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General Magnitude Representation in Human Infants

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Abstract

Behavioral demonstrations of reciprocal interactions among the dimensions of space, number, and time, along with evidence of shared neural mechanisms in posterior parietal cortex, are consistent with a common representational code for general magnitude information. Although much recent speculation has concerned the developmental origins of a system of general magnitude representation, direct evidence in preverbal infants is lacking. Here we show that 9-month-olds transfer associative learning across magnitude dimensions. For example, if shown that larger objects were black and had stripes and that smaller objects were white and had dots, infants expected the same color-pattern mapping to hold for numerosity (i.e., greater numerosity: black with stripes; smaller numerosity: white with dots) and duration (i.e., longer-lasting objects: black with stripes; shorter-lasting objects: white with dots). Cross-dimensional transfer occurred bidirectionally for all combinations of size, numerosity, and duration. These results provide support for the existence of an early-developing and prelinguistic general magnitude system, whereby representations of magnitude information are (at least partially) abstracted from the specific dimensions.

Keywords

magnitude representation; space, number, and time; infants

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Magnitude information comes in many forms, including the dimensions of space, number, and time. When reasoning about predators, for example, one can judge their size, how many of them are present, and the time it may take them to reach one's location. Although much research has focused on the processing of specific magnitude dimensions in isolation, recent work has investigated their associations. In the case of space and number, perhaps the classic demonstration of an association is the *SNARC* (spatial-numerical association of response codes) effect, which highlights the left-to-right organization of increasing numerical values (Dehaene, Bossini, & Giraux, 1993; see also Fischer, Castel, Dodd, & Pratt, 2003; Gevers, Verguts, Reynvoet, Caessens, & Fias, 2006). Other evidence for a spatial-numerical association includes findings that judgments of number are faster when digits and physical size are congruent (e.g., 2 7) rather than incongruent (e.g., 2 7; Henik & Tzelgov, 1982; see also Hurewitz, Gelman, & Schnitzer, 2006). Work demonstrating an association between space and time has shown that greater distances are associated with longer durations (Sarrazin, Giraudo, Pailhous, & Bootsma, 2004; see also DeLong, 1981); for example, perceived distance increases with temporal separation for sequentially presented stimuli, and perceived duration increases with spatial separation. For number and time, the classic demonstration of an association is that rats appear to treat numerical and temporal stimuli interchangeably, with 1 s approximately equal to a count of 5 (Meck & Church, 1983). In humans, recent evidence for a numerical-temporal association comes from comparisons of Arabic numerals presented for varying durations; adults' duration judgments were biased by numerical value such that small numbers were underestimated in duration and larger numbers overestimated (Oliveri et al., 2008). The pervasive nature of these behavioral associations, together with evidence of shared activation in posterior parietal cortex during spatial (Pinel, Piazza, Le Bihan, & Dehaene, 2004; Sereno, Pitzalis, & Martinez, 2001), numerical (Dehaene, Spelke, Pinel, Stanescu, & Tsivkin, 1999; Piazza, Pinel, Le Bihan, & Dehaene, 2007), and temporal (Leon & Shadlen, 2003; Maquet et al., 1996) processing, has led to the suggestion that magnitude is represented quite generally in a common representational format (Walsh, 2003).

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Much recent speculation has concerned the origins of general magnitude representation, and there has been particular interest in whether associations among space, number, and time exist early in human life (Feigenson, 2007; Walsh, 2003). Evidence consistent with the existence of at least some associations in children comes from early work by Piaget, who reported effects of spatial extent on judgments of number (Piaget, 1965) and time (Piaget, 1969; see also Levin, 1977; Siegler & Richards, 1979). In the classic number-conservation task, children judge that two unequal-length rows of objects differ in numerical value, believing that the longer row is greater in numerosity, even if the two rows are numerically identical or the longer row actually contains fewer objects. Evidence consistent with associations in infants comes from habituation-dishabituation studies showing that similar Weber ratios mediate discrimination sensitivity for different dimensions. Six-month-olds differentiate stimuli differing by a 2:1—but not 3:2—ratio in size (Brannon, Lutz, & Cordes, 2006), numerosity (Xu & Spelke, 2000), or duration (vanMarle & Wynn, 2006). Furthermore, sensitivity appears to increase in parallel over the 1st year of life for numerical (Lipton & Spelke, 2003) and temporal (Brannon, Suanda, & Libertus, 2007) information. These parallel discrimination functions, though consistent with general magnitude representation, could result from developmental changes in perception, memory, or attention, processes that are not specific to magnitude, and do not necessarily implicate a shared representational code for space, number, and time. In addition, discrimination functions have been observed for a restricted range of intensities, and it is unclear whether they would generalize to nontested intensities. It is known that there are range differences in number discrimination; for example, infants differentiate 2 versus 3 objects (Cordes & Brannon, 2009), but not 8 versus 12 dots (Xu & Spelke, 2000), despite identical ratios in the two cases.

To test directly whether associations among space, number, and time exist in preverbal infants, we modeled our approach on that of Meck and Church (1983), who found that rats trained to discriminate two durations spontaneously generalized their learning to number discriminations. We taught preverbal infants an arbitrary mapping between one magnitude dimension and color-pattern cues (e.g., larger size: black with stripes; smaller size: white with dots). In the initial (habituation) phase, infants were shown stimuli depicting the mapping until their looking times decreased to a criterion. During the subsequent test phase, they were presented with novel stimuli, which either maintained (*congruent trials*) or violated (*incongruent trials*) the mapping between magnitude and color-pattern presented during habituation. In Experiment 1, habituation and test trials involved the same magnitude dimension. In Experiment 2, magnitude dimensions varied between habituation and test. We predicted that if infants learned the color-pattern mapping, they would dishabituate to the incongruent stimuli, looking longer during incongruent than congruent test trials, whether these trials involved the same magnitude dimension presented during habituation (Experiment 1) or a different magnitude dimension (Experiment 2).

Experiment 1: Within-Dimension Discrimination

We conducted a first experiment to determine whether 9-month-olds are capable of learning arbitrary color-pattern mappings for the magnitude cues of size, numerosity, and duration. In the size condition, for example, infants might see that the larger rectangle in a pair was always black with white stripes and that the smaller rectangle was always white with black dots. Numerosity and duration conditions were similarly structured except that stimulus pairs varied with respect to the number of rectangles or the time rectangles remained visible on screen.

Method

Participants. Thirty-six full-term 9-month-olds (M = 9.2 months, SD = 0.47) participated, 12 (6 girls, 6 boys) in each of three conditions: size, numerosity, or duration. Eleven additional infants failed to complete the experiment because of fussiness (size: 4; numerosity: 2; duration: 5).

Stimuli and procedure. On each trial, infants saw a pair of stimuli featuring a mapping between magnitude and color-pattern. In each condition, there were three stimulus pairs. These pairs varied in magnitude (e.g., size) by a ratio of at least 2:1, which even 6-month-olds have been shown to discriminate for each of the three dimensions (size: Brannon et al., 2006; numerosity: Xu & Spelke, 2000; duration: vanMarle & Wynn, 2006). (See the Supplemental Material available online for specific stimulus values.) In the numerosity condition, the two arrays in each pair (e.g., 2 vs. 4) were equivalent in cumulative perimeter and surface area, so we could be sure that discriminations were based on number rather than spatially related cues (for discussion, see Mix, Huttenlocher, & Levine, 2002). In the duration condition, equal-size rectangles, which varied in presentation time (e.g., 1 vs. 2 s), were presented in repeating loops with a 0.5-s interstimulus interval.

Stimuli were presented using Habit X 1.0 software (Cohen, Atkinson, & Chatput, 2004) and were rear-projected onto a screen (92 cm × 67 cm). Infants sat on their parent's lap, approximately 90 cm from the screen. Parents kept their eyes closed so as to not influence infants' behavior. Each trial began with a beeping target to attract the infant's attention. The trial continued until the infant looked for at least 2 s, and then ended after looking time totaled 30 s or the infant looked away for a continuous 2 s. An experimenter (blind to condition) recorded looking times via a hidden camcorder, and recordings were confirmed off-line by another experimenter (also blind to condition). Interobserver agreement (calculated across trials at 100-ms intervals for each infant) was high in all three conditions (size: 91%; numerosity: 93%; duration: 93%).

Two stimulus pairs were presented during habituation trials; the third pair was retained for test trials (counterbalanced across infants). For example, in the numerosity condition, if infants were habituated to displays showing arrays of 2 versus 4 and 3 versus 6, they were then tested with arrays of 5 versus 10. For each pair, two trial types were formed by varying the left/right positions of the items, thus creating four unique habituation trials. During habituation, magnitude information varied systematically in color-pattern (e.g., larger size: black with stripes; smaller size: white with dots), with the magnitude and color-pattern mapping counterbalanced across infants. Trial order was randomized with the constraint that each of the four unique trials was presented once before repetition. The habituation phase ended when the average looking time on 4 consecutive trials was less than 50% of the average for the first 4 trials (a standard habituation criterion) or after 24 trials, whichever came first.

Following habituation, infants were presented with four test trials involving the third stimulus pair (left/right positions of the items were counterbalanced across trials). Congruent trials (i.e., magnitude and color-pattern mapping maintained) and incongruent trials (i.e., magnitude and color-pattern mapping violated) were presented in alternation (the trial type presented first was counterbalanced across infants).

Results and discussion

The mean number of habituation trials was 14.1, 13.8, and 13.4 in the size, numerosity, and duration conditions, respectively. Analyses of habituation trials (first four vs. last four) revealed that infants in each condition showed significant decreases in looking time—size: *t*(11) = 4.75; numerosity: *t*(11) = 7.26; duration: *t*(11) = 12.60; all *p*s < .001 (see Fig. 1). All infants met the habituation criterion.

We analyzed looking times during the test phase in an analysis of variance (ANOVA) with condition (size, numerosity, duration), stimulus pair (one of three possible pairs), and test order (congruent or incongruent trial first) as between-subjects variables and type of test trial (congruent vs. incongruent) as a within-subjects variable. This analysis revealed a significant main effect of test-trial type, *F*(1, 18) = 12.21, *p* < .01, but no other significant main effects or interactions (*p*s > .2). Follow-up ANOVAs conducted separately for each condition revealed that infants in all conditions looked significantly longer, on average, on incongruent than on congruent test trials—size: *F*(1, 11) = 4.97; numerosity: *F*(1, 11) = 4.88; duration: *F*(1, 11) = 6.15; all *p*s < .05 (Fig. 1). Infants in all conditions also looked significantly longer on the first incongruent test trial than on the first congruent test trial—size: *F*(1, 11) = 7.34; numerosity: *F*(1, 11) = 5.43; duration: *F*(1, 11) = 5.57; all *p*s < .05. The majority of infants looked longer at incongruent than at congruent test trials (size: 10 of 12 infants; numerosity: 9 of 12 infants; duration: 10 of 12 infants).

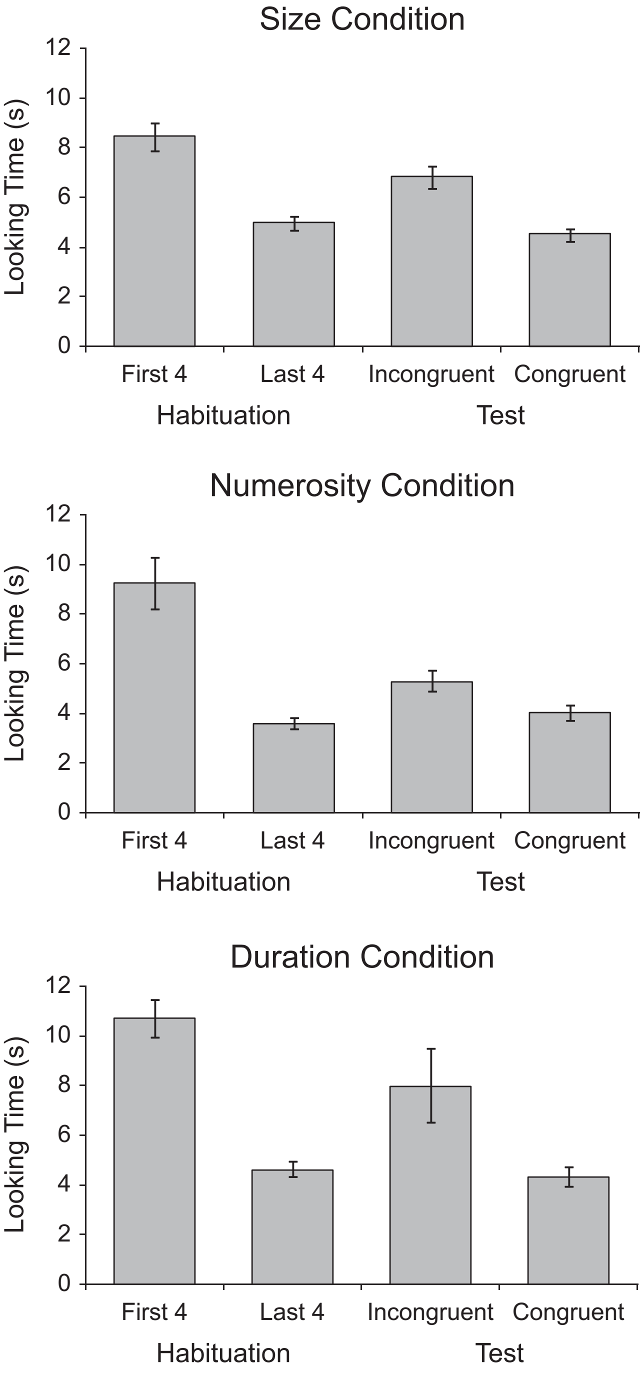

Fig. 1. Mean looking times for each condition in Experiment 1. For the habituation phase, results are shown for the first four and last four trials. For the test phase, results are shown for incongruent and congruent trials. Error bars represent standard errors.

Additional analyses comparing average looking times during test and the end of the habituation phase (average of the last four trials) confirmed dishabituation to incongruent test trials—size: *t*(11) = 2.13, *p* = .057; numerosity: *t*(11) = 3.38, *p* < .01; duration: *t*(11) = 2.21, *p* < .05. There was no dishabituation to congruent test trials—size: *t*(11) = −0.80; numerosity: *t*(11) = 0.91; duration: *t*(11) = −0.51; *p*s > .3. These data show that infants learned the arbitrary mapping between magnitude (whether size, numerosity, or duration) and color-pattern (see the Supplemental Material available online for an alternative explanation).

Experiment 2: Between-Dimension Discrimination

Having shown that 9-month-olds can learn an arbitrary mapping between magnitude information and color-pattern, we turned to the critical question: Does information related to one dimension of magnitude generalize to other magnitude dimensions? If infants represent magnitude generally across space, number, and time, they might expect the color-pattern mapping learned for one dimension to hold for other dimensions. We examined this issue by habituating infants to stimuli for one dimension (e.g., size), but then presenting them with stimuli for another dimension (e.g., numerosity or duration) during the test phase. Infants were tested with all possible pairing combinations of size, numerosity, and duration.

Method

Participants. Seventy-two full-term 9-month-olds (*M* = 9.3 months, *SD* = 0.33) participated, 24 (12 girls, 12 boys) in each of three conditions: space-number, space-time, and number-time. Twenty-three additional infants did not complete the experiment because of fussiness (space-number: 8; space-time: 7; number-time: 8).

Stimuli and procedure. The major difference from the previous experiment was the change in magnitude dimension between the habituation and test phases. Dimensions presented during habituation and test were counterbalanced across infants, creating two groups per condition (space-number: size-to-numerosity, numerosity-to-size; space-time: size-to-duration, duration-to-size; number-time: numerosity-to-duration, duration-to-numerosity).

Habituation trials presented two sets of stimulus pairs in which relative magnitude information was mapped systematically onto color-pattern. As in Experiment 1, pairs varied in magnitude by a ratio of at least 2:1. Additional variation (e.g., orientation of items), which could not be used subsequently to distinguish congruent and incongruent test trials, was incorporated to increase the salience of the mapping (see Figs. 2–4, top panels, and the Supplemental Material). There were 8 unique habituation trials for each group of infants, presented randomly and with no repetitions until each was sampled once. Habituation ended when the average looking time for 4 consecutive trials was less than 50% of the average for the first 4 trials or after 32 trials, whichever came first. Congruent and incongruent test trials were defined by the mapping between magnitude and color-pattern during habituation. For example, for the size-to-numerosity group, if larger-sized rectangles were black and had stripes and smaller-sized rectangles were white and had dots during habituation, then congruent test trials were those in which black items with stripes were presented in a larger numerical array than white items with dots, and incongruent test trials were those in which white items with dots were presented in a larger numerical array than black items with stripes. There were 6 test trials (left/right positions of items were counterbalanced across trials), alternating between congruent and incongruent types (the trial type presented first was counterbalanced across infants). Looking times were recorded as in Experiment 1, and interobserver agreement (calculated at 100-ms intervals) was high in all three conditions (space-number: 92%; space-time: 91%; number-time: 93%).

Space-number condition. In the size-to-numerosity group, habituation trials involved pairs of larger versus smaller rectangles; each trial consisted of sets of two or four rectangles, with the number of rectangles held constant within a trial. Each test trial presented a larger versus a smaller number array, the arrays being equivalent in cumulative perimeter and surface area. Equating extraneous spatial variables across number arrays ensured that any observed generalizations were between size and numerosity rather than size and other spatially related information.[1] In the numerosity-to-size group, habituation trials involved pairs of larger versus smaller number arrays. Cumulative perimeter and surface area were varied orthogonally to numerosity and color-pattern mappings, such that on half the trials, the larger number array was smaller in cumulative perimeter and area than the smaller number array, and on the other half, the larger number array was larger in cumulative perimeter and area than the smaller number array. Varying perimeter and area in this way ensured that infants habituated to number and that generalization was not supported by spatially related variables. Each test trial presented a larger-sized versus a smaller-sized set, the two sets being equivalent in number. (See the Supplemental Material for stimulus values and Fig. 2 for an illustration of the stimuli presented to both groups.)

Space-time condition. In the size-to-duration group, habituation trials involved pairs of larger versus smaller rectangles; each stimulus was presented in a repeating loop of 1.2 or 1.8 s (0.5-s interstimulus interval), and duration was held constant within each trial. Each test trial presented a longer-duration versus a shorter-duration set, the sets being equivalent in size. In the duration-to-size group, habituation trials involved pairs of longer versus shorter durations; the size of the rectangles varied across trials but was held constant within a trial. Each test trial presented a larger-sized versus a smaller-sized set, the sets being equivalent in duration. (See the Supplemental Material for stimulus values and Fig. 3 for an illustration of the stimuli presented to both groups.)

Number-time condition. In the numerosity-to-duration group, habituation trials involved pairs of larger versus smaller number arrays, as in the numerosity-to-size group. These number arrays were presented in repeating loops, as in the size-to-duration group. Each test trial presented a longer-duration versus a shorter-duration set (as in the size-to-duration group), the sets being equivalent in number. In the duration-to-numerosity group, habituation trials involved pairs of longer versus shorter durations; each trial consisted of sets of two or four rectangles, with the number of rectangles held constant within a trial, as in the size-to-numerosity group. Each test trial presented a larger versus a smaller number array; these arrays were equated for cumulative perimeter and surface area, as in the size-to-numerosity group, and also for duration, as in the duration-to-size group. (See the Supplemental Material for stimulus values and Fig. 4 for an illustration of the stimuli presented to both groups.)

Results and discussion

The mean number of habituation trials was 14.8, 18.0, and 16.8 in the space-number, space-time, and number-time conditions, respectively. Analyses of habituation trials (first four vs. last four) revealed significant decreases in looking time in each condition—space-number: $t(23) = 9.01$; space-time: $t(23) = 7.33$; number-time: $t(23) = 9.76$; all $ps < .0001$ (see Figs. 2–4, bottom panels). The habituation criterion was met by all but 6 infants (space-time: 3; number-time: 3).

We analyzed average looking times during the test phase in an ANOVA with condition (space-number, space-time, number-time) and test order (congruent or incongruent trial first) as between-subjects variables and test-trial type (congruent vs. incongruent) as a within-subjects variable. There was a significant main effect of test-trial type, $F(1, 66) = 29.32$, $p < .0001$, but no other significant main effects or interactions ($ps > .1$). To test for possible asymmetrical associations, we conducted a separate ANOVA for each condition with habituation dimension as the between-subjects variable. Looking times were significantly longer for incongruent than for congruent trials in all conditions—space-number: $F(1, 22) = 9.60$; space-time: $F(1, 22) = 10.50$; number-time: $F(1, 22) = 7.85$; all $ps < .05$ (Figs. 2–4, bottom panels). The majority of infants looked longer on incongruent trials (space-number: 18 of 24 infants; space-time: 19 of 24 infants; number-time: 16 of 24

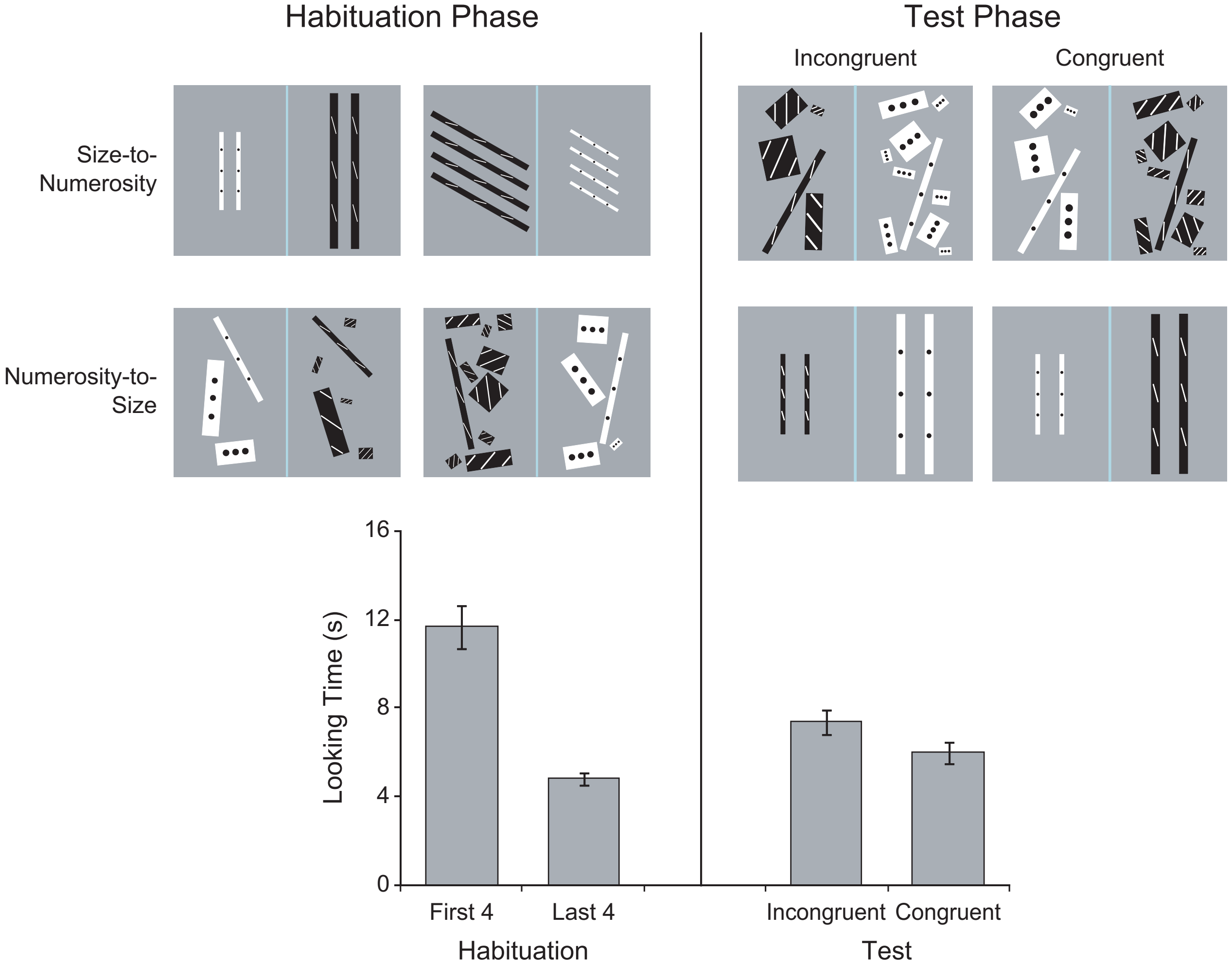

Fig. 2. Stimuli and results in the space-number condition of Experiment 2. The illustrations show examples of stimulus pairs presented during the habituation phase and incongruent and congruent test trials for the size-to-numerosity and numerosity-to-size groups. The graph presents mean looking time for the first four and last four habituation trials and for incongruent and congruent test trials; error bars represent standard errors. Results are collapsed across the two groups (size-to-numerosity and numerosity-to-size), as statistical analyses revealed no significant differences related to group (see the text).

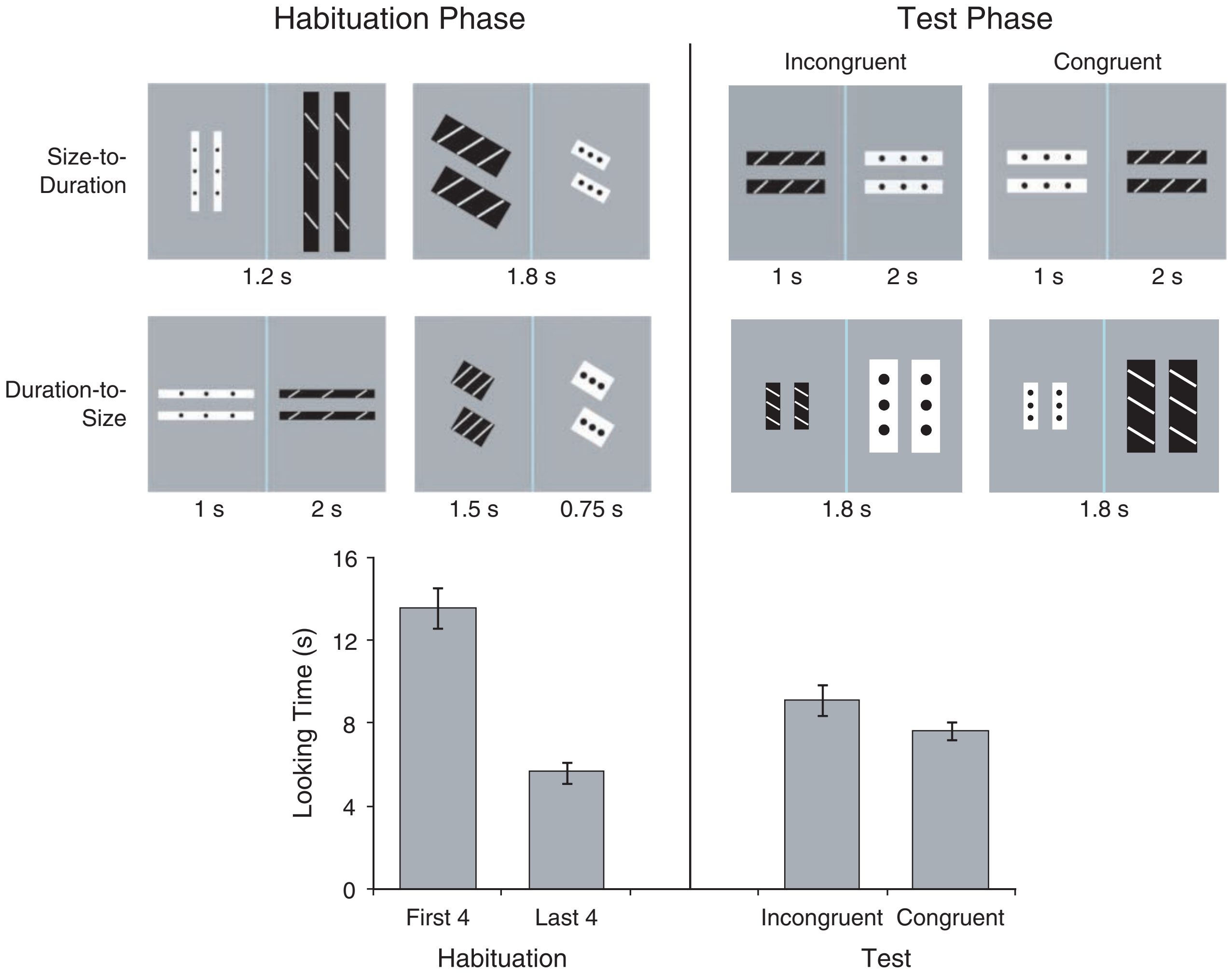

Fig. 3. Stimuli and results in the space-time condition of Experiment 2. The illustrations show examples of stimulus pairs presented during the habituation phase and incongruent and congruent test trials for the size-to-duration and duration-to-size groups. The graph presents mean looking time for the first four and last four habituation trials and for incongruent and congruent test trials; error bars represent standard errors. Results are collapsed across the two groups (size-to-duration and duration-to-size), as statistical analyses revealed no significant differences related to group (see the text).

infants[2]). There were no main effects of habituation dimension (*p*s > .1) and no interactions of test-trial type and habituation dimension (*p*s > .3). These results suggest that the transfer between magnitude dimensions was generally symmetrical.

Infants discriminated congruent and incongruent test trials, providing evidence for the generalization of arbitrary color-pattern mappings across size, numerosity, and duration. Generalizations occurred bidirectionally for all pairings, regardless of which dimension was presented during habituation; thus, infants extended learning from one dimension to another, despite not having previously seen the color-pattern variations for the test dimension. A possible explanation for these generalizations is that infants may have actually failed to discriminate between dimensions. One account of general magnitude representation posits that the dimensions are largely overlapping (one-bit representation), such that space, number, and time might be used interchangeably (Walsh, 2003). Analyses of the first test trials seem inconsistent with this possibility, however. Infants in all conditions looked significantly longer on the first test trial than on the last four habituation trials (averaged), whether that test trial was congruent or incongruent—congruent trials: space-number, $t(23) = 4.66$, $p < .01$; space-time, $t(23) = 4.96$, $p < .01$; number-time, $t(23) = 3.43$, $p < .01$; incongruent trials: space-number, $t(23) = 4.10$, $p < .001$; space-time, $t(23) = 6.28$, $p < .001$; number-time, $t(23) = 4.36$, $p < .001$. That infants dishabituated to both types of test trials indicates that they detected the change in stimuli from the habituation to the test phase and yet still generalized learning concerning the color-pattern mapping across dimensions.

We have suggested that infants in our study transferred learning about the dimension presented during habituation (e.g., duration) to the dimension seen at test (e.g., size).

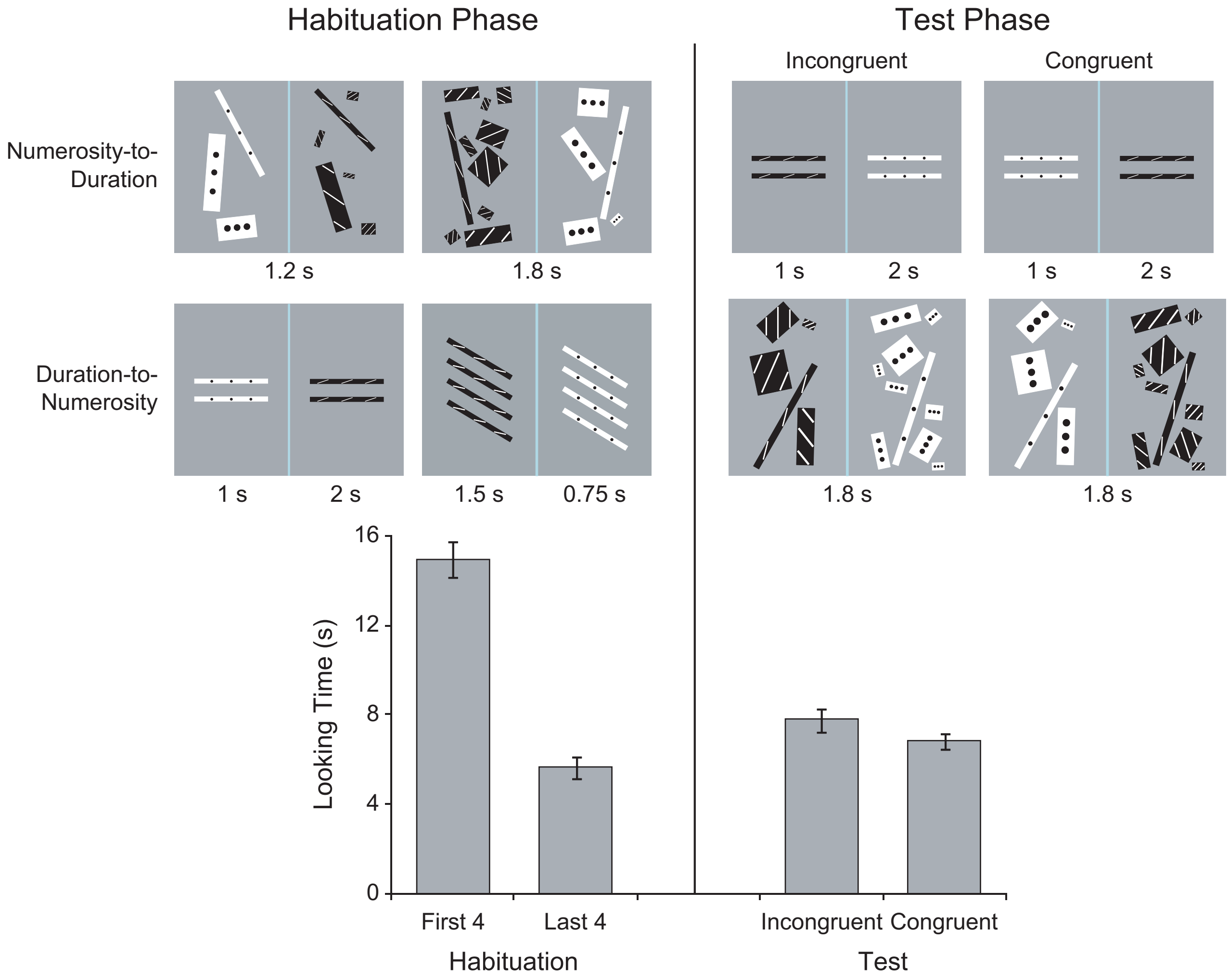

Fig. 4. Stimuli and results in the number-time condition of Experiment 2. The illustrations show examples of stimulus pairs presented during the habituation phase and incongruent and congruent test trials for the numerosity-to-duration and duration-to-numerosity groups. The graph presents mean looking time for the first four and last four habituation trials and for incongruent and congruent test trials; error bars represent standard errors. Results are collapsed across the two groups (numerosity-to-duration and duration-to-numerosity), as statistical analyses revealed no significant differences related to group (see the text).

Another possibility, however, is that generalizations occurred because of misperceptions at early stages of processing. It is possible that viewing one dimension of magnitude led to illusory experiences concerning other magnitude dimensions. Consider the duration-to-size group. If shorter and longer durations during habituation were additionally experienced as smaller and larger sizes, respectively, the novel test stimuli might have been compared with the previous illusory size information, rather than the durations. As stimuli in our study were always presented visually, we cannot exclude this possibility. Although such misperceptions would also provide support for associations among space, number, and time, future research should test for generalizations of magnitude information across different modalities (e.g., vision and audition). If transfer of learning supports generalization, similar patterns of performance should be observed across modalities (see General Discussion). If illusory experiences explained the behavior we observed, then generalizations would be less likely across modalities than within a single modality.

General Discussion

The present findings provide evidence for general magnitude representation early in human life. In our task, information related to one dimension of magnitude influenced preverbal infants' expectations about other magnitude dimensions. Infants appeared to expect, for example, that if black objects with stripes were larger in size than white objects with dots, they also ought to be more numerous and longer lasting. To our knowledge, these findings provide the first direct evidence of shared representations for space, number, and time in preverbal infants, suggesting early, prelinguistic origins of a general magnitude system.

In the case of number, infants have been shown to match numerosities across different sensory modalities (vision and audition), a phenomenon known as *cross-modal number matching* (e.g., Jordan & Brannon, 2006; Starkey, Spelke, & Gelman, 1983; but see Mix, Levine, & Huttenlocher, 1997). Although those findings suggest an abstract representation of number not tied to a particular modality, the present findings of *cross-dimensional magnitude generalization* suggest that number is merely one component of a still more abstract system not tied to specific dimensions. Within a single sensory modality (vision), infants in our study generalized associative learning across magnitude dimensions. Although the exact relation between these two phenomena is unknown, it is an intriguing possibility that magnitude reasoning is, at least partially, independent of both dimension (e.g., size vs. number) and modality (e.g., vision vs. audition). Some authors have argued that specific associations, such as those between number and time (vanMarle & Wynn, 2006), may be cognitively privileged. In our study, however, generalizations held across all combinations of dimensions tested, which suggests that the relation between number and time is only one type of association in a more general system of magnitude representation.

In recent years, much debate has concerned the origins and development of numerical reasoning. Whereas some researchers argue that young infants use cognitive numerical information to make discriminations and to perform arithmetic operations such as addition and subtraction (e.g., Brannon, Abbott, & Lutz, 2004; Wynn, 1992; Xu & Spelke, 2000), others argue that these abilities are supported by more perceptual spatial and temporal cues, such as area and contour length, as well as rate, rhythm, and duration (e.g., Clearfield & Mix, 1999; Mix et al., 2002). This debate presupposes that representations of space, number, and time are dissociable, with distinct underlying mechanisms (cf. Castelli, Glaser, & Butterworth, 2006). The present results, however, suggest that such an assumption may not be entirely accurate. Although the distinctions among magnitude dimensions may be salient to researchers, they may be less so from the perspective of the infant.

For any dimension of magnitude, paired items of unequal values involve an item that is “more than” or “less than” another. By drawing on a common language of measurement, namely, the ordered property of unequal values, a general magnitude system may facilitate comparisons across multiple dimensions. In extant models, shared processing resources are rooted in the need to represent covariance in the physical world, as well as to structure relevant action sequences (Gallistel & Gelman, 1992; Walsh, 2003). In a world where spatial, numerical, and temporal cues are highly correlated, representing different dimensions with a shared vocabulary may constitute a powerful learning mechanism, allowing information related to one dimension to be used in making predictions, and evaluating variation, in other dimensions. But just how general is general magnitude representation? Research with children and adults suggests that all information that can be conceptualized in ordinal (more/less) terms may share representational resources. Among the possible candidate dimensions are speed (Levin, 1977; Siegler & Richards, 1979), loudness (Smith & Sera, 1992), luminance (Levin, 1977; Pinel et al., 2004; Smith & Sera, 1992), and even less prototypical sources of magnitude information, such as emotional expression (Holmes & Lourenco, 2009).

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Declaration of Conflicting Interests

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Supplemental Material

Additional supporting information may be found at http://pss.sagepub.com/content/by/supplemental-data

Notes

1. Although it was not possible to systematically control for particular density cues, namely, interelement distances in the arrays presented during test, we attempted to ensure that smaller and larger distances were represented in both stimulus arrays in each pair across test trials. Nevertheless, the greater the number of items in an array, the smaller the interelement distances on average. It is unlikely, however, that differences in interelement distances can account for differences in looking times between congruent and incongruent test trials because the size stimuli presented during habituation involved equal interelement distances.
2. Within the specific groups, the numbers of infants showing longer looking times on incongruent test trials than on congruent test trials were as follows—size-to-numerosity: 10/12; numerosity-to-size: 8/12; size-to-duration: 10/12; duration-to-size: 9/12; numerosity-to-duration: 7/12; duration-to-numerosity: 9/12.

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