In the no-touch condition, most of the 4-year-olds said that the Blind agent was *looking* and did *see* (yes response *look* 89%; *see* 72%). By contrast, 6-year-olds were much less likely to respond "yes" to either *looking* or *seeing* (yes response *look* 42%, *see* 11%) and 9-year-olds almost never endorsed either (yes response *look* 8%, *see* 0%). The probability of saying that the Blind agent was *looking* at and did *see* the objects in front of her was significantly greater for 4- than 6- and 9-year-olds (4- vs. 6-year-olds: $\beta = -9.17$, 95% HDI = [−14.91, −3.45], $p < 0.001$ 4- and 6- vs. 9-year-olds: $\beta = -14.23$, 95% HDI = [−22.91, −5.66], $p < 0.002$).

Despite the fact that 4-year-olds were more likely to affirm both *looking* and *seeing* for the Blind agent, participants in all age groups agreed more often that the Blind agent was *looking at* the objects than that she did *see* them (look vs. see: $\beta = 6.46$, 95% HDI = [3.14, 9.86], p < 0.001; interactions with age all Ps > 0.05). We ran a follow-up model on the 4-year-olds' data alone to assess whether they, in particular, distinguished between active/stative verbs, despite endorsing both "look" and "see" as applied to the Blind agent at high rates, or whether only older children and adults were more likely to say "look" than "see". This analysis confirmed that 4-year-olds were more willing to say the Blind agent was looking than that she did see (look vs. see: $\beta = 4.8$, 95%

[4] A model testing for a fixed effect of age as well as type of fictional agent (Helmert coding: Sighted control agent vs. Wheelchair agent; the two Sighted agents vs. Blind agent) is provided as Supplementary Information.

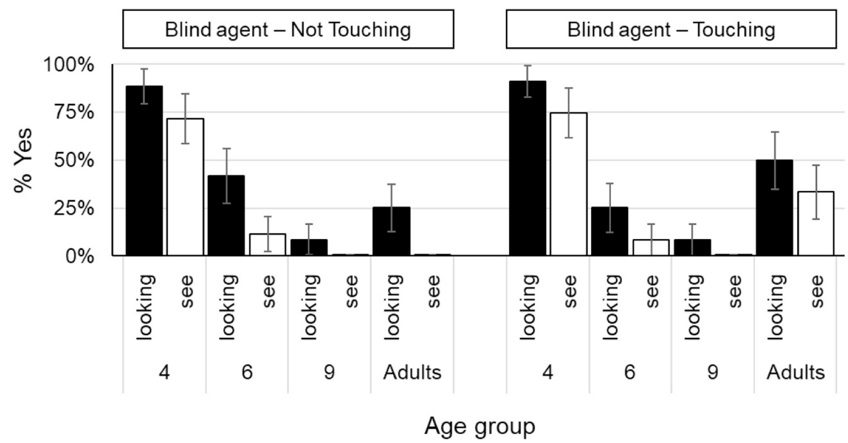

Fig. 5. Percentage of responses for the Blind agent to "Is she looking at the daxes?" (black) and "Does she see the daxes?" (white) for trials in which the agent is not touching (left panel) vs. touching (right panel) the objects. Error bars: standard error.

HDI = [1.02, 10], p < 0.001), suggesting that the active/stative distinction for visual verbs is already part of the lexicon by age 4.

Finally, although there was no main effect of tactile access, we found that adults were more likely than children to concur that the Blind agent was *looking* and did *see* the objects if she had tactile perceptual access (children vs. adults by touching vs. no touching: $\beta = 5.79$, 95% HDI = [0.16, 12.14], $p < 0.02$). Specifically, when the Blind agent was not touching the objects (Fig. 4 panel A) 25% of the adults said she was *looking* at the objects, but no one said she did *see* them. By contrast, when the Blind agent was touching the objects (Fig. 4 panel B), 50% of the adults said she was *looking* at the objects and 33% also said that she did *see* them. This pattern among adults is consistent with our previous findings suggesting that adults can readily apply visual verbs to blind agents, especially if they are using their hands to, e.g., *look* or *see*.

4.3. Discussion

Experiment 3 revealed several important results about how children interpret "*look*" and "*see*". First, 4-year-olds were far more likely than older children to say that a blind person *look*s and *sees* when an object is in their "line of sight", irrespective of whether the blind agent has physical contact with the object. By contrast, adults are more likely to concur that the Blind agent was *looking* and could *see* if she was touching the objects, suggesting that they were extending the modality of the visual verbs to the haptic modality, as they had in our previous experiments. The older children in the current study did not show evidence of extension, instead denying that the Blind agent was looking or seeing, whether or not she had physical contact with the object. These results are in line with the findings from Experiment 1 and 2, suggesting that the developmental changes in combining modality-specific aspect of visual verb meaning with agent capabilities between the age of 4 and 9 are robust and replicable across tasks.

Experiment 3 also finds that, in the very same task where 4-year-olds endorse that a Blind agent is *looking* and *seeing*, children of all ages uniformly deny that a blindfolded agent is either *looking* or *seeing*. This result suggests that the developmental changes observed are specific to combining the modality of the verb with an agent's capabilities. They do not generalize to occlusion of a sighted agent's eyes.

Finally, although 4-year-olds endorse *looking* (active) and *seeing* (stative) at high rates for blind agents, they are more likely to endorse *looking* than *seeing*. Thus, the way children and adults interpret "*look*" and "*see*" when applied to a Blind agent's perceptual experience preserves the difference between the active and stative meanings of these verbs. This distinction is controlled by children as young as 4 years of age.

5. General discussion

We found that children as young as 4 years of age know the modality typically associated with at least 15 different perception verbs, including verbs of all five modalities, as long as they were applied to canonical agents (i.e., the child him/herself or another sighted agent). That is, when asked what part of the body they themselves or a sighted adult would use to carry out acts of perception, all children correctly said, "*the eyes*" for visual verbs, "*the hands*" for tactile verbs, and so on for all modalities. Thus, young children know the canonical modality of common verbs corresponding to each of the modalities (e.g., "*look*", "*touch*", "*listen*", "*taste*", "*smell*") as well as those for less common verbs (e.g., "*peek*", "*sniff*") and their meanings of perception verbs accord with those stipulated by linguists and psycholinguists (Jackendoff, 1983, 1992; Levin, 1993; Miller & Johnson-Laird, 1976). This ceiling performance suggests that the canonical modalities of perception verbs is an early component of meaning that is mastered by young children.

We also found that the active/stative distinction is already present at age 4 and holds stable over development as children of all ages, as well as adults, were more likely to say that a blind agent was *looking* than that she did *see*. The asymmetry between *looking* and *seeing* indicates that even when applying visual verbs to non-canonical agents, the youngest children control the semantic distinction between active vs. stative forms.

In light of these early successes, areas of protracted development are even more striking: the ability to modify the modality interpretation of visual verbs as they are applied to blind agents develops slowly between 4- and 9 years of age. In contrast to adults and older children, 4-year-olds maintained that a blind person would use her eyes "*to see*" and "*to look*", even though they were instructed and explicitly offered that the blind agent's eyes "*don't work*". Moreover, despite being more likely to accept that the blind agent was *looking* than that she did *see,* more than two-thirds of the 4-year-olds still accepted both terms, even when the blind agent had no physical contact with the object.

This pattern continued to change significantly between 6 and 9 years of age. Unlike the 4-year-olds, 6-year-olds tended to answer that a blind person "*cannot [visual verb]*" and were overall less likely to accept that the blind agent was *looking* and did *see,* thus still adhering to the modality-specific (visual) meaning, but judging that if the eyes don't work, then the person simply cannot *look* or *see*. Between 6 and 9 years of age, children show signs of broadening their usage of the visual verbs and, like adults, they begin to answer that the blind agent could *look, see,* etc., using other parts of her body – for example, the hands or ears or even a cane. Six-year-olds in particular appeared to prefer the "cane" to the hands and ears, possibly showing reluctance to apply the visual verbs to body-parts which already have their own verbs (i.e., "*touch/feel*", "*listen/hear*").

Why do young children fail to apply visual verbs to blind agents in adultlike ways, despite having the modality and the active/stative aspects of verb meaning in place? By the age of 4, children have a large vocabulary and, as the findings from Experiment 1 and 2 show, they know the modality of several perception verbs and correctly use them in reference to canonical agents, suggesting that their failure with atypical agents does not depend on their general language knowledge (Bretherton & Beeghly, 1982; Davis & Landau, 2020, 2021; Frank et al., 2017). One possibility is that the failure stems from children's still developing capacity to reason explicitly about mental states. The transition from failing to passing classic false-belief tasks occurs in this age-range (Wellman, 1990; Wellman, Cross, & Watson, 2001; Wellman & Liu, 2004). Several aspects of the present data and prior evidence suggest that development of mentalizing capacities is not the limiting factor on children's application of "visual" verbs to blind agents. First, children correctly denied that a blindfolded agent was either "*looking at/seeing the dax*", suggesting that they understand how looking leads to knowing. This observation is consistent with prior evidence that the ability to understand occlusion develops in early infancy. Infants as young as 9–12 months already understand the importance of the eyes for seeing, and that eye closure or blindfolding disrupt vision (Brooks & Meltzoff, 2007). Two- and 3-year-olds already know some crucial facts about vision and make inferences about another person's knowledge based on their visual experience (e.g., whether she looked into a box or not; O'Neill, Astington, & Flavell, 1992; Pillow, 1993; Flavell, 2004; Teufel, Clayton, & Russell, 2013; inter alia).

Sighted children's understanding might be limited to a temporary loss of vision (i.e., blindfolding) – which they can relate to – whereas the consequences of a pervasive, permanent inability to see are beyond their imagination. Yet, when we explicitly asked whether the sighted and blind characters were *looking* and did *see* the objects in front of them in that specific moment (e.g., "*Right now, is Lisa looking at the daxes?*"), a question that in principle does not require understanding what it means to never being able to see, 4-year-olds still failed to recognize that a blind agent could not *look* and *see*, at least in the strictly visual sense of the verbs. These findings suggest that immature understanding of how seeing leads to knowing is an unlikely explanation of the current results.

Even more compelling is the fact that 4-year-old children's failures are not limited to verbs of perception, which require reasoning about mental and perceptual states. When we queried young children about the application of manner of motion verbs (e.g., "*walk", "jump"*) to a person whose "*legs don't work*" and hence uses a wheelchair, we found the same pattern and developmental changes. Four-year-olds responded that the agent in a wheelchair would [motion verb] by using her legs, 6-year-olds said she "cannot" or, as with the case of visual verbs, extended the motion verbs to the hands or wheelchair, as also shown by 9-year-olds and adults. This striking replication and extension to the wheelchair agent suggest that the children's responses to visual verbs were not specific to reasoning about perception or blindness and its consequences. Rather, 4-year-old children have general difficulties in applying their lexical entries to atypical agents whose capabilities violates the verbs' canonical modality requirements (i.e., using the eyes or legs). Since 4-year-olds are unable to apply leg-related motion verbs to wheelchair using agents in adult-like ways, their failure is unlikely to be caused by late maturing of mental state reasoning.

Another possibility is that children of this age lack an understanding of disabilities sufficient to arrive at appropriate inferences. Prior evidence suggests that by age 4 children already have some understanding of what disabilities are and how they affect an agent's ability to engage in particular actions (Diamond et al., 1997; Diamond & Hestenes, 1996; Huckstadt & Shutts, 2014; Nabors, 1996; Nabors, 1997; Scheepstra, Nakken, & Pijl, 1999). For example, when asked to decide what kinds of tasks different disabled agents might have trouble with (agents who are blind, hard of hearing or have a motor impairment), preschoolers judge that blind agents will have more trouble with visual than auditory tasks (Diamond & Hestenes, 1996). Three- to 6-year-old children have been reported to spontaneously comment on the impairments of disabled agents, making remarks on how these made them different and could limit their activities, and expressing the desire to help them (Diamond & Hestenes, 1996; Nabors, 1997). There is nevertheless also evidence that some reasoning about disabilities is not adult-like at this age. For example, children negatively judge the behavior of a blind agent when they violate the rules of a game by touching objects inside a box (Huckstadt & Shutts, 2014). In the current study, children received explanations and reminders of disabilities throughout the tasks and were scaffolded with videos and objects from the hypothetical agents. Children also spontaneously offered "*the eyes don't work*" for blind agents, suggesting some understanding. While we cannot rule out the possibility that children's immature verb use is related to lack of disability understanding, it seems unlikely to be the full story.

Finally, children's failure to modify verb interpretation could relate to a difficulty with extending word meanings in context-dependent ways in accordance with pragmatic constraints. There is evidence that by age 4, children are able to extend the meanings of systematically polysemous words. For example, when taught a novel word for one meaning of a polysemous English word (e.g., "bliket" for the animal chicken, as in "*the thirsty bliket*"), they extend it to its other related meaning (e.g., for the meat chicken, as in "*the tasty bliket*"), although they do not expect novel words to alternate between homophones (e.g., if "dax" labels a baseball bat, they don't expect it to also refer to an animal bat; Srinivasan & Snedeker, 2013). Four-year-olds also readily extend a novel verb referring to an action that involves an instrument to the name of the instrument (Srinivasan, Al-Mughairy, Foushee, & Barner, 2017). However, other evidence suggests that some aspects of verb extension are relatively late emerging. Young children fail to extend familiar verbs (e.g., "*go*", "*lick*") and newly learned novel verbs (e.g., "*twill*", "*tizz*") to new or unusual situations (Behrend, 1990; Imai et al., 2008; Imai, Haryu, & Okada, 2005; Seston, Golinkoff, Ma, & Hirsh-Pasek, 2009; Theakston, Lieven, Pine, & Rowland, 2002). For example, in one study 6-year-old children failed to extend instrument verbs beyond the instrument with which they are typically used. Children correctly interpret *vacuuming* to mean cleaning with a vacuum, but fail to understand phrases such as "*he vacuumed the milk off the table with his mouth*" (Seston et al., 2009).

Analogous limitations appeared, in the current study: 4-year-old children failed to extend the meaning of visual verbs to different body parts or instruments (i.e., *seeing* with the hands or cane). Why children succeed at word extension in some contexts and fail in others remains to be determined. But one common feature of the failures is that they occur when children are asked to extend verbs in a way that goes directly counter to their typical meaning rather than merely extending it to a related case. When "see" is applied to a blind agent, a component of its meaning (i.e., with the eyes) is negated and replaced with a different modality. It is possible that such extension is particularly challenging for young speakers.

Other evidence also suggests that children can be overly logical in their interpretation of linguistic expressions, failing to take pragmatics into account. For example, 4–7 year-olds who hear sentences like "Do some birds have wings" tend to interpret 'some' as 'all', unlike adults (Papafragou & Musolino, 2003; Skordos & Papafragou, 2016; Smith, 1980), and 5 year-olds who hear sentences like "There might be a parrot" tend to interpret 'might' as 'must' (Noveck, 2001). In such cases, young children's interpretations of the quantifiers conform to their logical meaning, not their pragmatically felicitous one. Likewise, in the current study, children failed to adjust the meaning of "look" and "see" according to the pragmatics of the situation (i.e., applying to a blind agent). Although these cases may be different from the children's failures to extend the verbs to non-canonical agents, it is still the case that young children in our studies adhere to the canonical ('logical') meanings of the visual verbs while older children and adults, by contrast, recruit the much more generalized meaning for *see* and *look* – mapping to perception by “best means”.

Regardless of the precise developmental mechanism, our findings clearly raise the question of how older children and adults come to extend the verb meanings to non-canonical contexts and what limitations there are to which extensions are acceptable. It is worth noting that while approximately half of the adults in the current study extended visual verbs to other effectors (e.g., hands and ears), another half instead said that a blind agent could not see/look. An interesting question is whether there are stable individual differences in willingness to extend verbs among adults and which factors might determine these differences.

In sum, the present results suggest that applying the meanings of verbs to agents whose sensory and motor capacities are atypical is a late emerging cognitive capacity. Further work is needed to uncover the precise cognitive and linguistic mechanisms whose development is responsible for this change. Prior evidence from children who are blind suggests, however, that the limitations of applying “visual” verbs to agents who are different from oneself is not in principle unsurmountable for children of this age. The failure of sighted 4-year-olds is particularly striking when considering that Kelli, the blind child observed by Landau and Gleitman (1985), was only 4 and yet already correctly applied “look” and “see” both to blind (herself) and sighted agents (e.g., her mother and sister), something we see slowly developing in sighted children between the age of 6 and 9. Why would a blind child have a more sophisticated understanding of visual verbs than her sighted peers? Unlike Kelli, who herself had no visual experience, sighted four-year-olds certainly are familiar with the experience of “not seeing” when the eyes are not available (e.g., when blindfolded). After all, infants as young as 9–12 months already understand the importance of the eyes for seeing, and that eye closure or blindfolding disrupt vision (Brooks & Meltzoff, 2007). One might therefore suppose that sighted 4-year-olds should find it obvious that looking and seeing with the eyes is impossible for a blind agent, as it is for them when their eyes are closed. Yet, Kelli succeeded where sighted 4-year-olds do not.

These findings suggest that when it comes to applying “visual” verbs to agents different from the self, children born blind have the advantage of more relevant learning opportunities than sighted children. Consider again the case of Kelli. Kelli grew up around sighted people using “look” and “see” to refer to acts of visual perception. Even when sighted individuals do not explicitly talk about vision and how it works, their use of visual language is highly informative. For example, a sentence like “*don’t go behind the shed, stay where I can see you*” conveys the idea that seeing is something that can happen at a distance but that can also be occluded. This extensive exposure to sighted agents and their language might enable children to acquire the “visual” use of visual verbs, independently of whether they themselves can see or not. By contrast, sighted children, who are rarely in contact with blind individuals, may lack rich and relevant input to inform their understanding of blind people’s experiences and how to talk about these experiences (Gelman, 2009). Diverse social and linguistic inputs provide the occasion for blind children to create an additional meaning for *see* and *look*.

Analogously, the way in which Kelli used “look” and “see” in reference to tactile perception when applied to herself is not solely the result of her sensory experience but was surely also a consequence of how those verbs were used in her environment. If, in her home, perception verbs were used strictly in the context of their canonical modality (i.e., *look* means use the eyes to visually explore), she might not have come to use the visual terms to refer to perceiving with the hands. Although, as Landau and Gleitman (1985) argued, the contexts of maternal usage of the visual verbs could not fully explain Kelli’s usage, her linguistic behavior is additional evidence that one’s own sensory experience is neither necessary nor sufficient to establish the mapping between a perceptual event and the verb describing it.

The current results are thus in line with modern theories of word learning which propose that children infer the meanings of words based on the information present in their social interactions and linguistic input, including both syntactic and semantic aspects of the linguistic signal (Fisher, 2002; Gelman, 2009; Gleitman, 1990; Landau & Gleitman, 1985; Tomasello, 2000). The results also point to the possible importance of pragmatics in extending uses of verbs to atypical agents, either blind or using a wheelchair. Once we consider these additional sources of information, the difference between sighted and blind children’s language use might not be as stark at it seems. Both sighted and blind children are immersed in a “visuocentric” world, surrounded by sighted people who use “look” and “see” in reference to their visual experiences.

This proposal makes the testable prediction not directly evaluated in the current study: that children’s ability to apply visual verb meanings to agents who are blind or wheelchair users depends on linguistic and social experience with people who are blind or use wheelchairs. In other words, sighted children who know people who are blind are more likely to experience verbs of visual perceptions being applied to those agents. Knowing someone who is blind could also provide sighted children with an impetus to infer the relevant meanings. In the current study, we did not ask whether our sighted participants knew any blind individuals. In view of the low incidence of total blindness, it is likely that most participants did not. Some evidence in support of the linguistic/social experience hypothesis comes again from Landau and Gleitman (1985). Kelli was not the only one using “look” and “see” to describe her perceptual experiences (e.g., looking at a toy with her hands). Her sighted sister, Sommer, also used the “tactile” meaning of look and see when referring to Kelli – such as when she said, “*don’t see it!*” while taking a toy out of her sister’s hands. Both children might have acquired the extended meaning of these verbs through their interactions with each other and their mother, as they considered which perceptual modalities were actually available to each perceiver. Further studies with a larger numbers of siblings of blind children or children of blind adults would provide valuable information on the contribution of social and linguistic experience to lexical development.

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