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PAPER

To generalize or not to generalize: spatial categories are influenced by physical attributes and language

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Abstract

The current work explored the conditions under which infants generalize spatial relationships from one event to another. English-learning 5-month-olds habituated to a tight- or loose-fit covering *event dishabituated to a change in fit during a* containment *test event, but infants habituated to a visually similar* occlusion *event did not. Thus, infants' responses appeared to be driven by the physical nature of the fit rather than visual similarity. This response pattern was replicated with Korean-speaking adults, but English-speaking adults showed no sensitivity to change in fit for either event. These findings suggest that language development links linguistic forms to universal, pre-existing representations of meaning, and that linguistic experience can shape sensitivity to distinctions that are marked in one's native language.*

Introduction

Young infants are posed with a daunting task of figuring out how objects typically behave and interact. Recent research that probes the origins of spatial knowledge has revealed that one way infants may tackle that task is to divide object events into smaller categories and then learn within these more narrowly defined object events. For example, Baillargeon and her colleagues have demonstrated that there are separate developmental trajectories for infants' expectations about support, occlusion, containment, and covering events (Aguiar & Baillargeon, 1999; Baillargeon & Devos, 1991; Hespos & Baillargeon, 2001a, 2001b; Needham & Baillargeon, 1993; Wang, Baillargeon & Paterson, 2005).

Questions remain about the source of these event category distinctions. One possible factor that is related to these distinctions is that physical attributes of the events are helpful in predicting the outcomes of events (Baillargeon & Wang, 2002). For example, in an occlusion event, either the object that does the occluding or the object that is occluded can be a screen, cover, or container. However, the objects in containment and covering are more restricted in that the objects involved in containment or covering events must have the physical attributes that allow one object to be put inside the other object. In addition, a container must have an open top, closed bottom, and side walls. Similarly, a cover must have a closed top, open bottom, and side walls. The degree to which infants are sensitive to these attributes and use them in categorizing spatial events remains open to investigation.

Here we probe the origins of prelinguistic spatial categories further. Can preverbal infants generalize features from one type of event to another type of event? Hespos and Spelke (2004) habituated infants to support and containment events that varied on their tight/loose relationships and found that for both support and containment, infants were able to generalize the tight/loose spatial relationship to test events. In addition, they found that English-speaking adults were not sensitive to the spatial relationships that 5-month-old infants were able to detect. These findings imply that linguistic experience can shape sensitivity to distinctions that are marked in one's native language because the tight/loose relationship is marked obligatorily in some languages (i.e. Korean) but not the native language for the population that was tested (English). In the current experiments, we investigated two new spatial categories: covering and occlusion. In Experiment 1, we habituated infants to events in which an object was partially occluded behind another object or partially covered, and tested whether infants generalized the relationship seen in habituation to test events (see Figure 1). To isolate the factors important in the ability to generalize across events we varied the spatial relationships between objects from habituation to test trials. Infants were habituated to either a narrow or a wide object and in test trials all infants saw a narrow object placed inside a narrow or wide container. In the covering condition, this translated to seeing either a tight- or loose-fit relationship in habituation and test. In the occlusion condition, the tight-/loose-fit relationship did not apply in habituation trials but was seen in test trials. In Experiment 2, we tested whether there were cross-

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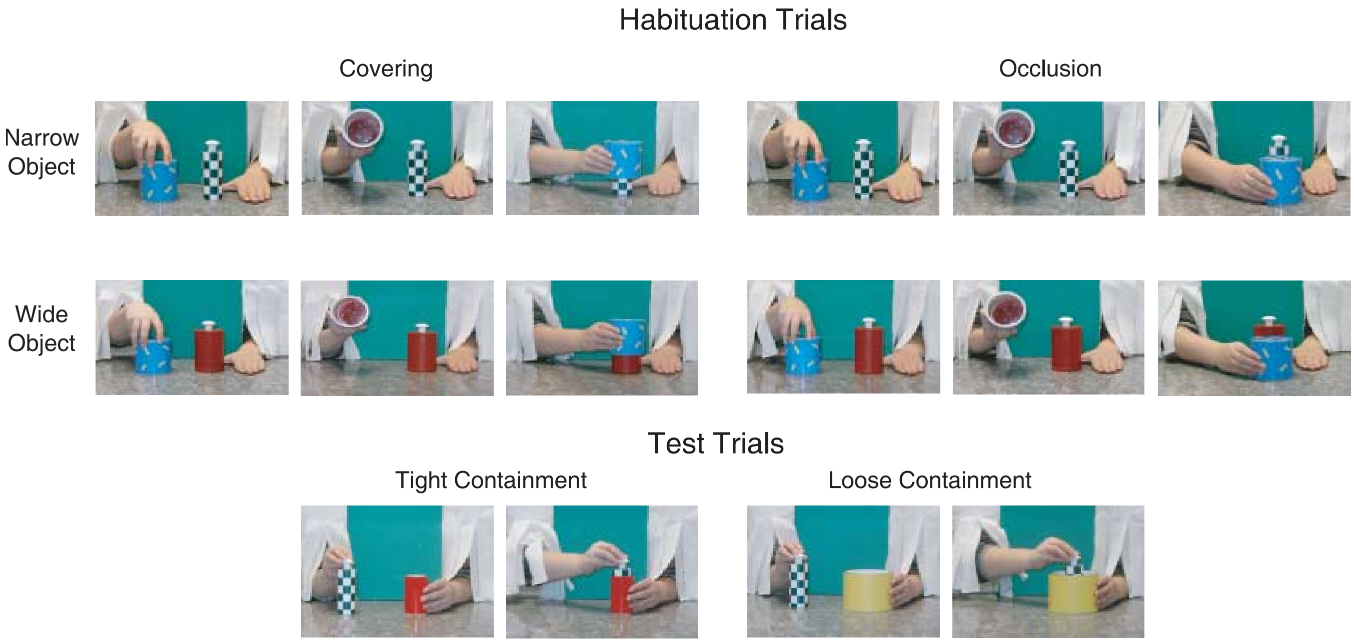

Figure 1 *Habituation and test trials for Experiment 1. The pictures show the patterns of motion in the covering and occlusion habituation trials and the containment test trials. The experimenter's right hand grasped the cover, rotated the opening toward the infant (1 s), and then with the opening oriented down, moved to the right until it was centered above the object (1 s). The experimenter then lowered the cover over (covering condition) or in front of (occlusion condition) the object (2 s). Next, the experimenter raised the cover above the object (2 s), moved it back to the left (1 s), and lowered it to the stage floor (2 s). The 9-second cycle was repeated continuously until the computer signaled that the trial had ended. In the test trials, the object was lifted vertically (1 s), and then moved to the right until it was centered above the narrow or wide container (1 s). The experimenter then lowered the object into the container (2 s). Next, the experimenter raised the object above the container (2 s), moved it back to the left (1 s) and lowered it to the stage floor (2 s). The 9-second cycle was repeated continuously until the computer signaled that the trial had ended.*

linguistic differences in adults when they were shown the same displays.

We chose occlusion and covering for spatial categories because they make different predictions with regard to the underlying mechanism: (a) If generalization is based on physical attributes (e.g. spatial relationships that predict how objects interact), then discrimination during test trials should occur for infants habituated to covering but not occlusion, because the physical attributes (in this case, relevance of tightness or looseness of fit) are similar between covering and containment but dissimilar between occlusion and containment; (b) If generalization is based on visual similarity, then discrimination during test trials should occur for infants habituated to occlusion but not covering, because the object protrudes above in the occlusion and containment events, but is below in the covering events; (c) If the ability to generalize is completely flexible, then discrimination during test trials should occur for both covering and occlusion; (d) If generalization is based on the figure/ground relationship between the two objects then neither condition will show discrimination during test trials.

Experiment 1

Infants were tested using a habituation–dishabituation paradigm, relying on infants' tendency to habituate to repeated events and look longer at a novel ones (Bornstein, 1985). Five-month-olds were shown either a covering event or an occlusion event. In the covering condition, a cover was lowered over a narrow (loose-fit) or wide (tight-fit) object. In the occlusion condition, a cover was lowered in front of a narrow or wide object. After reaching habituation criterion, infants were presented with test trials that consisted of two containment events. Test trials alternated between two kinds: one where the narrow object was lowered into a narrow container (tight fit) or the narrow object was lowered into a wide container (loose fit). The rationale was that if infants could generalize what they saw in habituation trials, they would look longer at the novel compared to the familiar test trials. If generalization is predicted by physical attributes, there should be a significant difference in the covering but not the occlusion condition because the horizontal motion of the object is constrained by the covering and containment but not occlusion. If generalization is predicted by visual similarity, there should be a significant difference in the occlusion but not the covering condition because the object protrudes above in occlusion and containment events but the object protrudes below in the covering event. By habituating half of the infants with the narrow object and the other half with the wide object, we could determine the extent to which the habituation condition (as opposed to some intrinsic preference for the events) was responsible for any preferences that infants might display for the events.

Method

Participants

Participants were 64 healthy, term infants, 29 male and 35 female (age range = 4 months, 14 days to 5 months, 18 days; M = 5 months, 0 days). Infants were randomly assigned to either the covering or occlusion condition. Within each condition, approximately half of the infants were randomly assigned to the *narrow object* habituation trials (n = 31; M = 4 months, 29 days), and the remaining infants were assigned to the *wide object* habituation trials (n = 33; M = 5 months, 2 days). Ten additional infants were tested but eliminated, seven due to fussiness, two to inattentiveness, and one to interference by the parent.

Infants' names in this and subsequent studies were obtained from birth records and purchasing commercial mailing lists. The participants' parents were contacted by letters and follow-up phone calls. They were given a T-shirt or book as a thank you gift but were not compensated for their participation. The ethnicity of the sample was 83% non-Hispanic. The racial make-up was 78% white, 7% Asian, and 2% Black/African American. The remaining 13% were split between multiracial and 'chose not to answer'.

Apparatus

The apparatus consisted of a wooden display box 210 cm high, 106 cm wide, and 78 cm deep that was mounted 76 cm above the room floor. Infants sat on a caretaker's lap facing an opening in the front of the apparatus 60 cm high and 99 cm wide. The opening revealed a stage on which all objects were displayed. The back wall had two rectangular openings, each 30.5 cm high and 15.5 cm wide. The experimenter manipulated objects on the stage by reaching through these openings. At the start of each trial, a screen made of hardboard covered the opening in the front of the apparatus, concealing the stage. The trial began when the screen was raised and the stage became visible. At the end of each trial, the screen was lowered again.

The stimuli were made of plastic pipe. In the covering condition, the object used in the narrow-object habituation trials was 5 cm in diameter and 14.5 cm tall, closed on both ends, and covered with contact paper. A white knob 3.5 cm in diameter was affixed to the top of the cylinder. The object used in the wide-object habituation trials was identical except that it was 7.5 cm in diameter. The covers used during the habituation trials were 10 cm tall and 7.6 cm in diameter on the inside, open on one end. There were six different covers, each covered with contact paper of a different color or pattern, to help the infants notice that different objects were shown across trials.

The objects used in the occlusion condition were the same as those used in the covering condition. The occluders were the same as the covers, except that they were lowered in front of the objects rather than over them.

Two different sizes of containers were used in the test trials. The narrow container was 9.5 cm tall and 5.2 cm in diameter on the inside, and the wide container was 9.5 cm tall and 11.5 cm in diameter on the inside. Different patterns and colors were used to decorate the short and tall containers.

Procedure

During the experiment, the infant sat on the parent's lap in front of the apparatus. The parents were asked to refrain from interacting with their infant during the experiment, and to close their eyes during the test trials. Each infant's looking behavior was monitored by two observers who watched video images of the infant captured by a camera hidden in the front face of the apparatus. All trials ended when the infant either looked away for 2 consecutive seconds after having looked at the event for at least 2 seconds, or looked at the event for 60 cumulative seconds without looking away for 2 consecutive seconds. The habituation criterion was at least a 50% decline in total looking duration when the first three and the last three habituation trials were compared or a maximum of nine trials. Infants viewed six test trials, alternating between tight-in and loose-in events. The type of event shown first was counterbalanced across infants. The endings of the trials were determined by a computer, which then signaled the experimenter. Interobserver agreement averaged 94%.

Preliminary analyses revealed no significant effect of habituation type, sex, or test trial order (tight first vs. loose first) on the looking times of the infants; the data were therefore collapsed across these variables in subsequent analyses.

Results

Mean looking times to the habituation and test trials were calculated for each infant (see Figure 2). While infants in the two conditions looked comparably during habituation, they showed significantly different patterns during test trials. Specifically, infants in the covering condition detected a change between tight and loose fit, but infants in the occlusion condition looked comparably at the two test events (Figure 2).

Habituation trials

Infants' looking times during habituation trials were analyzed using a general linear model (GLM) with habituation condition (covering vs. occlusion) and type (narrow vs. wide object) as between-subjects factors and trial (1–6) as a within-subject factor. A main effect of trial, $F(5, 60) = 32.31$, $p < .001$, revealed that looking time decreased significantly over the course of habituation trials. There were no other significant main effects or interactions.

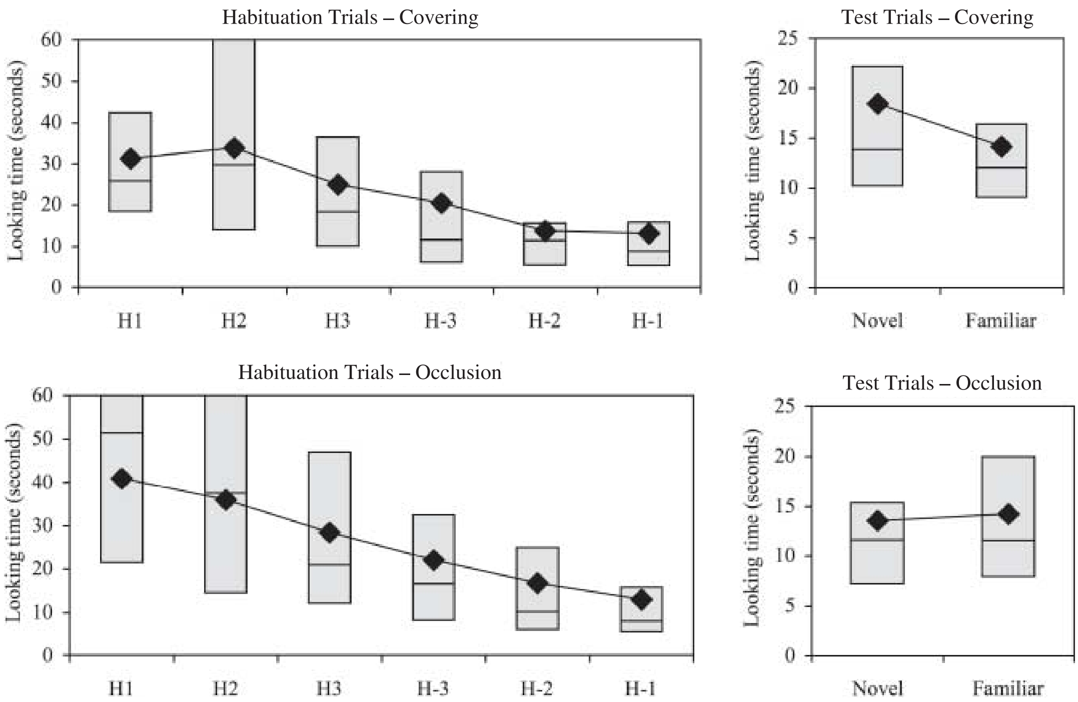

Figure 2 *Box plots for mean looking time during habituation and test trials in Experiment 1. In the habituation graph, the boxes represent the means for the first three trials and last three trials prior to meeting the habituation criterion. In both graphs, the black diamonds represent the mean, the central line in the box is the median and the upper and lower portions of the box represent the 75th and 25th quartiles on either side of the mean. In habituation trials there was no significant difference across conditions. In test trials only the infants in the covering condition discriminated between the novel and familiar events.*

Test trials

A GLM with condition (covering vs. occlusion) as a between-subjects factor and event (novel vs. familiar) and trial pair (1st, 2nd, 3rd) as within-subjects factor revealed a main effect of event, $F(1, 62) = 4.15$, $p < .05$, which was qualified by an interaction between event and condition, $F(1, 62) = 7.84$, $p < .01$. Infants in the covering condition looked longer at the novel ($M = 18.46$) compared to the familiar test event ($M = 14.12$), but infants in the occlusion condition looked equally at the novel ($M = 13.53$) and familiar events ($M = 14.22$). Nonparametric binomial tests confirmed these findings; in the covering condition 26 out of 32 infants looked longer at the novel event ($p < .01$, binomial comparison). In contrast, for the occlusion condition only 15 out of 32 infants looked longer at the novel event.

The novelty preference was evident in the covering condition regardless of whether infants were habituated to the narrow or wide objects (see Figure 3). Infants habituated to the narrow object looked significantly longer at the tight test trials, $F(1, 16) = 9.85$, $p < .01$, and infants habituated to the wide object looked significantly longer at the loose test trials, $F(1, 14) = 5.40$, $p < .05$. In each condition, 13 out of 16 infants looked longer at the novel compared to the familiar events ($p < .05$, binomial comparison). In contrast, infants in the occlusion condition showed no preference. There was no main effect of event in either the narrow or wide object condition, $F(1, 15) < 1$.

Discussion

Experiment 1 provides evidence that physical attributes predict how infants generalize across events, because 5-month-old infants detected a change between tight and loose fit in the covering condition and there was no discernible pattern in the looking times during test trials for the occlusion condition. Because of the counterbalanced design (e.g. the test trials that were novel for half of the infants were the familiar test trials for the other half of the infants), it is unlikely that the preferences for the novel events could be attributed to any inherent bias.

Both human infants and non-human primates represent the physical attributes of objects by analyzing the arrangements and motions of surfaces (Baillargeon, 2004; Hauser, 1998; Santos, 2004; Santos & Hauser, 2002; Spelke, 1990), and these relationships differ for tight- versus loose-fitting objects. When an object enters a loose-fitting container, it can move independently in the container up to the container's boundaries. In contrast, when an object enters a tight-fitting container, typically any motion of the object will induce a corresponding motion in the container. This same physical attribute is true of covering, but not occlusion. Thus, the fact that infants generalized the tight/loose physical attribute from a covering event to a containment event suggests that the categorical distinction between tight- and loose-fitting relationships may be a product of a more general, language-independent system of representing object mechanics. In this respect, the early development

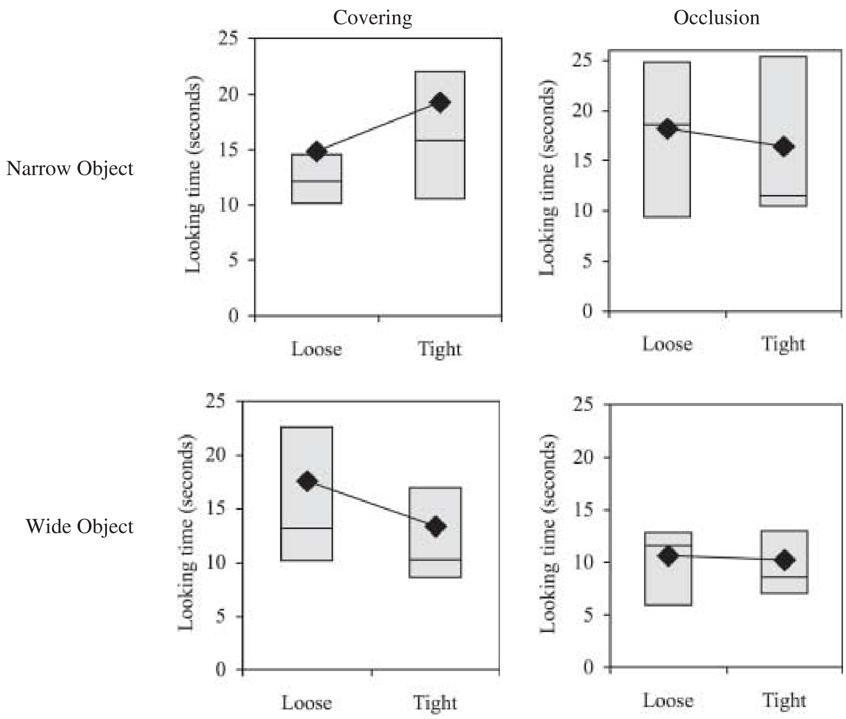

Figure 3 *Box plots for test trials separated by habituation condition. The novelty preference was evident in the covering condition regardless of whether infants were habituated to the narrow or wide objects. There was no discernible pattern in the occlusion condition.*

of semantic categories parallels the development of phonological categories and suggests that natural language semantics, like natural language phonology, evolved so as to capitalize on pre-existing representational capacities (Hauser, Chomsky & Fitch, 2002).

Experiment 2

Experiment 1 suggests that physical attributes (i.e. a cognitive factor) influenced whether infants would generalize across events. There is new interest in questions that lie at the intersection of cognition and language, regarding how we arrive at our inventory of spatial categories. One view (supported by Experiment 1) is that spatial language derives from universal, non-linguistic representations of objects and the spatial layout. Because all animals are subject to the same physical and geometrical laws, knowledge of these laws may be internalized in human perceptual and cognitive systems (Gibson, 1979; Shepard, 1984; Spelke, Breinlinger, Macomber & Jacobson, 1992) and available for language learning (Jackendoff, 1983; Landau & Jackendoff, 1993; Li & Gleitman, 2002; Talmy, 1983). On a contrasting view, spatial and mechanical categories are constructed by children as they learn their native language. Because different languages capture different spatial and mechanical relationships (Bowerman, 1996; Choi & Bowerman, 1991; S.C. Levinson, 1996; Sinha & Jensen de Lopez, 2000), speakers of different languages may form different representations of space and objects (Boroditsky, 2001; Levinson, Kita, Haun & Rasch, 2002; Whorf, 1956). Intermediate views also are possible, whereby systems of spatial representation in language and in perception are partially independent or mutually interacting (Munnich, Landau & Dosher, 2001; Slobin, 2000).

Part of the motivation for choosing these particular spatial relationships was that the tight/loose category boundary is marked obligatorily in Korean but not English. Therefore, we could present adults with the same displays that the infants saw to test for any cross-linguistic differences. If adults make a language-independent categorical distinction between tight- and loose-fit events, then both English- and Korean-speaking adults should be sensitive to the crossing of the category boundary between tight and loose fit. However, if adults' category distinctions are shaped by natural language, then Korean- but not English-speaking adults should be sensitive to the crossing of the category boundary between tight and loose fit.

As a control and to make sure it was the spatial relationship of fit that was critical, a separate group of adults were shown the same objects in an occlusion spatial relationship. Because no tight/loose spatial relationship occurs in occlusion events and English and Korean do not differ in the obligatory demarcation of occlusion, we predicted no difference across languages or test trials.

Method

Participants

Participants were 73 adults, 32 native English speakers (17 women) and 41 native Korean speakers (22 women) recruited from the university student community. Participants were randomly assigned to either the covering or occlusion condition and within each condition half saw preliminary trials with either the narrow or wide object. An additional 11 Korean adults were in a control condition where they saw a prototypical *nehta/kkita* (tight/loose) exemplar, to verify that the paradigm worked (for a more detailed description of the stimuli for this condition refer to Hespos & Spelke, 2004, Experiment 1). The English participants were monolingual. For the Korean participants, native Korean speaker status was determined using the Language Experience and Proficiency Questionnaire (LEAP-Q). This is a questionnaire that assesses a multilingual individual's self-reported relative fluency in each known language (Marian, Blumenfeld & Kaushanskaya, 2007).[1] For the Korean participants, the experimenter gave the instructions in Korean and the question sheet was written in Korean (Gardner, Gabriel & Lee, 1999; Hong, Morris, Chiu & Benet-Martinez, 2000).

Apparatus

The apparatus and stimuli were the same as those used in Experiment 1.

Procedure

Adults saw six preliminary trials followed by two test trials. The trials were the same as a single cycle of the trials seen by the infants in Experiment 1. After viewing the preliminary trials, adults rated the similarity between the preliminary trials and each of the test trials (1 = not at all similar to 10 = very similar). The rationale was that if adults detected a change in fit then the adults who saw the tight preliminary trials would rate the loose test trials as different, and the adults who saw the loose preliminary trials would rate the tight test trials as different.

Coding

We calculated a difference score for each participant. The difference score was calculated by subtracting the two similarity scores with respect to the preliminary trials (e.g. if the participant was shown the narrow object in preliminary trials then the difference score equaled the similarity-to-loose containment minus the similarity-to-tight containment). Preliminary analyses revealed no significant effect of sex on the adults' responses, so the data were collapsed across this variable in subsequent analyses.

[1] A native Korean speaker was defined as someone who reported that: their current dominant language is Korean, the culture that they identify most with is Korean, and they are currently exposed to the Korean language more than 20% of the time. Of the Korean speakers, seven additional participants were excluded, one because they failed to comply with the experimenter's instructions and six because they did not meet our criteria.

Results

As can be seen in Figure 4, the Korean covering and the control conditions were the only ones in which participants' scores were significantly different from chance, $t(16) = 2.68$, $p = .017$ and $t(10) = 2.45$, $p = .034$, respectively. The other three conditions were not statistically different from zero (all ts < 1). Further analysis revealed that there was a significant difference between Korean adults' responses to covering and occlusion, $t = -1.76$ (28), $p = .044$ (one-tailed), but native English adults' responses to these same conditions were equivalent ($t < 1$). Similarly for the control condition, there was a significant difference between scores for containment and occlusion, $t = 2.338$ (22), $p < .03$ (two-tailed), but no difference between containment and covering, $t = -1.44$ (26), $p > .16$ (two-tailed).

A nonparametric statistical analysis confirmed this pattern of results. We categorized each participant's set of responses as one of three patterns: (a) consistent – the test event that matched the preliminary trials was rated higher (e.g. the participant saw a tight-fit covering event and then rated the tight-fit test event as more similar to the preliminary trial than the loose-fit test event); (b) equal – the participant gave both test events the same rating; or (c) inconsistent – the test event that did not match the preliminary trials was rated higher (e.g. the participant saw a tight-fit covering event and then rated the loose-fit test event as more similar). Table 1 shows the distribution of choices by language and condition. For the Korean speakers in the covering condition, these proportions were significantly different from chance, $\chi^2(2, n = 17) = 7.52$, $p = .023$. None of the other conditions was different from chance.

In sum, the only conditions that showed performance different from chance were those in which the spatial category distinctions were obligatorily marked in the corresponding language (Korean containment and

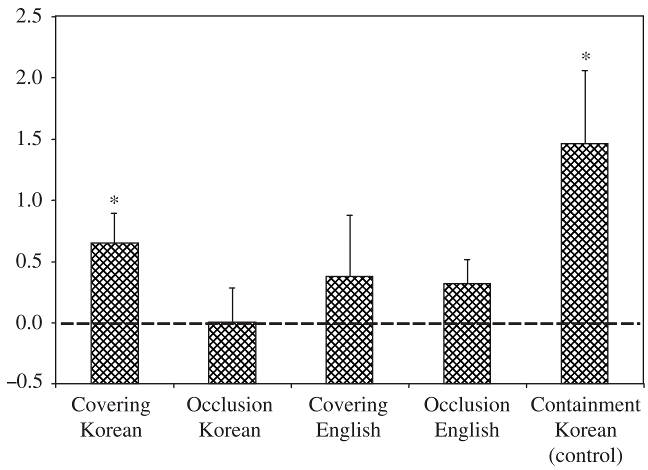

Figure 4 *Mean difference scores for Korean- and English-speaking adults in Experiment 2. Chance performance was zero. Error bars represent standard error. Only the Korean covering and containment conditions were significantly different from chance (* means* p < *.05).*

Table 1 *Number of participants who: detected the fit change in the spatial relationship (consistent), rated all spatial relationships as the same (equal), or went in the opposite direction predicted by the spatial relationship of fit (inconsistent)*

Language	Condition	Consistent	Equal	Inconsistent
Korean	Covering*	11	3	3
	Occlusion	4	4	5
English	Covering	6	6	4
	Occlusion	6	8	2

Note: * means that this pattern is significantly different from that predicted by chance ($p < .05$).

covering). Participants in the other conditions revealed means in the same direction, but the effects were not as prominent.

Discussion

Experiment 2 provided evidence that there are differences in how Korean- and English-speaking adults categorize the same spatial events. Korean-, but not English-speaking, adults detected the change between tight- and loose-fitting relations for the covering and containment events. The English-speaking adults showed trends in this direction but their differences were not significant. These findings are consistent with the possibility that the shared physical attributes are activated more strongly when the language requires it be attended to (Korean) than one that makes no such requirement (English).

General discussion

The present results suggest two main conclusions. First, infants' ability to generalize across events is predicted by the shared physical attributes between the two events. Experiment 1 provides evidence that there are spatial categories prior to language and gives insight into the nature of the mechanisms that guide the formation of these categories. Second, adults' sensitivity to spatial relationships is predicted by the extent to which their native language highlights those relationships. Experiment 2 elaborates the findings from Experiment 1, demonstrating that language influences spatial category boundaries by emphasizing distinctions that are marked in the native language. Taken together, these studies show that the performance of 5-month-old infants growing up in an English-speaking community more closely resembled the pattern of Korean-speaking adults than English-speaking adults.

There are interesting insights to be gained by looking at the parallels between semantic and phonological development. For example, infants are sensitive to the phonological distinctions of non-native languages (Kuhl, 1992) and here we demonstrated that 5-month-old infants were sensitive to spatial categories that were not lexicalized in their native language. In addition, adults' sensitivity to acoustic distinctions is best for differences that are captured by their native language. Similarly, here we demonstrate that Korean-speaking adults were more sensitive to the tight/loose category boundary that is obligatorily marked in their language compared to English-speaking adults whose language did not highlight the distinction. One difference between these two developmental trajectories is that in the case of speech perception, it is difficult to recover some sensitivity to non-native phonological distinctions through training and through manipulations of attention (Pisoni, Aslin, Perey & Hennessy, 1982). However, spatial categories are easier to recover, as Experiment 2 demonstrated. English- and Korean-speaking adults had means that went in the same directions, but the effects were larger for the Korean speakers, whose language marked the distinction.

These findings reveal a nuanced relationship in terms of when infants generalize from one event to another. To illustrate the focal contrast in the literature we describe two seemingly contradictory developmental studies that investigated the precursors to spatial language. Experiment 1 above provided evidence that 5-month-old infants are sensitive to a tight–loose spatial distinction that is not emphasized in their native language. Casasola (2005) found that 18-month-old infants failed to discriminate a support category that is marked in their native language unless they heard the requisite spatial term. The difference between these two studies may stem from the scope of generalization that the infants needed to make (Gentner & Christie, in press). In Experiment 1 the habituation and test trials utilized highly similar events, both in terms of the motions involved and the objects used. In the Casasola (2005) study, the habituation and test events were quite varied and the objects involved were perceptually rich and differed across trials. If, as Gentner and Christie suggest, we consider that performance in these studies derives in part from abstractions formed during the study, then both kinds of study are informative. We can see these studies as spanning a range. At one pole are studies in which the intended relation is perfectly aligned across exemplars with few distracting surface differences (e.g. Experiment 1) – an ideal situation in which to form a generalization, albeit one that may not apply far beyond the initial stimuli. At the other pole are studies with complex learning conditions, in which the relation is instantiated over different kinds of objects (e.g. Casasola, 2005). That infants form the abstraction under perfect conditions tells us that this potential is there prior to language. But the variable learning experience given to the infants in the Casasola studies may better match real-life learning conditions.

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