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Auditory information for spatial location and pitch–height correspondence support young infants' perception of object persistence

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ABSTRACT

Perception of object persistence across occlusion emerges at around 4 months of age for objects moving horizontally or vertically. In addition, congruent auditory information for movement enhances perception of persistence of an object moving horizontally. In two experiments, we examined the effect of presenting bimodal (visual and auditory) sensory information, both congruently and incongruently, for a vertical moving object occlusion event. A total of 68 4-month-old infants (34 girls) were tested for perception of persistence of an object moving up and down, passing at each translation behind a centrally placed occluder. Infants were exposed to these visual events accompanied by no sound, spatially colocated sound, or congruent or incongruent pitch–height correspondence sounds. Both spatially colocated and congruent pitch–height auditory information enhanced perception of trajectory continuity. However, no impairment occurred when pitch–height sound information was presented incongruently. These results highlight the importance of taking a multisensory approach to infant perceptual development.

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Introduction

The importance of taking a multisensory approach to research on infant perception is now widely recognized (Bahrick, 2010). A multisensory approach is realistic because object perception in the real world does not usually occur through stimulation of a single sensory channel, and multisensory cues will often be available to the infant, particularly when an object is moving within the natural environment. Indeed, when looking at the nature of many toys designed specifically to be used by young infants, the multisensory (moving/flashing/musical) nature is apparent. A number of studies have illustrated sensitivity in young infants to auditory–visual synchrony in discrete events (Bahrick, 1992; Spelke, 1976, 1981), and there is compelling evidence that presentation of information through more than one sensory channel enhances perception. In particular, presenting the same information about the world redundantly to more than one sense recruits attention and leads to more rapid perceptual learning (Bahrick, 2010; Bahrick, Lickliter, & Flom, 2004).

An important aspect of perception of reality concerns perception of the persistence of objects when they pass behind occluders. This capacity begins to emerge in human infants at around 4 months of age, although it is constrained by a number of factors such as time out of sight (Johnson, Bremner, et al., 2003), distance out of sight (Bremner et al., 2005), and trajectory orientation (Bremner et al., 2007; Bremner, Slater, Mason, Spring, & Johnson, 2017). However, perception of object persistence appears to be well developed by 6 months of age (Johnson, Amso, & Slemmer, 2003; Johnson, Bremner, et al., 2003) and is likely an important perceptual precursor of conceptual object permanence (Bremner, Slater, & Johnson, 2015).

Bremner, Slater, Johnson, Mason, and Spring (2012) examined the effects of presentation of multisensory information in a moving object occlusion event. They presented different forms of auditory information (e.g., spatially colocated sound, static continuous sound, spatially dislocated sound, discontinuous sound) alongside a visual representation of a moving object undergoing periodic occlusion. The occluder width in the study was selected so as to be wide enough that 4-month-olds would not have been able to perceive trajectory continuity during events based on visual information alone (cf. Bremner et al., 2005). Bremner et al. (2012) found that the addition of a colocated sound significantly enhanced perception of trajectory continuity at 4 months of age. It was also found that presentation of a static continuous sound during habituation resulted in a slight positive enhancement of perception of trajectory continuity. In contrast, when a dislocated spatial sound (i.e., the sound localization presented at opposites to the point of travel of the visual display) was presented, there was a trend toward an opposite effect on infants' perception of persistence. In other words, auditory–visual spatial incongruence slightly impaired 4-month-olds' performance. The fact that this was a relatively weak effect is in keeping with our previous finding that it is easier to support veridical perception than to interfere with it (Bremner et al., 2005).

These findings are in keeping with the intersensory redundancy hypothesis (IRH; Bahrick, 2010; Bahrick et al., 2004), according to which presentation of redundant information across two or more sensory channels enhances infants' attention to and perception of events. In the case of the moving object occlusion events summarized above, there are different levels at which information is redundant across auditory and visual modalities. At the simplest level common onset and offset of auditory and visual events provide redundant information, but at a more complex level auditory information and visual information redundantly specify the changing location of the object. It seems likely that the second level of redundancy was primary in Bremner et al. (2012) because only spatially congruent auditory information enhanced perception of trajectory continuity despite the fact that common onset and offset applied in both conditions. In addition, in a condition where the sound ceased and recommenced as the object disappeared and reappeared at the occluder, there was a negative effect on perception of continuity, although in this case onset and offset correspondence was maximized.

Despite our increasing knowledge of the conditions necessary for enhancing 4-month-olds' perception of trajectory continuity across the horizontal dimension, we do not know whether perception of persistence of objects moving vertically will be enhanced by exposure to multisensory information. Given that auditory localization in the vertical dimension develops more slowly than localization in the horizontal dimension (Morongiello & Rocca, 1987a, 1987b), it is possible that any effect of sound in the vertical dimension will be smaller than is the case with horizontal trajectories if indeed there is any effect seen at all.

More important, examination of the effects of multisensory cues on persistence of objects moving in the vertical dimension brings with it the opportunity to investigate a different respect in which intersensory congruence might support object persistence. Adults experience unconscious intersensory correspondences between stimulus dimensions such as auditory loudness and perceived weight, and auditory pitch and object sharpness/roundness and object elevation in the visual field (Spence, 2011), and it appears clear that these correspondences make an important contribution to crossmodal binding in adults. Recent studies have begun to examine the detection of these correspondences in young infants. For example, Peña, Mehler, and Nespor (2011) showed an association between object size and vowel pitch (with high-pitched vowels being associated with small objects and low-pitched vowels being associated with large objects) in 4-month-olds. In addition, 2- and 3-month-olds appear to associate certain colors and shapes (Wagner & Dobkins, 2011), and 4-month-olds spontaneously associate pitch (sound) with height in the visual field and with object angularity (Walker et al., 2010) and object thickness (Dolscheid, Hunnius, Casasanto, & Majid, 2014). The pitch–height correspondence may well be fundamental because it has been detected in newborns (Walker et al., 2018). Thus, in addition to the possibility that spatially colocated auditory information may enhance 4-month-olds' perception of vertical trajectory continuity, it is also possible that presenting a sound that varies in pitch congruently with the changing vertical location of the object could have a similar effect. Furthermore, given that auditory localization in the vertical dimension develops more slowly than localization in the horizontal dimension, a pitch–height cue to movement in the vertical dimension might be even more effective in enhancing perception of persistence than a colocated sound because it does not rely on direct locational cues to elevation.

The two experiments reported in this article examined how these two types of auditory information affect young infants' perception of object persistence. Specifically, we examined how the addition of auditory information for vertical movement affects 4-month-olds' perception of trajectory continuity in a vertical moving object occlusion event. We know that congruent sound enhances 4-month-olds' perception of continuity across occlusion in the case of an object moving on a horizontal trajectory (Bremner et al., 2012); therefore, in Experiment 1 we replicated Bremner et al.'s (2012) procedure with a vertical moving object occlusion event, using a spatially colocated sound during habituation trials, comparing this with a silent baseline condition. In addition, because the vertical trajectory case uniquely allows for examination of the effect of adding a vertical movement cue based on the pitch–height correspondence, in Experiment 2 we investigated the effects of congruent and incongruent pitch information on perception of continuity.

If young infants' perception of vertical localization of an auditory stimulus is sufficiently developed, we expected that a spatially colocated sound would enhance 4-month-olds' perception of persistence of an object moving on a vertical trajectory, as it did in the case of an object moving horizontally (Bremner et al., 2012). Furthermore, we predicted that a pitch–height congruent sound would enhance perception of persistence of an object moving vertically. However, an alternative possibility is that any effect of pitch–height correspondence manipulation is located in the fact that both pitch and height change "direction" at the end points of the cycle and that it is the congruence of these changes that supports trajectory continuity. In terms of the IRH (Bahrick et al., 2004), this temporal co-occurrence constitutes redundant intersensory information about the timing of reversal and, as such, would not rely on pitch–height correspondence. However, such an effect would apply equally in a condition where sound pitch fell as the object rose, and vice versa, because reversals co-occur in this case as well. Thus, it is particularly important to include this incongruent pitch–height condition in order to be able to distinguish between these alternative possibilities.

Experiment 1

Here we adapted the procedure used by Bremner et al. (2012) in which a stereophonically presented sound simulated left–right movement. In the first experiment, we replicated fairly exactly the presentation conditions in Bremner et al. (2012) except for the fact that the object movement (and colocated sound) occurred in the vertical dimension. In this and the following experiment, we adopted the habituation–novelty technique that has proved to be successful in previous work on object persistence/trajectory continuity. Infants are habituated to an event in which an object moves on a linear path, disappearing and reappearing behind a centrally placed occluder (see Fig. 1). Following habituation, infants are presented with alternating test trials with the occluder absent and the object moving either continuously or discontinuously, in the latter case disappearing and reappearing as it did during habituation. The rationale is that if infants perceive trajectory continuity during habituation, they should show a novelty preference for the discontinuous test display, reflected in longer looking, whereas if they perceive a discontinuous trajectory during habituation, they should show a novelty preference for the continuous test display. A preference in these test trials can be safely attributed to habituation trial experience because previous work (Bremner et al., 2005, 2007), including with vertical trajectory conditions (Bremner et al., 2017), has revealed no preexisting preference for one test trial over the other when infants were exposed only to test trials. Given these numerous findings of null baseline preference, therefore, we chose not to run an additional control condition in which infants were exposed only to test trials. As in Bremner et al. (2012), we presented test trials in silence because we were specifically interested in the effect of sound during habituation trials. Although removal of sound for test trials could lead infants to treat test trials as new and unrelated to habituation trials, no such effect (which would lead to the usual null baseline preference between test trials) was obtained in Bremner et al. (2012).

Method

Participants

A total of 32 4-month-old infants (*M* = 125.4 days, range = 115–135; 16 girls) took part in the first experiment. Of the 32 infants, 16 were assigned to the experimental condition and 16 were assigned to the baseline condition. A further 9 infants did not complete testing due to fussiness.

Apparatus and stimuli

Adobe Animate software was used to create the visual displays and to input sound files for presentation alongside the visual display. The stimuli consisted of a habituation display and two test displays (detailed in Fig. 1) as well as an attention getter in the form of a sounding oscillating rattle image for presentation between trials. The frame rate of each display was 48 frames per second.

A Macintosh computer with HABIT software (Cohen, Atkinson, & Chaput, 2000) and a Samsung 100-cm color monitor were used to present stimuli and collect looking time data. An observer viewed infants on a second monitor, and infants were recorded on videotape for later independent coding of looking times by a second observer. HABIT software presented the displays on the color monitor, recorded looking time judgments, calculated the habituation criterion for each infant, and changed

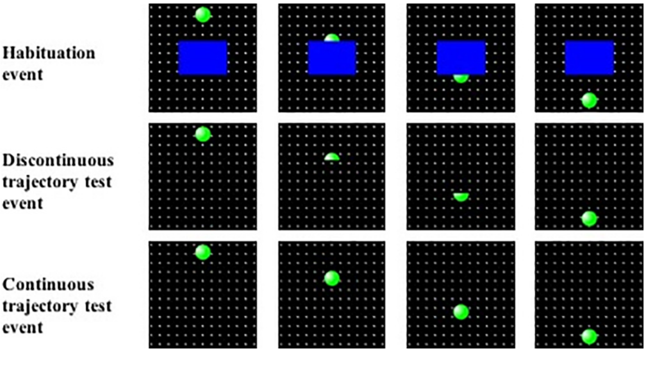

Fig. 1. Illustration of displays used to test perception of trajectory continuity. The ball moves up and down for a maximum of 60 s for each event.

the display after criteria were met. The observer's judgments were input with a key press on the computer keyboard.

The habituation display consisted of a stationary centrally placed blue occluder with vertical extent 14.8 cm (8.5° visual angle) and horizontal extent 21.5 cm (12.3°) and a 6.7-cm (3.8°) green ball undergoing continuous vertical cyclic motion at a rate of 16.8 cm/s (10.4°/s), with the center of the trajectory concealed by the occluder. The ball was visible in its entirety for 1067 ms and was completely occluded for 667 ms. The display was run as a continuous loop for the duration of the trial. In the experimental condition, a repetitive musical stereo sound (Bremner et al., 2012, Experiment 1) was presented through two speakers located at the top and bottom of the display monitor so that it appeared, to a small sample of adults, to move congruently with the object. For the adult sample to perceive vertical localization of the sound, it was necessary to position the speakers 172 cm apart (measured from the center of one speaker to the center of the other), with each speaker being equidistant from the center of the display monitor (a distance of 86 cm from monitor center to each speaker). As in Bremner et al. (2012), the effect was achieved through varying the balance at a constant rate from one extreme in which the sound came from only one speaker (located at the top of the display), to equal volume from each speaker, to the other extreme in which sound came only from the other speaker (located at the bottom of the display). In the baseline condition, habituation trials were presented in silence.

The test displays omitted the blue occluder but showed the green ball cycling up and down in the same way as on habituation trials and were presented in silence. In the continuous test display, the ball was always visible and moved continuously. In the discontinuous test display, the ball disappeared and reappeared by progressive deletion and accretion at horizontal linear boundaries in the same positions as the edges of the occluder in the habituation display (see Fig. 1). In all displays, objects were presented against a black background, with a 12×12 grid of white dots measuring 48 cm × 48 cm (27° × 27°) serving as texture elements.

Procedure

Timing of a habituation trial commenced when the infant fixated the screen after display onset. The observer pressed a key as long as the infant fixated the screen and released it when the infant looked away. A trial was terminated when the infant looked away for 2 s or 60 s had elapsed.

During habituation trials, the display was presented until looking time across 4 consecutive trials, from the 5th trial onward, added up to less than half the total looking time during the first 4 trials. This meant that habituation trials could end between Trial 8 and the maximum 12 trials. During the test trials that followed, half of the infants in each condition viewed the continuous trial first and half viewed the discontinuous trial first. Test trials alternated thereafter until a total of 6 trials (3 continuous and 3 discontinuous) had occurred. As with the habituation trials, a trial was terminated when the infant looked away for longer than 2 s or when 60 s (the maximum trial length) had elapsed. Between trials, the attention getter was shown to attract attention back to the screen.

At a later date, a second observer coded looking times from videotape for the purpose of assessing reliability of looking time judgments. Data for one third of the sample were subject to second coding, with participant cases selected at random from across the whole sample. Interobserver correlations ranged from .978 to .985 (M = .982) across the two experiments in this article.

Results and discussion

To investigate whether the presence of auditory information affected infants' attention during habituation trials, we first compared total habituation trial looking times between the sound and silent conditions. Infants in the sound condition looked significantly longer (M = 108.94 s, SD = 50.80) than infants in the silent condition (M = 77.71 s, SD = 22.60), $t(30) = 2.25$, $p = .032$.

Fig. 2 displays mean looking times to the discontinuous and continuous test displays by infants in the sound and silent conditions. A Condition (colocated sound vs. silent) × Test Trial Type (discontinuous vs. continuous) × Test Trial Order × Test Trial Block mixed analysis of variance (ANOVA) yielded a significant interaction between test trial type and condition, $F(1, 28) = 4.83$, $p = .036$, $\eta_p^2 = .15$. Infants looked longer at the discontinuous test display than at the continuous test display in the colocated

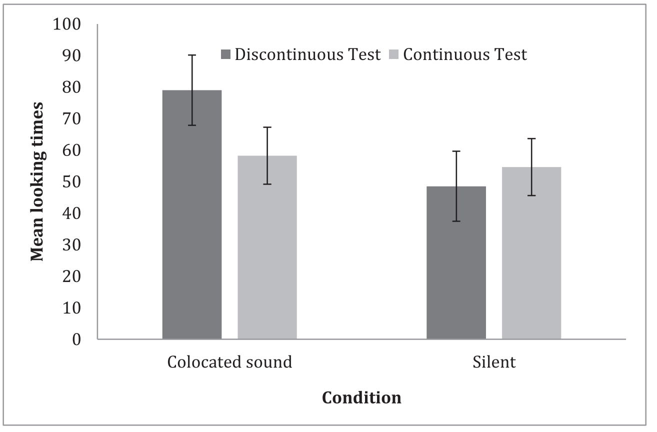

Fig. 2. Mean looking times to the two test displays in the sound and silent conditions. Error bars display standard errors.

sound condition, $F(1, 14) = 9.20$, $p = .009$, $\eta_p^2 = .40$, but there was no reliable difference in the silent condition, $F(1, 14) = 0.36$, $p = .56$, $\eta_p^2 = .025$. Further comparison showed that there was marginally more looking at the discontinuous test display in the sound condition than in the silent condition, $F(1, 30) = 3.59$, $p = .068$.

There was also a significant interaction between order and condition, $F(1, 28) = 5.56$, $p = .026$, $\eta_p^2 = .17$. The effect of order was significant in the silent condition, $F(1, 14) = 7.58$, $p = .016$, $\eta_p^2 = .35$, but not in the sound condition, $F(1, 14) = 1.47$, $p = .25$, $\eta_p^2 = .095$. Infants in the silent condition looked longer when presented with the discontinuous test trial first than when presented with the continuous test trial first. Such effects are hard to interpret but are common, particularly in cases where there is no overall effect of test trial type.

The finding that infants in the colocated sound condition looked longer during habituation than infants in the silent condition is in keeping with the basic principle of the IRH, namely that presentation of redundant information across sensory channels recruits attention. The significant novelty preference for the discontinuous test display in the colocated sound condition indicates that in the presence of auditory information congruent with the object's visual trajectory infants perceived trajectory continuity in the vertical dimension. In contrast, the lack of an effect of test trial type in the silent condition indicates that infants did not perceive trajectory continuity in the absence of auditory information. This pattern of results corresponds with those obtained by Bremner et al. (2012) in the case of an object moving on a horizontal trajectory. The null effect in the silent condition coincides with the results obtained for horizontal movement by Johnson, Bremner, et al. (2003) and Bremner et al. (2012) for that occluder width. In summary, just as in the case of an object moving horizontally, the addition of congruent auditory information for movement led infants to perceive persistence of an object moving on a vertical trajectory. Again, this is in keeping with the IRH. In addition to recruiting attention, presentation of redundant information for object movement enhanced perception of the visual event. It appears likely that it was colocation of auditory and visual information that was important here, rather than some less specific effect of the presentation of sound, because Bremner et al. (2012) did not obtain significant perception of continuity of a horizontal trajectory when the sound was stationary.

Experiment 2

In our second experiment, we investigated whether auditory–visual pitch–height correspondence would also enhance perception of trajectory continuity in the vertical dimension. Although this might appear to be a less direct cue to vertical location than a colocated sound, it does not rely on auditory localization as such. Thus, although the results of Experiment 1 suggest that infants' vertical localization is sufficient to detect changing location of sound, pitch–height correspondence might be a particularly effective cue through not relying on precise localization of sound. Consequently, in one condition, instead of stereophonically simulating a sound moving vertically, we presented a sound that varied in pitch congruently with the vertical location of the object, such that the pitch rose and fell in accordance with the ball's movement. Our prediction was that, similar to the effect in Experiment 1, presentation of this congruent cue would support perception of trajectory continuity. We also ran an incongruent pitch–height condition where the pitch rose as the object fell and the pitch fell as the object rose. This condition provides a control to distinguish between alternative interpretations of a positive effect in the congruent pitch–height condition. If such an effect is based on the pitch–height correspondence, where higher pitch is associated with greater spatial elevation, it should be limited to the congruent condition alone. But we need to entertain the possibility that the effect is due to the amodal cue of time locked reversal of pitch and trajectory. If this is the basis for the effect, it should apply equally to the congruent and incongruent conditions. In addition, the inclusion of this condition allowed us to assess whether any effect of the pitch–height cue is symmetrical, that is, whether it supports perception of trajectory continuity when it is congruent but interferes with perception of trajectory continuity when it is incongruent. In other words, does the incongruent pitch–height cue have a negative effect, leading to perception of trajectory discontinuity?

Method

Participants

A total of 36 4-month-old infants (M = 123 days, range = 112–142; 18 girls) took part in the second experiment. Of the 36 infants, 18 were assigned to each condition. A further 9 infants did not complete testing due to fussiness.

Apparatus, stimuli, design, and procedure

These were identical to those in Experiment 1 in all respects other than the form of the auditory information presented during habituation trials. In piloting, we initially investigated using the musical sound from Experiment 1, imposing an overall rising and falling pitch on this. However, a lack of any clear effect of this sound on perception of continuity suggested that it was too complex to yield a simple percept of rising and falling pitch. Thus, we adopted a sound similar to the sound used by Dolscheid et al. (2014). Piloting suggested that the uppermost pitch of this sound (pitch range of 1633.333–830.609 Hz) was too high for infants to tolerate in a habituation setting, with infants quickly becoming upset with repeated presentation of the sound. Therefore, the pitch range was lowered to give a new frequency range of 830.609–415.301 Hz. This resulted in a pitch range that infants appeared to tolerate well. Infants were assigned randomly to one of two habituation sound conditions: congruent or incongruent. In the case of the congruent condition, the pitch rose and fell in accordance with the ball's movement. In the case of the incongruent condition, the pitch rose and fell in opposition to the ball's movement. The sound was presented at equal volume from the two speakers, such that it appeared to emanate from the center of the visual display.

Results and discussion

There was no difference in the times that infants in the congruent condition (M = 122.57 s, SD = 44.78) and the incongruent condition (M = 114.10 s, SD = 60.63) spent looking during habituation, $t(34) = 0.48$, $p = .64$.

Fig. 3 displays mean looking times to the discontinuous and continuous test displays by infants in the congruent and incongruent conditions. A Condition (congruent vs. incongruent) × Test Trial Type (discontinuous vs. continuous) × Test Trial Order × Test Trial Block mixed ANOVA yielded no significant effect of test trial type, $F(1, 32) = 1.43$, $p = .24$, $\eta_p^2 = .04$. However, there was a significant interaction between test trial type and condition, $F(1, 32) = 5.08$, $p = .031$, $\eta_p^2 = .14$. Infants looked longer at the discontinuous test trial in the congruent condition, $F(1, 16) = 6.40$, $p = .022$, $\eta_p^2 = .29$, but not in the incongruent condition, $F(1, 16) = 0.52$, $p = .48$, $\eta_p = .032$. There was also a significant interaction between test trial type and order, $F(1, 32) = 8.88$, $p = .005$, $\eta_p^2 = .22$. Across the congruent and incongruent conditions,

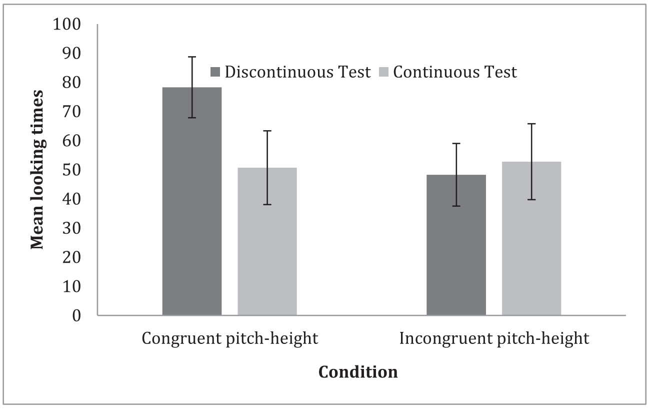

Fig. 3. Mean looking times to the two test displays in the pitch–height congruent and incongruent conditions. Error bars display standard errors.

the effect of test trial type was significant when the discontinuous test trial was displayed first, $F(1, 18) = 18.16$, $p < .001$, $\eta_p^2 = .50$, and not when the continuous test trial was displayed first ($p = .36$). This was likely due to the contribution of a reduction of looking across trials because there was a main effect of test trial block, $F(2, 64) = 3.70$, $p = .03$, $\eta_p^2 = .10$. Post hoc comparison showed that looking times in Block 1 ($M = 73.10$ s) were marginally longer than in Block 3 ($M = 46.14$ s, $p = .054$) but not in Block 2 ($M = 54.88$ s).

Next, we included the silent (baseline) condition from Experiment 1 as a comparison in this experiment. During habituation trials, relative to infants in the silent condition, infants looked longer in the congruent condition, $t(32) = 3.62$, $p = .001$, and in the incongruent condition, $t(32) = 2.26$, $p = .031$. A Condition (congruent vs. incongruent vs. silent) × Test Trial Type (discontinuous vs. continuous) × Test Trial Order × Test Trial Block mixed ANOVA yielded a significant interaction between test trial type and condition, $F(2, 46) = 3.46$, $p = .04$, $\eta_p^2 = .13$. The effect of test trial type was significant in the congruent condition, $F(1, 16) = 6.40$, $p = .022$, $\eta_p^2 = .29$, but not in the incongruent condition, $F(1, 16) = 0.52$, $p = .48$, $\eta_p = .032$, or the silent condition, $F(1, 14) = 0.36$, $p = .56$, $\eta_p = .025$. Post hoc Tukey tests showed that the comparison between conditions was not significant for discontinuous test trials ($p \geq .125$) or for continuous test trials ($p \geq .991$). Although it is not ideal to rely on comparisons between experiments run sequentially, the result in the silent condition corresponds to the null results obtained for horizontal trajectories with that occluder width (Bremner et al., 2012; Johnson, Bremner, et al., 2003). However, analysis of preference data (total looking to discontinuous trials divided by total looking to discontinuous plus continuous test trials) confirms this comparison, indicating that whereas in the congruent pitch–height condition there was a significant preference for the discontinuous test trial, $t(18) = 2.34$, $p = .032$, there was a null preference in the incongruent pitch–height condition, $t(18) = 0.26$, $p = .80$.

Interestingly, total looking across habituation trials did not differ between the congruent and incongruent conditions, but it was significantly greater than in the silent baseline condition of Experiment 1. This suggests that the presence of auditory information increased attention whether or not it provided congruent information about the visual event.

The results on test trials confirmed our prediction that presentation of congruent pitch–height information would enhance infants' perception of continuity of the visual event. In contrast, in the incongruent pitch–height condition, no significant effect was obtained. Interestingly, when the silent condition from Experiment 1 was included in the analysis, no difference emerged between the silent and incongruent sound conditions. Thus, incongruent pitch–height information does not lead to a decrement in performance relative to baseline.

There was also a general interaction between test trial type and order, such that there was a preference across both the congruent and incongruent conditions for the discontinuous test display when it occurred first. Again, this effect is relatively common in this sort of work, probably due to the contribution of a reduction in looking across test display.

General discussion

In keeping with our predictions, the results of these experiments indicate that perception of continuity of an object moving on a vertical trajectory can be supported by both spatially colocated sounds and sounds that are congruent in terms of pitch–height correspondence. The first finding is striking given evidence that during early infancy vertical localization is underdeveloped relative to horizontal localization (Morongiello & Rocca, 1987a, 1987b). Clearly, vertical localization is well enough developed for dynamic auditory information for location to be used to support perception of object persistence. It is unlikely that the effect was due simply to the fact that the sound was continuous across occlusion, first, because a static continuous sound condition in Bremner et al. (2012) did not lead to significant perception of continuity for a horizontally moving object and, second, because sound continuity cannot explain the differential results obtained between the congruent and incongruent conditions in Experiment 2.

In Experiment 2, we obtained a null result in the incongruent pitch–height condition, significantly different from the positive effect obtained in the congruent pitch–height condition. Thus, there was no evidence that object persistence was supported simply by the fact that auditory information specified the sudden changes in direction at the end of each upward or downward transit through a reversal from rising to falling pitch or vice versa. This cue was present equally in the congruent and incongruent conditions, so it should have had a similar effect in both cases. Interestingly, there was no evidence that incongruent pitch–height information had a negative effect on perception of trajectory continuity. That is, a null result was obtained just as in the silent condition of Experiment 1. The lack of any negative effect is in keeping with previous evidence that negative effects of incongruence have been either absent (Bremner et al., 2005) or weak (Bremner et al., 2012). Thus, there appears to be an asymmetry in the effects of congruent and incongruent cues.

Our positive results for the congruent mapping are also in keeping with the finding that congruent relations between visual size and auditory duration facilitate 5-month-olds' learning more than incongruent relations (Hyde, Porter, Flom, & Stone, 2013). Interestingly, their effect could not be explained in terms of differences between conditions in redundancy of intersensory information, and Hyde et al. (2013) suggested that infants are biased to learn certain relations. We would suggest that this bias may extend to intersensory correspondences such as those investigated in Experiment 2.

It appears clear that we are dealing with a specific effect of pitch–height correspondence, and Experiment 2 is important through showing, for the first time, that intersensory correspondences of this sort are not just detected but also can be used to support veridical perception in object occlusion events. It seems likely that these correspondences have an important part in early infant perception, but there is a theoretical issue to be faced regarding how they should be incorporated within general accounts of intersensory perception. The auditory–visual colocation information presented in Experiment 1 may be described as redundant in the sense that at every instant auditory information and visual information specify the same object location. However, the auditory information and visual information presented by pitch–height correspondence in Experiment 2 are nonredundant (Spence, 2011). This correspondence would conventionally be identified as an arbitrary relation (Bahrick, Netto, & Hernandez-Reif, 1998) or as involving modality-specific information (Bahrick, 2010), and so assumed to be necessarily a learned relation. Although there are those who argue that intersensory correspondences are learned from correlations that exist in the environment (Spence & Deroy, 2012), there is growing evidence that they exist early and without a clear basis in experience for their learning (Dolscheid et al., 2014; Walker et al., 2010, 2018). If the pitch–height correspondence is learned from experience, this must happen within the first few days after birth or in utero (Walker et al., 2018). It appears that the appropriate pitch–height correlations may be available in the environment because Parise, Knorre, and Ernst (2014) demonstrated that ambient sounds emanating from higher in space were on average higher in pitch than those emanating from lower in space. Learning from these correlations within days of birth seems to imply impressive intersensory sensitivity. Thus, if detection of these relations is not innate, it would appear that even newborns are strongly biased to be sensitive and learn such relations. Therefore, it may be important to add a category of relations that infants are predisposed to detecting. This category likely includes *metathetic* correspondences (concerned with different qualitative dimensions), such as between pitch and height or between pitch and angularity, but also *prothetic* correspondences (concerned with amount of sensory information), such as the relation between auditory duration and visual extent (Hyde et al., 2013).

Looking beyond infancy, evidence is growing that points to some of these correspondences, such as between sound pitch and object roundedness (Walker et al., 2010), having a formative role in early language by supporting sound symbolism (Ozturk, Krehm, & Vouloumanos, 2013). Thus, in contrast to accounts that propose a linguistic basis for these correspondences, evidence indicates that they exist prior to language and it is likely that their presence supports its emergence.

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