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REPORT

Perception of serial order in infants

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Abstract

Serial order is fundamental to perception, cognition and behavioral action. Three experiments investigated infants' perception, learning and discrimination of serial order. Four- and 8-month-old infants were habituated to three sequentially moving objects making visible and audible impacts and then were tested on separate test trials for their ability to detect auditory, visual or auditory-visual changes in their ordering. The 4-month-old infants did not respond to any order changes and instead appeared to attend to the 'local' audio-visual synchrony part of the event. When this local part of the event was blocked from view, the 4-month-olds did perceive the serial order feature of the event but only when it was specified multimodally. In contrast, the 8-month-old infants perceived all three kinds of order changes regardless of whether the synchrony part of the event was visible or not. The findings show that perception of spatiotemporal serial order emerges early in infancy and that its perception is initially facilitated by multimodal specification.

Introduction

Serial order is fundamental to perception, cognition and behavioral action (Baldwin & Baird, 2001; Fraisse, 1982; Lashley, 1951; Zacks & Tversky, 2001). For example, the perception and interpretation of language, music, dance and the behaviors of others all depend, in part, on our ability to perceive the sequential ordering of a series of elements (Baldwin & Baird, 2001; Zacks & Tversky, 2001). Perhaps the most impressive way in which we capitalize on this ability is our knack for 'reading' other people's intentions from the sequential structure of their actions.

It has been proposed that the ability to read others' intentions is mediated by a generative knowledge system that discerns intentions in actions based specifically on their sequential organization (Baldwin & Baird, 2001). It is likely that this knowledge system depends, in part, on the ability to parse the surface characteristics of sequentially organized events (Conway & Christiansen, 2001). Based on Piaget's (1952) observations of infant behavior, it is reasonable to postulate that the ability to parse the surface characteristics of sequential events and the ability to perceive their structure most likely has its developmental roots in infancy. Piaget claimed that serial order skills emerge during the fourth stage of sensorimotor development (between 8 and 9 months of age) where infants begin to develop relatively complex means–ends skills. It is at this stage that infants first become capable of stringing together familiar but distinct action patterns into a series of actions and that such a series then provides them the means to an end. Furthermore, and perhaps even more importantly, it is at this stage that infants can recombine a series of actions into novel sequences. Piaget interpreted this newly emerging ability as a reflection of concurrent elaborations in the infant's mental capacities needed to support the production of sequentially organized actions.

In general, indirect as well as direct empirical evidence supports to some extent Piaget's claims regarding infants' serial order skills. Indirect evidence on infants' ability to detect and perceive the temporal distribution of information (an essential sub-component of serial order processing) shows that infants can perceive various forms of temporal information. For example, infants can perceive: (a) the temporal rate of audiovisual events (Lewkowicz, 1992), (b) the rhythmic structure of auditory (Trehub & Thorpe, 1989) and audiovisual events (Lewkowicz, 2003; Pickens & Bahrick, 1997), (c) intersensory relations based on temporal synchrony and duration (Lewkowicz, 2000) and (d) they can form expectations based on temporal relations (Canfield & Haith, 1991). Perhaps most impressive is the finding that by 6 months of age infants exhibit evidence of audiovisual illusions resulting from the specific spatiotemporal relations between ambiguously

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moving objects and sounds (Scheier, Lewkowicz & Shimojo, 2003).

More direct evidence that comes from studies that have examined infants' response to or production of serially organized sequences also suggests that infants possess serial order skills. Briefly, it has been reported that infants can: (a) perceive word order (Mandel, Nelson & Jusczyk, 1996), (b) learn to move a series of mobiles and remember the order in which they moved them 24 hours later (Merriman, Rovee-Collier & Wilk, 1997), (c) learn the transitional probabilities between adjacent members of a sequence of speech sounds (Aslin, Saffran & Newport, 1999) and (d) learn, remember and reproduce multi-act sequences in the correct order (Bauer, Wiebe, Waters & Bangston, 2001; Carver & Bauer, 1999, 2001; Wenner & Bauer, 1999). Unfortunately, not all of this evidence can be unambiguously interpreted as proof that infants perceive serial order *per se*. For example, infants' reported ability to perceive word order actually appears to be based on the overall prosody of the sentences in which the words were embedded rather than on their order. Infants' apparent ability to remember the order in which they kicked a series of mobiles actually depends on first being primed with the directly preceding mobile (Gulya, Rovee-Collier, Galluccio & Wilk, 1998). The necessity for priming with the directly preceding mobile suggests that rather than learning the overall serial ordering of the mobiles, infants might have simply learned to pair adjacent actions. In a similar vein, infants' ability to learn the transitional probabilities between the adjacent members of a sequence of speech sounds only provides evidence of paired-associate learning. Finally, Bauer and colleagues' results clearly show that infants can encode the order of a series of actions. Unfortunately, these investigators did not manipulate the specific ordering of the component actions and thus do not provide data that are of particular relevance to the current study.

The greatest challenge to studies investigating serial order perception is being able to rule out low-level explanations for successful performance. As noted earlier, a number of studies to date provide, at best, evidence that infants can form paired associates. Lashley (1951) pointed out, however, that associative chaining cannot account for the complexity of sequential temporal organization observed in behavior, and he made the critical point that it is the overall 'syntax' of a sequence that gives it true meaning. Lashley noted that the syntax of a sequence is determined not only by local associations between adjacent elements but by distant relations as well. Thus, more convincing proof that infants can perceive sequential organization requires evidence that they can perceive the ordinal position of each of a series of items. Adult pigeons, monkeys (Chen, Swartz & Terrace, 1997; Orlov, Yakovlev, Hochstein & Zohary, 2000) and humans (Ebenholtz, 1963) possess such a skill but it is not known whether infants do. Evidence that infants possess this skill would provide further support for its non-verbal nature and would shed additional light on the processes that contribute to the ultimate developmental emergence of many perceptual, cognitive, linguistic and social skills.

The aim of the current study was to investigate whether infants can perceive serial order, with a particular emphasis on whether they can detect the ordinal position of the members of a series of items. The study was based on the premise that infants are most likely to exhibit successful detection of serial order if the events used to test this ability are multimodal in nature. This premise is based on the fact that most of our everyday sensory experiences are multimodal in nature (Stein & Meredith, 1993) and on the theoretical expectation that multimodal specification of the perceptual array is likely to be a particularly salient source of information, both for adults (Gibson, 1979) and for infants (Gibson, 1984). This premise is also based on the findings from a large body of evidence showing clearly that adults (Partan & Marler, 1999; Rowe, 1999) as well as infants (Lewkowicz, 1988, 2002) often profit from multimodal redundancy.

With specific regard to early development, Gibson's (1969, 1984) increasing specificity view of perceptual development emphasizes the fact that young infants derive a special perceptual learning benefit from multimodal event specification. Indeed, recently, Bahrick and Lickliter (2000) have provided a particularly clear example of this principle by showing that infants can learn about a rhythmical event more easily when it is specified multimodally than if it is specified unimodally. If multimodal redundancy plays an especially important role in early perceptual development, then it is reasonable to hypothesize that it also may play a role in younger infants' perception, learning and discrimination of serial order. As infants get older, however, they become increasingly better at perceiving the unimodal and modality-specific features of events (Bahrick, 1994). As a result, it is likely that older infants may not rely as much on multimodal specification and may exhibit equally facile detection of unimodally and multimodally specified serial order.

To put these predictions to empirical test, 4- and 8-month-old infants were habituated to an audiovisual display consisting of sequentially moving and sounding objects and then tested in separate test trials for their ability to detect changes in the auditory, visual and audiovisual attributes of serial order. Experiment 1 provided baseline data on infants' perception and discrimination of serial order and indicated that 4-month-old infants did not detect it but that 8-month-old infants did. Experiment 2 tested the hypothesis that the younger infants' attention to a local perceptual attribute (i.e. the audiovisual impact part of the event) blocked their perception of the global attribute of order. Results confirmed this hypothesis in showing that the younger infants now detected the change, although only the multimodal one. Finally, Experiment 3 tested discrimination of serial order following exposure to its visual-only instantiation and showed that only the 8-month-old infants could perceive, learn and discriminate visually specified serial order.

Experiment 1

The purpose of this experiment was to determine whether infants can perceive a reordering of a series of identical items. Thus, infants were habituated to one spatiotemporal ordering of three sequentially moving objects and their impact sounds (e.g. an ABC ordering) and then were given separate discrimination test trials in which a CAB ordering of either the objects, the sounds, or of both was presented.

Method

Participants

Twenty-four 4-month-old infants (mean age = 19.6, SD = 1.0 week; 15 boys and 9 girls) and 24 8-month-old infants (mean age = 35.4, SD = 3.5 weeks; 9 boys and 15 girls) were tested. All the infants tested in this as well as in the subsequent experiments were full-term at the time of birth and were born without complications.

Apparatus and stimuli

Multimedia movies of sequentially moving/sounding objects were presented on a 15-inch computer monitor at a distance of 50 cm from the infant. The audio part of the movie was presented through speakers placed on either side of the monitor. The objects in the movies (see Figure 1) were labeled as follows: Object A – the circle, Object B – the triangle, Object C – the square. The impact sounds were 'wav' files included with the Microsoft Windows 98 operating system and were labeled as follows: Sound A – the JungleSingDrumMono.wav sound, Sound B – the UtopiaDink.wav sound and Sound C – the SportsPPongMono.wav sound. Four movies were made to represent the four possible combinations of auditory and visual order: auditory-ABC/visual-ABC, auditory-CAB/visual-CAB, auditory-CAB/visual-ABC and auditory-ABC/visual-CAB.

The objects and their corresponding sounds were used to construct a sequence that had the following temporal parameters. At the start of the sequence, the first object emerged out of the grey spout and began to move down. It was followed 0.5 s later by the second object, which was then followed 0.5 s later by the third object. All three objects moved down at the same and constant speed until each contacted the top of the ramp. It took each object 1.55 s to contact the ramp. At the point of contact, the impact sound corresponding to the respective object was played. As soon as each object contacted the ramp, it changed direction without stopping and slid down the ramp to the right until it came to rest. The objects came to rest 5.15 s, 5.4 s and 5.65 s, respectively, after they appeared. Once the last object came to rest, all

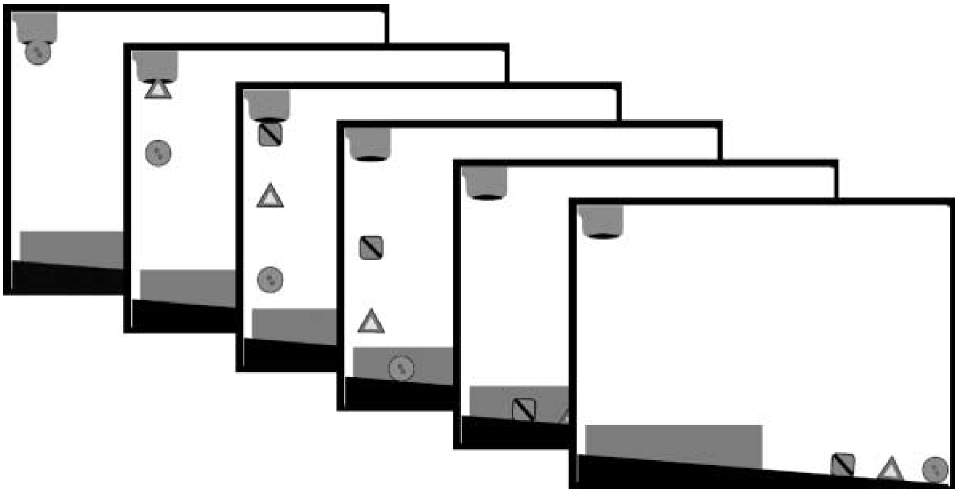

Figure 1 *The three visual objects and the schematic representation of their movement over time in Experiment 1. As can be seen, the objects moved in front of the grey rectangle.*

Table 1 *The temporal orders presented to each habituation group and the specific order changes in each of four types of test trials. The letters A, B and C designate each distinct object and its corresponding impact sound (see Method section for details)*

	Test trials			
Habituation group	Familiar	Auditory	Visual	Auditory-visual
ABC	Auditory-ABC Visual-ABC	Auditory-CAB Visual-ABC	Auditory-ABC Visual-CAB	Auditory-CAB Visual-CAB
CAB	Auditory-CAB Visual-CAB	Auditory-ABC Visual-CAB	Auditory-CAB Visual-ABC	Auditory-ABC Visual-ABC

three objects remained visible for 0.5 s , then disappeared for 0.75 s. At the end of this period, the sequence started anew. The total cycle time from the appearance of the first object to its reappearance at the start of the next cycle was 6.9 s.

In addition to the four serial order movies, two additional movies were made. One was an attention-getter movie showing an expanding and contracting green disk. The purpose of this stimulus was to attract the infant's attention back to the monitor after the infant looked away from the monitor. The other movie consisted of a segment of a Winnie-the-Pooh cartoon and was used in a pre- and post-test trial.

Procedure

Infants were observed by an experimenter who was located in a separate control room and, thus, was blind with respect to the specific stimulus condition being administered during the test session. Whenever the infant was not looking at the monitor, the attention-getter was shown to attract the infant's attention. As soon as the infant looked at the attention-getter, it disappeared and the appropriate movie began to play.

An infant-controlled habituation/test procedure was used to test learning and discrimination. This meant that the length of each trial, regardless of whether it was an habituation or a test trial, was controlled by the infant's looking at the monitor. In essence, whenever the infant looked at the monitor, the appropriate movie (i.e. trial) commenced. Whenever the infant either looked away from the monitor for more than 1 second or accumulated a total of 48 seconds of looking, the trial ended. The habituation trials continued up to the point when a habituation criterion was reached. The criterion required that the total duration of looking during the last three habituation trials decline to 50% of the total duration of looking during the first three habituation trials. Once an infant reached the habituation criterion, the test phase was initiated without any interruption.

The experiment began with a single pre-test trial. The purpose of this trial was to measure the infant's initial level of attention. This was followed by the habituation phase. Half the infants at each age were randomly assigned to an auditory-ABC/visual-ABC habituation movie and half were assigned to an auditory-CAB/visual-CAB habituation movie. The test phase consisted of four types of test trials (see Table 1). The first test trial for all infants was the familiar (F) test trial. The duration of looking in the F test trial provided a baseline measure of attention against which response recovery to each of the novel, order-change test trials was compared. The test trials that followed the F test trial were designed to separately test infants' perception of combined audio-visual order changes as well as changes only in the auditory or only in the visual modality. These trials were presented equally often in each ordinal position in this series of test trials. A significant increase in the duration of looking in any of the order-change test trials relative to the duration of looking in the F trial was taken as evidence that infants detected the respective order changes. The experiment ended with the presentation of a single post-test trial during which the cartoon was presented again to measure the terminal level of attention.

Results and discussion

Figure 2 shows the results from the habituation and test trials from Experiment 1. A two-way, repeated-measures analysis of variance (ANOVA), with age (2) as the between-subjects factor and habituation trials as the within-subjects factor, was used to determine whether the two age groups differed in their habituation response profiles. As can be seen in Figure 2, the course of habituation was virtually identical in the two age groups and this was borne out by the ANOVA which yielded a significant overall trials effect, $F(5, 230) = 49.9$ $p < .001$, but no other effects. The absence of an age × trials effect indicates that the habituation response profiles did not differ in the two age groups and, thus, that any differential results in the test trials could not have been affected by habituation. The test trial data were analyzed by way of a four-way, repeated-measures ANOVA, with age (2), habituation stimulus (2) and test trial ordering (6) as

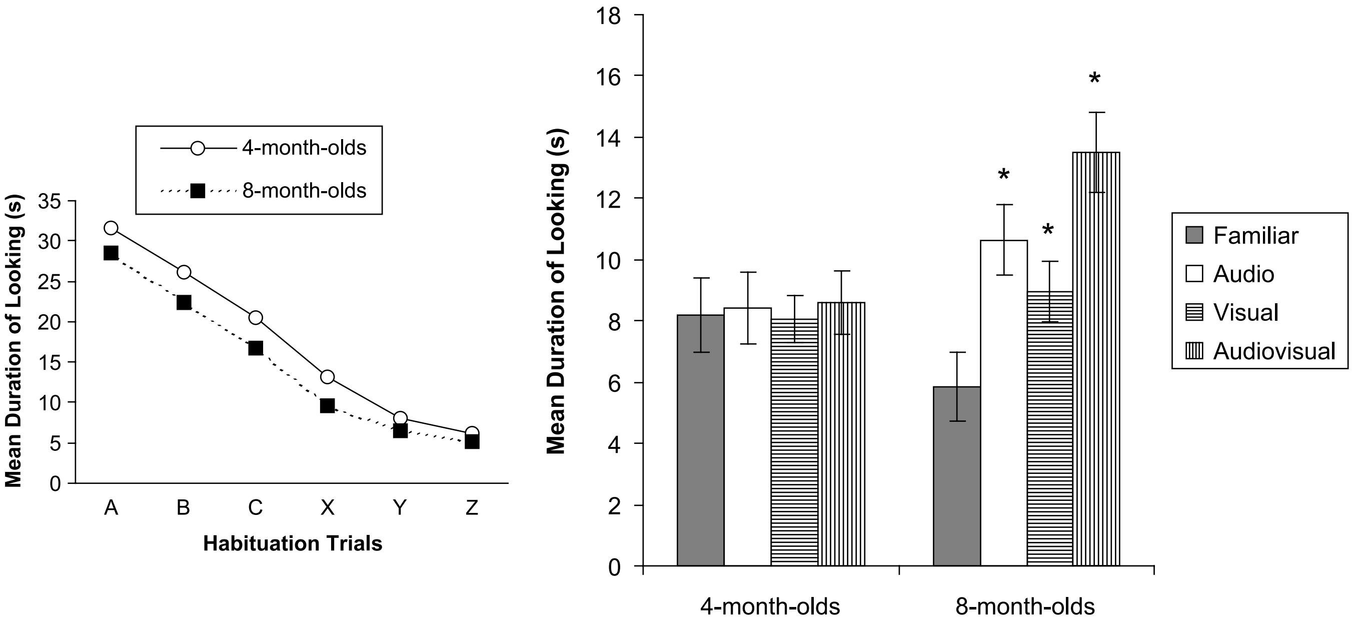

Figure 2 *Left panel shows the duration of looking during the first three (A, B and C) and last three (X, Y and Z) habituation trials for each infant in Experiment 1. The right panel shows the duration of looking to the auditory, visual and auditory-visual order changes in the test trials of Experiment 1. Error bars indicate the standard error of the mean and asterisks indicate significant response recovery.*

between-subjects factors, and test trial type (4) as the within-subjects factor. This analysis yielded a significant trials effect, $F(3, 72) = 3.69$, $p < .025$, and a significant trials × age interaction, $F(3, 72) = 2.92$, $p < .05$. This overall analysis was then followed up with separate planned comparison tests at each age, comparing the duration of looking in each order-change test trial, respectively, and the duration of looking in the F test trial. Results of these tests revealed that the 4-month-old infants exhibited no significant response recovery in any of the three test trials. In contrast, results showed that the 8-month-old infants exhibited significant response recovery in the auditory, $F(1, 24) = 5.35$, $p < .05$, visual, $F(1, 24) = 4.63$, $p < .05$, and auditory-visual, $F(1, 24) = 16.52$, $p < .001$, test trials.

To determine whether the younger infants' failure to detect the order changes might have been due to fatigue, the duration of looking in the post-test trial was compared to the duration of looking in the pre-test and in the F test trials, respectively. Because the cartoon presented in the pre- and post-test trials was very different from the stimulus events, its inherent novelty should have elicited a high level of looking at the start and end of the experiment if infants were not fatigued. Indeed, the 4-month-olds looked an average of 31.1 s in the pre-test trial and an average of 36.7 s in the post-test trial. The 8-month-olds looked an average of 15.8 s in the pre-test trial and an average of 17.8 s in the post-test trial. Moreover, the 4-month-olds exhibited greater looking in the post-test trial relative to the F test trial, $F(1, 24) = 153.09$, $p < .001$, as did the 8-month-olds, $F(1, 24) = 26.8$, $p < .001$. Thus, the findings from the pre- and post-test trials indicate that the younger infants' failure to exhibit response recovery in the order-change test trials cannot be explained by fatigue.

The findings from this experiment suggest that the ability to perceive and learn an audiovisual, spatiotemporally ordered sequence emerges between 4 and 8 months of age and that by the time it is present, infants can perceive its audible, visible and audiovisual attributes equally well. Given the previously cited reports of infants' ability to perceive serially organized events and/or to produce serially organized actions, the 4-month-old infants' failure to discriminate even the most salient, audiovisual change suggests that perception of a reordering of a series of elements is more difficult for infants at this age than might be the perception of paired associates.

Experiment 2

Previous research (Lewkowicz, 1996) has shown that when young infants watch a moving object and hear its impact sound, they tend to focus on the temporal synchrony part of such an event. This suggests that the 4-month-old infants' natural propensity to attend to audiovisual synchrony may have hindered their perception of serial order in Experiment 1. In other words, the 4-month-olds' failure to perceive serial order may have been due to their uniquely developmental predisposition to attend to what in the present case is a 'local' event feature. To determine if this was the case, the auditory-visual synchrony part of the event was blocked from view in Experiment 2. It was hoped that this would shift the younger infants' attention to the more 'global', serial-order nature of the event. In addition, based on the fact that the auditory-visual order change is the most perceptually salient, it was hoped that blocking the local feature would, at the least, enable the 4-month-old infants to perceive the most salient, auditory-visual, order change.

Method

Participants

The participants were 24 4-month-olds (mean age = 18.8, SD = 0.9 weeks; 13 boys and 11 girls) and 24 8-month-olds (mean age = 35.1, SD = 4.3 weeks; 12 boys and 12 girls).

Apparatus, stimuli and procedure

This experiment was identical to Experiment 1 except that the grey rectangle shown in Figure 1 was moved in front of the objects' motion path. As a result, the impact sounds could still be heard but the visible impacts could no longer be seen.

Results and discussion

Figure 3 shows the results from the habituation and test trials from Experiment 2. The two-way, repeated-measures ANOVA, with age (2) as the between-subjects factor and habituation trials as the within-subjects factor, yielded a significant trials effect, $F(5, 230) = 52.6$, $p < .001$, but no significant age × trials interaction. This result shows that the two age groups did not differ in their habituation response profile. The test trial data once again were analyzed by way of a four-way, repeated-measures ANOVA, with age (2), habituation stimulus (2) and test trial ordering (6) as between-subjects factors and test trial type (4) as the within-subjects factor. This analysis yielded a significant trials effect, $F(3, 72) = 6.18$, $p < .001$ and no other effects.

It should be noted that even though Figure 2 suggests that the 4-month-olds showed a recovery to all three types of changes, the planned comparison tests indicated that only the auditory-visual change reached statistical significance, $F(1, 24) = 5.94$, $p < .025$ (auditory: $F(1, 24) = 2.89$, *ns*; visual: $F(1, 24) = 2.06$, *ns*). In contrast to the younger infants and similar to the findings from Experiment 1, the 8-month-old infants responded to all three types of changes: auditory, $F(1, 24) = 6.14$, $p < .025$, visual, $F(1, 24) = 7.58$, $p < .025$, and auditory-visual,

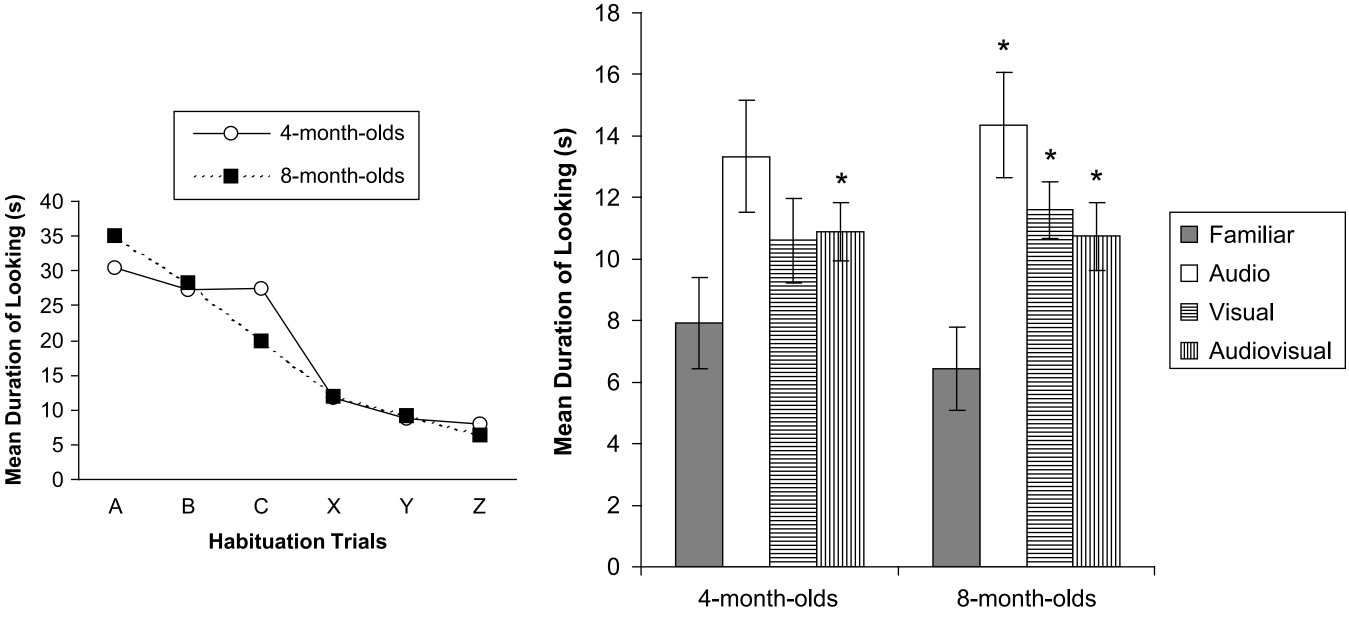

Figure 3 *Left panel shows the duration of looking during the first three (A, B and C) and last three (X, Y and Z) habituation trials for each infant in Experiment 2. The right panel shows the duration of looking to the auditory, visual and auditory-visual order changes in the test trials of Experiment 2. Error bars indicate the standard error of the mean and asterisks indicate significant response recovery.*

F(1, 24) = 12.27, $p < .01$. Finally, neither the 4- nor the 8-month-old infants exhibited any evidence of fatigue. The 4-month-olds looked an average of 40.1 s in the pre-test and 37.6 s in the post-test trials and the 8-month-olds looked an average of 12.5 s in the pre-test and 18.1 s in the post-test trials. Also, the 4-month-olds exhibited significant response recovery in the post-test trial, *F*(1, 24) = 118.6, $p < .001$, as did the 8-month-olds, *F*(1, 24) = 17.9, $p < .001$. This last finding shows, once again, that fatigue could not have accounted for the 4-month-olds' failure to respond to the auditory or to the visual serial order changes.

Experiment 3

The 4-month-old infants' response to the auditory-visual order change supports the initial prediction that the redundancy of multisensory specification may facilitate serial order perception in early development. Likewise, the 8-month-olds' response to all three types of changes is consistent with the conclusion that perceptual differentiation during development most likely makes it possible for older infants to take advantage of unisensory input specifying serial order. What is not clear from Experiments 1 and 2, however, is whether it is essential that the initial learning of serial order be multimodal, *per se*, and whether multimodal specification of order in the test trials affects infants' discrimination performance. To put this question to empirical test, in this experiment infants were habituated and tested with unimodal sequences consisting of the same moving objects as presented in the prior two experiments except that this time no impact sound was presented.

Method

Participants

The participants were 24 4-month-olds (mean age = 19.1, SD = 1.1 weeks; 16 boys and 8 girls) and 24 8-month-olds (mean age = 36.6, SD = 0.77 weeks; 9 boys and 15 girls).

Apparatus and stimuli

The apparatus and stimuli were identical to those used in Experiment 1 except that no impact sounds were presented.

Procedure

Infants were habituated with the ABC order and tested with the CAB order. The calculation of the habituation criterion in this experiment was based on a sliding window where the three terminal habituation trials began with the second trial (rather than with the fourth trial as in the previous two experiments). This was done to reduce the overall duration of the habituation phase to minimize participant loss due to the less interesting nature of the silent events.

To determine whether making the visual impact part of the event invisible affected responsiveness, half the 4-month-olds and 11 of the 8-month-olds watched the moving objects while they passed in front of the grey rectangle and half the 4-month-olds and 13 8-month-olds watched the objects while they passed behind the grey rectangle. As before, infants were given a pre- and a post-test trial to measure fatigue effects. The test phase consisted of two trials: an F test trial and a novel order test trial. The test trials were presented in counterbalanced order across infants at each age.

Results and discussion

Figure 4 shows the results from the habituation and test trials from Experiment 3. Because an infant could reach the habituation criterion in a minimum of four trials, the habituation part of Figure 4 shows the first (A) and the last three (X, Y and Z) habituation trials (please note that 22 of the 4-month-olds and 22 of the 8-month-olds took at least five or more trials to habituate). The two-way, repeated-measures ANOVA, with age (2) as the between-subjects factor and habituation trials as the within-subjects factor, yielded an overall trials effect, *F*(3, 138) = 63.6, $p < .001$, but no significant age × trials interaction. This shows that the two age groups did not differ in their habituation profiles.

The right panel of Figure 4 shows that the 4-month-old infants did not detect the serial order change but that the 8-month-old infants did. A three-way, repeated-measures ANOVA, with age (2), impact visibility condition (2) and test trial order (2) as between-subjects factors and test trial (2) as the within-subjects factor yielded an overall trials effect, *F*(1, 40) = 7.10, $p < .025$. Planned comparisons showed that this effect was due to a significant response recovery in the 8-month-olds, *F*(1, 40) = 6.38, $p < .025$, but not in the 4-month-olds, *F*(1, 40) = 1.54, $p = ns$. Fatigue did not account for the 4-month-olds' failure to discriminate. They looked an average of 35.2 s in the pre-test trial and 36.3 s in the post-test trial and exhibited significant response recovery in the post-test trial, *F*(1, 40) = 104.5, $p < .001$. The 8-month-olds looked an average of 16.3 s in the pre-test trial and 27.7 s in the post-test trial and exhibited recovery in the post-test trial, *F*(1, 40) = 60.26, $p < .001$.

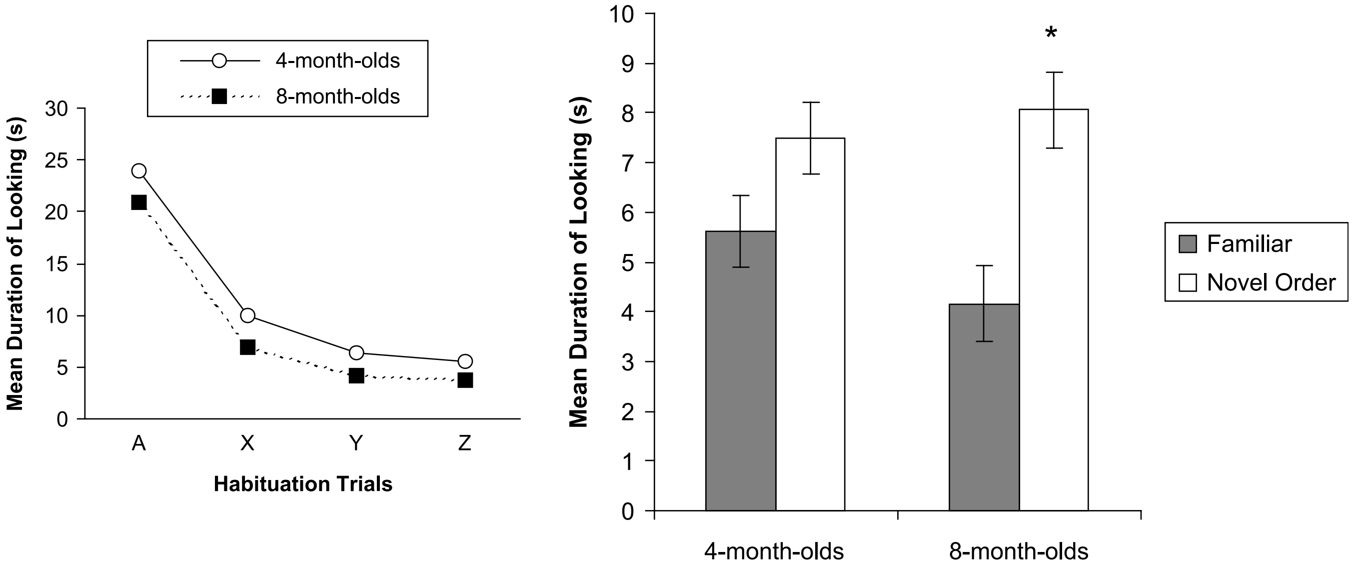

Figure 4 *Left panel shows the duration of looking during the first (A) and the last three (X, Y and Z) habituation trials in Experiment 3. The right panel shows the duration of looking to a serial order change specified solely in the visual modality in Experiment 3. Error bars indicate the standard error of the mean and the asterisk indicates significant response recovery.*

General discussion

Together, the current findings provide the first direct evidence that infants can perceive and learn the sequential ordering of a series of items and then detect its reordering. Interestingly, and consistent with theoretical expectations, this ability initially appears to depend on multimodal specification. That is, 4-month-old infants perceived spatiotemporal serial order but only if it was multimodally specified during the learning and discrimination phases. In contrast, 8-month-old infants perceived serial order regardless of whether it was multimodally or unimodally specified. In fact, what was most impressive about the older infants was that they displayed the ability to attend selectively to changing order information in one modality while at the same time ignoring unchanging order information in the other modality.

The finding of a multimodal redundancy effect raises an interesting question regarding the mechanisms underlying this effect. Might infants have been responding to the objects and their sounds as intermodally integrated units? The nature of the events makes this unlikely because the visual information specifying order became available at the beginning of each event cycle whereas the auditory information specifying order did not become available until 1.55 s into the cycle and, then, only for a brief moment. In other words, the absence of a clear, one-to-one, audio-visual relation made it difficult to perceive the auditory and visual attributes of the event as unified. In addition, the 4-month-olds only successfully detected an order change when the audio-visual synchrony part of the event was blocked from view in Experiment 2. This finding suggests that the 4-month-olds processed the order information in terms of parallel and separate streams of unimodal information. The results from the 8-month-old infants also suggest that they processed the information as separate streams because they responded to the two unimodal changes in Experiments 1 and 2 and because they did so regardless of whether or not the synchrony part of the event was blocked from view.

The temporal nature of the events presented here raises the possibility that infants based their successful discriminative responses either on the difference in the first object, the first sound, or on both. This is unlikely for several reasons. First, the 4-month-olds did not respond to the change in the visual test trial in Experiments 1 and 2 even though the first object differed across the habituation and test phases in this trial. Second, the 4-month-olds' failure to detect the visual order change suggests that their successful detection of the auditory-visual order change in Experiment 2 could not have been based solely on the visual aspects of this change (and thus the difference in the first object). Third, the 4-month-olds did not respond to the visual-only order change in Experiment 3 despite the fact that the events again differed in terms of their first object. Fourth, it is also unlikely that infants relied on the bimodally specified differences defined by the first object and its sound because the first impact sound did not even occur until

1.55 s had elapsed. By the time 1.55 s elapsed, all three objects were already visible. This would have made the perceptual segregation of the first object and the first sound essentially impossible. Finally, we have recently obtained direct empirical evidence that definitively rules out the role of the first object and its sound in discrimination (unpublished observations). Using procedures identical to those used in Experiment 1, we habituated 4-month-old infants with an ABC sequence of objects and sounds and then tested them with an ACB sequence. Despite the fact that the first object/sound element of the two sequences did not differ, infants still exhibited significant discrimination of the audio-visual change.

The finding that the ability to perceive the ordering of a series of items emerges prior to the emergence of language is interesting because this is a basic skill involved in many complex functions, including language (Lashley, 1951). The fact that infants as young as 4 months of age can perform this spatiotemporal serial order task is even more impressive. In general, findings show that the perception and learning of serial lists that are temporally distributed is more difficult than if such lists consist of spatially distributed and simultaneously available items. For example, adult monkeys can successfully learn whether a probe item was part of a previously seen list consisting of as many as 20 simultaneously visible items (Sands & Wright, 1980) but show considerably lower accuracy when they have to remember which of two images appeared earlier in a list of five arbitrarily chosen items (Gower, 1992). The fact that infants as young as 4 months of age can perceive and learn spatiotemporally distributed lists, especially when they are multimodally specified, is a testament to humans' greater sequential learning powers early in development and the potency of multimodal specification for perception. Perhaps such an early emergence of this ability is no accident. As noted earlier, this ability provides the necessary underpinnings for the subsequent development of complex linguistic, cognitive and social interaction skills that characterize human behavior and, thus, its early developmental appearance makes a great deal of sense.

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