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ARTICLE WITH PEER COMMENTARY AND RESPONSE

Sound induces perceptual reorganization of an ambiguous motion display in human infants

Christian Scheier,[1] David J. Lewkowicz[2] and Shinsuke Shimojo[1,3]

1. *California Institute of Technology, USA*
2. *New York State Institute for Basic Research in Developmental Disabilities, USA*
3. *NTT Communication Science Laboratories, USA*

Abstract

Adults who watch an ambiguous visual event consisting of two identical objects moving toward, through, and away from each other and hear a brief sound when the objects overlap report seeing visual bouncing. We conducted three experiments in which we used the habituation/test method to determine whether these illusory effects might emerge early in development. In Experiments 1 and 3 we tested 4-, 6- and 8-month-old infants' discrimination between an ambiguous visual display presented together with a sound synchronized with the objects' spatial coincidence and the identical visual display presented together with a sound no longer synchronized with coincidence. Consistent with illusory perception, the 6- and 8-month-old, but not the 4-month-old, infants responded to these events as different. In Experiment 2 infants were habituated to the ambiguous visual display together with a sound synchronized with the objects' coincidence and tested with a physically bouncing object accompanied by the sound at the bounce. Consistent with illusory perception again, infants treated these two events as equivalent by not exhibiting response recovery. The developmental emergence of this intersensory illusion at 6 months of age is hypothesized to reflect developmental changes in object knowledge and attentional mechanisms.

Introduction

Even though the world is specified by physically distinct multimodal sensory inputs, our perceptual experiences are of unified and unitary objects and events. This raises a fundamental question for behavioral neuroscience: how are distinct sensory inputs integrated into unified perceptual experiences (Marks, 1978)? Research has shown that intersensory integration relies heavily on the spatio-temporal correspondences that normally help to bind the distinct heteromodal features of objects and events (Gibson, 1966; Stein & Meredith, 1993; Welch & Warren, 1986). The ability to take advantage of such correspondences emerges early in human development (Lewkowicz, 2000; Lewkowicz & Lickliter, 1994). Indeed, perception of intersensory relations is fundamental to the development of perception, cognition and action (Gibson, 1969; Piaget, 1952; Thelen & Smith, 1994; Werner, 1973). To date, studies investigating the developmental emergence of intersensory abilities have focused mainly on infants' perception of intersensory equivalence relations. Sights and sounds can, however, be related in other ways besides specifying the same information. Thus, seeing something can change the way we hear it. For example, the McGurk (McGurk & MacDonald, 1976) effect shows how when we see lips produce a syllable that conflicts with a simultaneously heard syllable we perceive a change in its audible character. The ventriloquism effect (Bertelson & Radeau, 1981) shows how the localization of a sound source can be changed by a spatially discordant visual stimulus. These kinds of illusory effects demonstrate the strong links between the sensory modalities and the perceptual system's propensity for unifying distinct sensory inputs.

Recently, Sekuler, Sekuler and Lau (1997) reported a new type of intersensory illusion that demonstrates the power of a simple auditory stimulus to reorganize visual perception. These investigators reported that when adult subjects watch two identical disks moving from opposite sides toward and then past one another at equal and constant speed, most perceive them as streaming through one another when no sound is presented. In contrast, when a sound is presented at the moment when the two visual stimuli coincide, a significant number of subjects

Address for correspondence: Christian Scheier, California Institute of Technology, Biology Division, MC 139-74, CA 91125, Pasadena, USA; e-mail: scheier@mediaanalyzer.com

report perceiving bouncing. This effect is intriguing because it mimics a real-world collision between two objects that in reality do not collide. It suggests that perceptual interpretation of such an event depends on the occurrence of the sound in spatio-temporal register with the objects' coincidence.

Shimojo and his colleagues have argued that it is rapid attentional shifting that governs the ambiguity-solving in the bouncing illusion task in adults (Watanabe & Shimojo, 1998, 2001). Specifically, they have suggested that visual attention is allocated to visual motion processing *per se* in the absence of sound and that this results in the perception of visual streaming. In contrast, they have suggested that visual attention is drawn away from motion processing in the presence of sound and that this results in the perception of bouncing. The results from a series of experiments using a dual-task technique support this conclusion. Subjects had to make judgments about the existence and orientation of an opening in a bullseye display, while at the same time judging whether they perceived bouncing or streaming. Results showed that the perception of bouncing was significantly increased, presumably because allocation of endogenous attention to the bullseye interrupted motion processing. Other studies where subjects viewed ambiguously moving visual stimuli while either a visual flash or a train of vibration on the skin were presented have yielded similar effects as long as the flash or the vibration were synchronized with the spatial coincidence of the visual stimuli (Shimojo & Shams, 2001; Shimojo, Watanabe & Scheier, 2001; Watanabe & Shimojo, 2001). Shimojo and colleagues interpreted these results to mean that attentive tracking of a moving object enhances location motion signals in the direction of the disks' trajectories, thereby enhancing perception of streaming. When, however, attentional tracking is disrupted either through manipulation of exogenous or endogenous attentional mechanisms, processing of motion signals is reduced, thereby reducing the perception of streaming and increasing the perception of bouncing. Other, and independent, evidence also indicates that spatial attention plays an important role in the perception of visual motion as well as in the perception of ambiguous displays (Raymond, 2000).

Despite the fact that the types of crossmodal interactions that produce the bounce illusion are important for understanding general perceptual mechanisms, no studies to date have examined the possibility of these kinds of illusions in infants. We now report the results of three experiments demonstrating for the first time such illusory perceptual effects in human infants and pinpoint their developmental emergence. We hypothesized that if rapid attentional shifting underlies the illusory bounce effect, we would expect that only infants with an attentional system capable of relatively rapid attentional shifts would perceive illusory bouncing. It so happens that the nature of attention changes rather dramatically during infancy. Thus, initially in development infants exhibit relatively rigid and inflexible control over their attentional behaviors. As development progresses over the first 6 of months of life, however, attentional behaviors become more flexible and of a more voluntary nature. In other words, rapid attentional shifts become increasingly possible (Johnson, 1990; Johnson & Tucker, 1996; Ruff & Rothbart, 1996) as development progresses. Based on this fact, we predicted that the bounce illusion might emerge sometime during the first half year of life.

Experiment 1

Experiment 1 was explicitly based on the design of the previous experiments with adults showing the bounce illusion (Sekuler *et al.*, 1997; Watanabe & Shimojo, 1998, 2001) with the aim of determining whether infants also experience this illusion. Specifically, we wished to determine whether infants would respond differently to an ambiguous motion display consisting of two disks moving toward, through, and past one another depending on whether a simple sound was presented at the same time that the disks coincided with one another or at a time when they did not coincide. To test this possibility, we first habituated separate groups of 4-, 6- and 8-month-old infants to what adult subjects usually report to be an illusory bouncing event and then tested them with a non-illusory event. If infants, like adults, perceived the habituation event as an illusory bounce then they were expected to exhibit a significant novelty response to the test event.

Methods

Participants

The sample for this experiment consisted of a total of 143 infants and comprised separate groups of 4-, 6- and 8-month-old infants. To insure greater generalizability of findings, infants were tested in two separate laboratories (D.L.'s laboratory at the Institute for Basic Research and S.S.'s laboratory at the California Institute of Technology). Table 1 shows the distribution of infants as a function of age and laboratory. An additional 28 infants were tested but did not contribute usable data because of fussing (14), inattentiveness (10) or equipment failure (3). All infants in this experiment, as well as in the two subsequent ones, were healthy at the time of testing and full-term at birth.

Table 1 *Breakdown of experimental groups as a function of ages and laboratory in which they were tested*

Laboratory	(D.L.)			(S.S.)		
Experiment	1			1		
	N	Age (weeks)	SD	*N*	Age (weeks)	SD
4 month	23	19.0	1	24	17.4	0.8
6 month	24	27.4	2.7	24	26.3	1.1
8 month	24	36.0	2.3	24	34.9	1.9
Experiment	2			3		
	N	Age (weeks)	SD	*N*	Age (weeks)	SD
4 month	16	18.6	1.0	18	18.2	1.5
6 month	16	27.8	0.8	18	25.6	1.8
8 month	15	36.4	0.6	18	35.3	2.6

Apparatus and stimuli

Infants sat in an infant seat located 50 cm from a 21 inch computer monitor and their visual fixations were monitored via a video camera placed on top of the computer monitor and simultaneously recorded on videotape. The visual stimuli were produced with the Psychophysics Toolbox™ and consisted of two identical computer-generated yellow disks (each subtending 3° of visual angle). At the start of a trial, the disks appeared on opposite sides of the monitor (separated by 12° of visual angle) and immediately began to travel laterally (at a constant velocity of 4°/sec.) toward one another, coincided without stopping, and continued until they reached the other's starting point at which time they disappeared. A hundred ms later the disks reappeared in their original position and the motion was repeated; the presentation of this display continued for the duration of a single trial. A complex tone, 100 ms in duration and measuring 65 dB at the infant's ear (ambient sound pressure level was 40 dB in D.L.'s lab and 42 dB in S.S.'s lab), generated with a PowerPC built-in sound card, was presented through a speaker located behind or below the monitor (see Figure 1 for a schematic description of the visual stimuli). The temporal relation between sound presentation and visual stimulus motion varied depending on experiment and testing condition and is described in more detail below. At the beginning of each trial, the infant's visual attention toward the center of the monitor was attracted by an alternately expanding/contracting yellow disk.

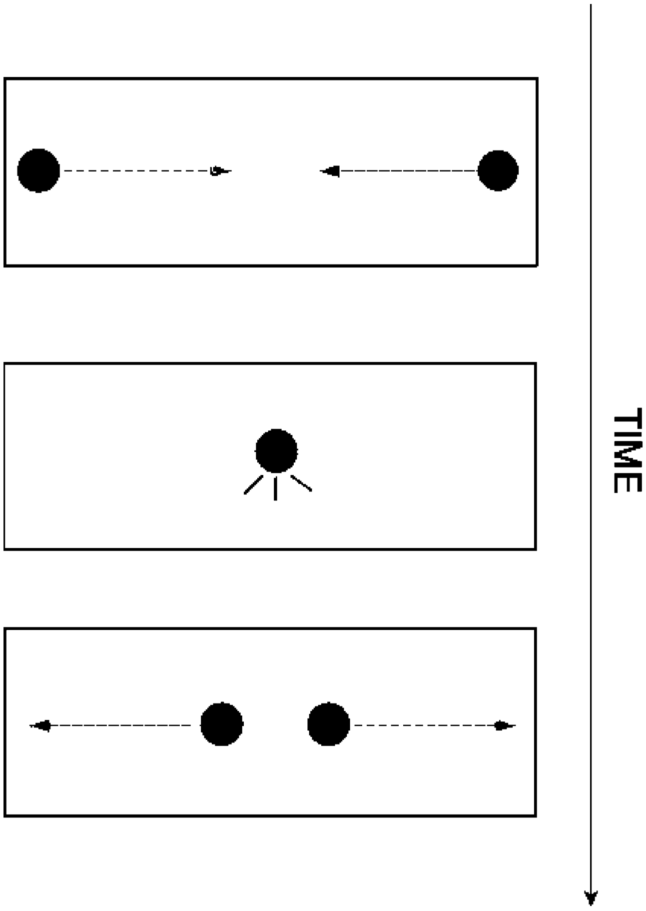

Figure 1 *Visual stimulus configuration. The arrows denote the direction of motion of the two disks.*

Procedure

We used an infant-controlled habituation/test procedure to test for discrimination. An experimenter, who was blind with respect to stimulus presentation, observed the infant on a closed-circuit television monitor and initiated stimulus presentation by pressing a key on the computer each time the infant looked at the monitor. Whenever the experimenter was not pressing the key, the expanding/contracting yellow disk was visible on the computer monitor. As soon as the infant fixated the disk, the experimenter pressed the key to signal to the computer to initiate presentation of the stimulus. The experimental session consisted of a series of discrete trials whose onset, duration and termination was controlled by the infant's looking behavior. A 1 s look-away criterion was used to terminate a trial; this meant that the infant had to look away from the monitor for more than 1 s in order to terminate it. The length of looking during each trial constituted the dependent measure.

In this experiment, each infant was habituated to a display of the two moving disks together with the auditory stimulus that sounded each time the disks coincided. Once the infant reached a habituation criterion defined as a 50% decrease in looking duration (calculated by comparing the total duration of looking in the first three trials versus the duration of looking in the last three), we administered three test trials. These trials consisted of a familiar test trial and two desynchrony test trials. The familiar test trial was identical to the habituation stimulus, whereas the desynchrony test trials consisted of one where the sound was presented 1.3 s before the disks coincided (pre-coincidence test trial) and one where the sound was presented 1.3 s after the disks coincided (post-coincidence test trial). These desynchrony values were chosen because they are far above infants' audiovisual (A-V) desynchrony threshold for highly similar stimulus events (Lewkowicz, 1996). The order of the three test trials was counterbalanced across infants within each age group.

Results and discussion

The mean duration of looking in the test phase is depicted in Figure 2. As can be seen, the two older groups of infants exhibited increased looking in the novel test trials relative to looking in the familiar test trial whereas the youngest infants did not show this pattern. Although we made an *a priori* decision to simultaneously test infants in the two laboratories and then combine the data for purposes of analysis, we wanted to first assure ourselves that the results were not affected by the particular laboratory in which testing was done. Thus, we conducted a preliminary repeated-measures analysis of variance (ANOVA) that included laboratory (2) and age (3) as the between-subjects factors and test trial type (3) as a within-subjects factor. Results indicated that there was no significant effect of laboratory and that laboratory did not interact with the other two factors. Consequently, the results from the two laboratories were collapsed and a new ANOVA was performed with age (3) and test trial type (3) as the two factors.

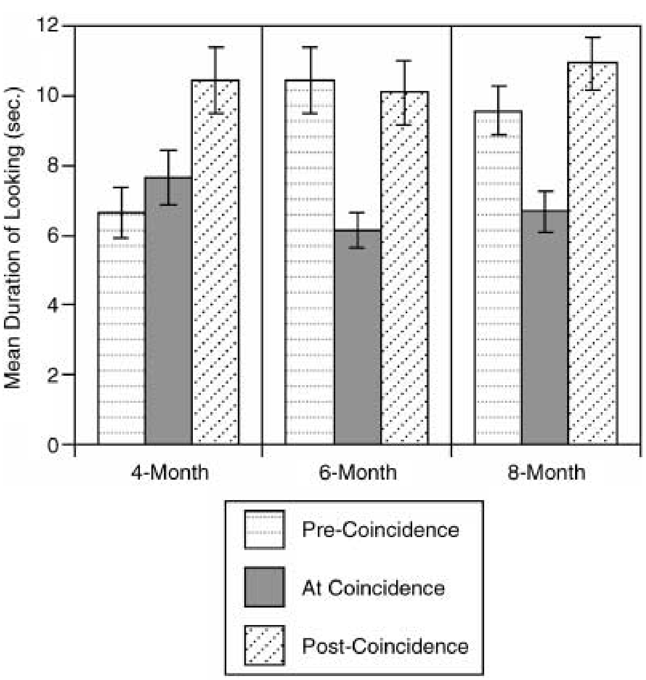

Figure 2 *Mean duration of looking in Experiment 1 during the familiar test trial (sound at coincidence) and the two desynchrony test trials (sound presented pre- and post-coincidence). Error bars, ± standard errors of the mean.*

The new analysis showed that there was a significant test trials effect, $F(2, 405) = 15.35$, $p < .01$, indicating that responding across the three test trials differed. To follow up this effect and to determine its source, we compared looking in each desynchrony test trial against looking in the familiar test trial by way of separate planned comparison tests. These tests indicated that the 4-month-olds exhibited significant response recovery in the post-coincidence test trial ($p < .01$) but not in the pre-coincidence trial. In contrast, the 6- and the 8-month-old infants exhibited significant response recovery in each type of test trial (ps $< .01$).

The findings from this experiment showed that whereas the 4-month-olds exhibited an inconsistent pattern of response to the two types of test trials, the 6- and 8-month-old infants discriminated both types of test trials from the coincident event. The key and only difference between the habituation and test phase events was the spatio-temporal relation of the sound vis-à-vis the moving disks. As noted earlier, adults perceive bouncing when the sound corresponds to the disks' coincidence (Sekuler *et al.*, 1997; Watanabe & Shimojo, 1998, 2001). Based on these findings and based on the fact that the older groups of infants treated the habituation and test phase events as different, the findings from this experiment suggest that the 6- and 8-month-old infants perceived bouncing during habituation.

The 4-month-old infants' failure to exhibit the same consistent discriminative response is interesting because previous research has shown that infants as young as 2 months of age can perceive the spatio-temporal relation between very similar moving visual stimuli and sounds (Lewkowicz, 1996, 2000). If the discriminative task in this experiment only required a detection of the A-V spatio-temporal relation then the 4-month-old infants also should have detected both types of desynchrony represented by the two test trials. The fact is, however, that the spatio-temporal relation specified in the current experiment was considerably more complex. That is, in the previous studies the sound was synchronized with the actual reversal of visual motion and, thus, the spatio-temporal A-V relation was unambiguously specified. In contrast, in the present experiment the sound was not associated with the reversal of visual motion but, rather, was ambiguously related to the visual information. The fact that only the two older groups of infants systematically detected the difference between the habituation and test events suggests that the basis for their successful discrimination was different. Based on the findings from adults, the most reasonable interpretation is that the older infants perceived the habituation and test events as categorically different and thus, by extension, perceived illusory bouncing.

Experiment 2

We have argued that it was unlikely that differences in A-V spatio-temporal relations alone were the source of the discriminative behavior observed in the older infants because of their complex and ambiguous nature. Nonetheless, we felt that it was important to obtain additional and converging evidence of illusory perception. Thus, in this experiment we habituated infants to an event that adults perceive as an illusory bounce and then tested their response to an event depicting an actual physical bounce that was also accompanied by the sound. Given our interpretation of the findings from Experiment 1 that the older infants perceived the habituation and test conditions as categorically different from one another (i.e. bounce vs. stream), we expected that infants would not respond differentially to the habituation and test events because they were perceptually and categorically the same. In other words, we explicitly predicted a negative finding in this case (for similar experimental logic see Csibra, Gergely, Biro, Koos & Brockbank, 1999).

Methods

Participants

The participants in this experiment consisted of a new group of 47 infants, aged 4, 6 or 8 months of age (see Table 1 for details). All the participants in this experiment were tested in D.L.'s laboratory. An additional 9 infants were tested but did not contribute usable data because of fussing (8) or sleepiness (1).

Apparatus and stimuli

The apparatus in this experiment was identical to that used in Experiment 1. The habituation stimulus was the display of the two moving disks streaming through each other and the auditory stimulus that sounded each time the disks coincided. The test stimulus was identical to the habituation one except that rather than streaming past one another, the disks bounced against one another at the point of coincidence. In order to produce the physical bounce, the one frame where the disks overlapped was omitted. In effect, this created a pause while the two disks were adjacent to each other and thus resulted in a clear impression of bouncing for adult observers. The sound was presented in synchrony with the pause.

Procedure

The procedure was identical to that in Experiment 1 except that this time infants were given only two test trials. One was the familiar test trial during which the same stimulus presented during the habituation phase was presented again and the other was the novel test trial during which the disks were seen bouncing against each other. The order of these two test trials was counterbalanced across infants.

Results and discussion

Results supported our prediction and as can be seen in Figure 3, infants did not increase their looking time

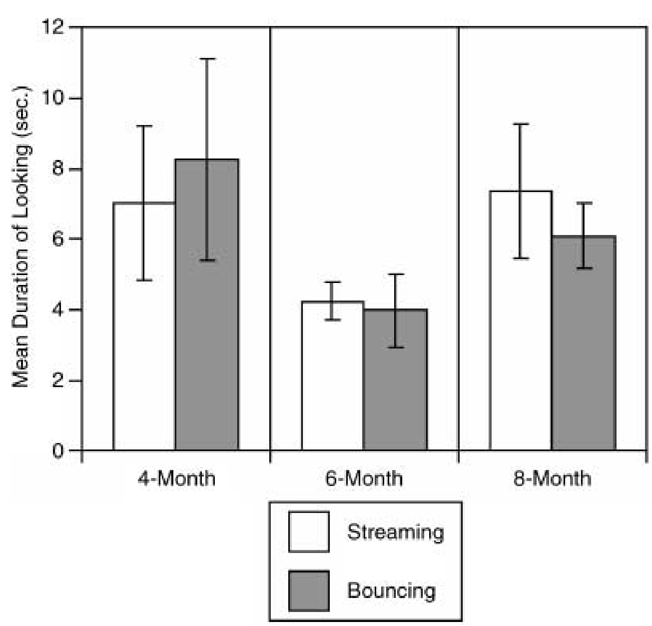

Figure 3 *Mean duration of looking in Experiment 2 during the familiar (i.e. streaming) test trial and the bouncing test trial. Error bars, ± standard errors of the mean.*

during the test trial relative to their looking in the familiar test trial at any of the ages. This finding was confirmed by an age (3) × test trials (2) ANOVA showing that the trials effect was not significant ($p > .53$). These results confirm our *a priori* prediction and provide additional support for the conclusion that the two older groups of infants must have perceived bouncing when the sound was synchronized with the disks' coincidence during the habituation phase. If they had not, they would have responded to the physically bouncing disks in the test phase as perceptually different.

Experiment 3

In this final experiment we asked once again whether infants would perceive streaming visual motion as categorically different depending on whether it was accompanied by a sound when the disks coincided or not. This time, however, we used an experimental design that was opposite to the one used in Experiment 1. Specifically, we habituated infants to a streaming visual display that was accompanied either by a sound that occurred prior to the disks' spatial coincidence or to the same display accompanied by a sound that occurred after their coincidence. Following habituation, all infants were tested with the streaming display again but this time the sound was presented when the disks coincided. Thus, infants were habituated to a display that did not produce illusory bouncing and then tested with a display that did. If the two older groups of infants perceived the habituation and test stimulus displays as categorically different then they were expected to exhibit significant response recovery in the test trial.

Methods

Participants

The participants in this experiment consisted of a new group of 54 infants comprising separate groups of 4-, 6- and 8-month-old infants (see Table 1). All participants in this experiment were tested in S.S.'s laboratory. An additional 16 infants were tested but did not contribute usable data because of fussing (7) or inattentiveness (9).

Apparatus and stimuli

All apparatus and stimuli were identical to those in Experiment 1.

Procedure

The procedure was identical to the procedure followed in Experiment 1. The only difference was that in this experiment half the infants at each age were habituated to the streaming visual display together with a sound that occurred 1.3 s before the disks' coincidence and the other half were habituated to the streaming display together with the sound occurring 1.3 s after coincidence. The test trials consisted of the familiar test trial and a novel test trial during which sound presentation was synchronized with the streaming disks' coincidence.

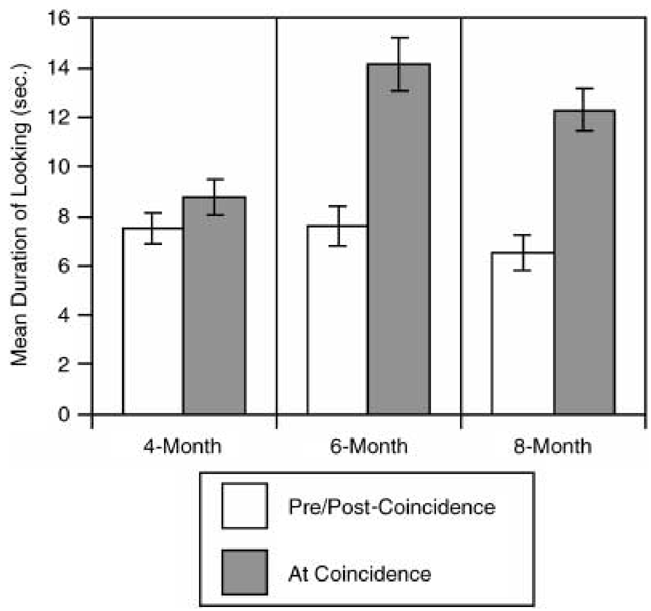

Figure 4 *Mean duration of looking in Experiment 3 during the familiar (i.e. pre- or post-coincidence) test trial and the coincidence test trial. Error bars, ± standard errors of the mean.*

Results and discussion

Figure 4 shows the results from this experiment. An ANOVA, with age (3) and test trial type (2) showed that there was a significant trials effect, $F(1, 102) = 49.41$, $p < .01$. The planned comparison tests showed that the 6- and 8-month-old infants exhibited significant response recovery (ps $< .01$) but that the 4-month-olds did not. The clear evidence of discrimination found in the two older groups of infants is consistent with the perception of illusory bouncing and replicates the findings from Experiment 1 but with the reverse experimental design.

General discussion

When the results from the three experiments are considered together they provide strong evidence that sound can induce perceptual reorganization of ambiguous motion in infants beginning at 6 months of age. To summarize, the results from Experiment 1 showed that following habituation to a display of two identical visual stimuli streaming through each other together with a sound that occurred each time the visual stimuli coincided, 6- and 8-month-old infants responded to this visual display as different when the sound was presented either prior to or after the point of coincidence. Experiment 2 provided further evidence of illusory perception. It showed that the two older groups of infants perceived streaming disks and a sound presented at their coincidence as equivalent to disks that physically bounced against each other while a sound accompanied their bounce. Finally, Experiment 3, employing a reversed stimulus presentation design in the habituation and test phases, replicated the findings obtained in Experiment 1. Following habituation to a streaming display accompanied by a sound presented either before or after coincidence, 6- and 8-month-old infants exhibited response recovery when tested with a streaming display accompanied by a sound at the disks' coincidence. Considered together, the findings from the three experiments provide impressive evidence of the power of a simple and brief sound to induce perceptual reorganization of an ambiguous motion display. A brief and simple sound presented at the point of coincidence of two identical and ambiguously moving visual stimuli appeared to cause the two older groups of infants to perceive the visual stimuli as categorically different from the same stimuli if a sound was presented either before or after their coincidence. Based on these findings we conclude that the 6- and 8-month-old infants perceived illusory bouncing in a manner similar to that previously found in adults.

Our interpretation that illusory bounce perception emerges by 6 months of age is critically dependent on the fact that the response profile that we obtained in the current study cannot be explained by discrimination of differences in A-V spatio-temporal relations. Findings from a number of infant studies show clearly that infants in the age range tested here are quite limited in the kinds of spatio-temporal discriminations that they are capable of making and suggest that it is highly unlikely that they could distinguish between the spatio-temporal differences in the current study. For example, although studies by Lewkowicz (1992a, 1992b, 1996) and Spelke, Born and Chu (1983) have shown that infants as young as 4 months of age are sensitive to audio-visual spatio-temporal relations inherent in events consisting of a single moving object and a simple sound, they also show how limited these infants' capabilities are. Specifically, although infants are sensitive to the synchronous occurrence of a sound and a moving object, this sensitivity is limited to the case where the sound occurs when the visual object undergoes a trajectory reversal and, thus, is involved in discontinuous motion. When a sound is associated with a specific spatial position of a continuously moving object, infants are not capable of perceiving this relation (Spelke *et al.*, 1983). Additional evidence of the limited nature of infants' spatio-temporal discriminative abilities comes from studies by Lewkowicz (1992a, 1994). Thus, Lewkowicz (1992a) found that infants as old as 8 months of age only preferred to look at one of two visual stimuli in the presence of a sound that was synchronized with the bounce that one of them made if this stimulus happened to appear first at the start of a motion cycle. Moreover, infants only exhibited such a preference when the two visual stimuli moved at the same speed and out of phase with respect to each other but not when they moved at different speeds. In other words, only if the infants' attention was first directed to the 'correct' visual stimulus as the stimuli began to move did they differentiate between the two visual stimuli on the basis of the audio-visual spatio-temporal relation and only if the stimuli moved at the same speed. Finally, Lewkowicz (1994) showed that infants' failure to make spatio-temporally based audio-visual matches when two visual objects moved at different speeds could not be overcome with additional perceptual experience. That is, infants failed to make intersensory matches despite being given an initial familiarization during which they could learn to perceptually differentiate between the two visual stimuli moving at different speeds and to learn that each object could have a sound synchronized with its visible bounce. In sum, these findings show that infants as old as 8 months of age find it difficult to detect even simple and unambiguous A-V spatio-temporal relations. Given that infants only can associate unambiguously moving visual objects with sounds that occur at points of visual discontinuity, it becomes clear that the differential responsiveness observed in the two older groups of infants in the current study cannot be explained by discrimination of spatio-temporal A-V relations. This is because in the current study two identical visual objects moved in an ambiguous fashion with respect to one another and a sound occurred while these objects moved continuously through space. Thus, the only reasonable conclusion that can be made is that the two older groups of infants perceived the displays in a categorical manner and that this was due to the induction of an illusory bounce when the sound occurred at the point of the disks' coincidence.

The failure of the 4-month-old infants to respond in a manner similar to the two older groups of infants provides interesting clues about the emergence of illusory bouncing in early human development. It seems that when the spatio-temporal integration of auditory and visual information involves ambiguous visual information that could potentially be interpreted as the collision of two visual objects, 4-month-old infants apparently lack the necessary mechanisms and/or knowledge about the behavior of real objects and thus fail to be influenced by the illusion-inducing effects of the sound. Our findings suggest that the mechanisms (and possibly knowledge about the behavior of objects) that are necessary for reorganizing visual perception of ambiguously moving visual displays in the presence of sounds emerges by 6 months of age. At the same time, however, it is highly unlikely that our findings reflect the kinds of higher-level, cognitive inferences that 9-month-old infants apparently can make about the intention of visual stimuli vis-à-vis one another (Csibra *et al.*, 1999). The infants in our studies were younger and the motion trajectories followed by the objects in our study were too simple to cause infants to reason about them and invest them with intentional attributes.

Consequently, we propose that the developmental emergence of illusory bounce perception found here may be due to two developmental influences. The first may be the developing perceptual/cognitive representation of the behavior of real objects (such as collisions). Research on infants' response to simple causal events involving the motion of two objects has shown that infants younger than 5.5 months of age do not exhibit an understanding of the causal aspects of such motion (even though they respond to the spatio-temporal features of such moving objects) but that infants 6 months of age and older do respond to the objects' causal properties (Cohen, Amsel, Redford & Casasola, 1998). The second developmental influence that may enable the older infants to perceive the illusion is the emerging ability to flexibly modulate attentional orienting to significant events. Perception of illusory bouncing requires spatial, crossmodal, integrative and flexible attention. This type of attention would be expected to develop in conjunction with the development of categorical perception of real-world causal and non-causal events. Earlier we indicated that the perception of bouncing and the illusory 'causality' of the event in adults depends on the ability to flexibly and quickly modulate attentional orienting to significant events (Shimojo *et al.*, 2001; Watanabe & Shimojo, 1998, 2001). This type of flexible attentional control emerges during the age span studied here as indicated by the fact that the posterior attentional pathway in the parietal cortex, which makes flexible attentional control possible (Johnson, 1990; Johnson & Tucker, 1996; Ruff & Rothbart, 1996), begins to gradually exert control over behavior in infancy at around the time when we first obtained evidence of illusory bouncing. Thus, we hypothesize that in addition to infants' developing knowledge about the behavior of objects, the functional onset of more flexible attentional mechanisms makes it possible for infants to quickly engage and disengage attention from different aspects of the visual display depending on the presence or absence of sound and thus also facilitates their ability to perceive the illusory bouncing as a real physical event.

The two-factor hypothesis offered here is eminently testable. For example, if general attentional mechanisms are responsible for the illusion then a similar pattern of the developmental emergence of the illusion should be observed when ambiguous motion displays are presented together with any other type of stimulus regardless of modality. In other words, as long as the stimulus is presented in synchrony with the coincidence of the disks then one should be able to interrupt the processing of visual motion at that point and induce the bounce illusion with any other type of auditory, visual or even tactile stimulus (our preliminary work with adults has shown this to be the case). Likewise, if the development of knowledge about object relations plays a role, then displays of non-ambiguous motion (e.g. specified by two distinct objects or by objects only partly passing through each other) should not produce illusory responses.

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