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Perception of visual and audiovisual trajectories toward and away from the body in the first postnatal year

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ABSTRACT

Perceiving motion in depth is important in everyday life, especially motion in relation to the body. Visual and auditory cues inform us about motion in space when presented in isolation from each other, but the most comprehensive information is obtained through the combination of both of these cues. We traced the development of infants' ability to discriminate between visual motion trajectories across peripersonal space and to match these with auditory cues specifying the same peripersonal motion. We measured 5-month-old (n = 20) and 9-month-old (n = 20) infants' visual preferences for visual motion toward or away from their body (presented simultaneously and side by side) across three conditions: (a) visual displays presented alone, (b) paired with a sound increasing in intensity, and (c) paired with a sound decreasing in intensity. Both groups preferred approaching motion in the visual-only condition. When the visual displays were paired with a sound increasing in intensity, neither group showed a visual preference. When a sound decreasing in intensity was played instead, the 5-month-olds preferred the receding (spatiotemporally congruent) visual stimulus, whereas the 9-month-olds preferred the approaching (spatiotemporally incongruent) visual stimulus. We speculate that in the approaching sound condition, the behavioral salience of the sound could have led infants to focus on the auditory information alone, in order to prepare a motor response, and to neglect the visual stimuli. In the receding sound condition, instead, the difference in response patterns in the two groups

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may have been driven by infants' emerging motor abilities and their developing predictive processing mechanisms supporting and influencing each other.

Introduction

The ability to perceive motion in depth has an undeniable importance. Being able to discriminate motion directions in the three-dimensional space, and in particular to discriminate whether something or someone is moving toward our body, is necessary for our brain to judge how we should interact with the moving person or object. This ability becomes even more crucial as stimuli move closer to the body, crossing the boundary between external space and peripersonal space. Although information about motion in space can be conveyed by visual and auditory cues presented in isolation, observers get the most comprehensive information about motion in peripersonal space through the integration of cues coming from both the visual and auditory modalities at the same time. Research with human adults demonstrated that the processing of looming signals is significantly and selectively facilitated when both visual and auditory cues are present (Cappe et al., 2009) and also that multisensory looming stimuli are preferentially integrated in the brain (Cappe et al., 2012; Tyll et al., 2013). Surprisingly, only a few studies have investigated the development of the ability to discriminate different motion directions and to combine auditory and visual cues conveying motion information in human infancy.

Starting in the 1970s, a few studies investigated infants' ability to discriminate visual looming stimuli by measuring their defensive responses (Ball & Tronick, 1971; Bower et al., 1971; Náñez, 1988; Schmuckler et al., 2007; Yonas et al., 1977). One study in particular (Yonas et al., 1977) suggested an extended development of defensive responses to visual looming and, based on the absence of blinking before 4 months of age, concluded that young infants are unable to discriminate whether a moving stimulus is approaching their body. A more recent study (Orioli, Filippetti, et al., 2018) measured newborns' looking behavior in response to visual stimuli moving in different directions and demonstrated that even in the first days after birth human infants can differentiate different motion trajectories with respect to their body and that they show a visual preference for trajectories approaching them as opposed to moving in other directions. Although these results might seem to contradict the earlier findings, they most likely suggest a developmental offset between infants' ability to discriminate among different motion directions in peripersonal space and their display of defensive reactions (Orioli, Filippetti, et al., 2018). In fact, on one hand stimuli moving toward the body are not necessarily threatening (e.g., an approaching smiling face, an approaching toy), and on the other hand infants need to gain experience to discriminate whether a stimulus is signaling an upcoming danger before being able to show defensive reactions to it (Farroni et al., 2007; Johnson et al., 2015; Orioli, Filippetti, et al., 2018).

Although visual moving stimuli are considerably salient, it is likely that in their everyday experience infants perceive motion through visual and auditory cues simultaneously. This leads to the question of how infants begin to match crossmodal information specifying congruent motion trajectories (Tham et al., 2019). Very few studies explored the developmental bases of infants' ability to match audiovisual information about motion in depth, leading to contradictory findings that do not provide us with a clear picture of infants' developing crossmodal matching ability in this context. One study found that 5-month-old infants show a visual preference for audiovisual stimuli moving in congruent directions (when a parallel presentation paradigm was employed), demonstrating an ability to detect the spatial congruency of audiovisual stimulation conveying information on motion direction (Walker-Andrews & Lennon, 1985). By contrast, Schiff et al. (1989) found a visual preference for incongruent audiovisual motion events in 5-month-old infants. Morrongiello and Fenwick (1991) provided yet another different picture, showing progressive development of infants' ability to match audiovisual cues about static and moving stimuli from 5 to 9 months of age. They showed that younger infants demonstrate a reliable visual preference for congruent audiovisual static stimuli, but not for stimuli moving in depth, and that the preference for stimuli moving in the same direction begins to emerge at 7 months and fully develops by 9 months, when infants can coordinate audiovisual motion information for both approaching and receding stimuli. More recently, an intersensory matching study with newborns (1–3 days old) found that, soon after birth, humans demonstrate a strikingly early ability to match dynamic auditory and visual stimuli based on whether they specify motion toward or away from their own body (Orioli, Bremner, et al., 2018). This study showed multisensory matching in infants much younger than those involved in earlier studies, providing yet again another view into the development of infants' ability to match multisensory cues about motion in depth.

Here, we aimed at tracing the development of infants' ability to discriminate between different directions of visual motion and to match audiovisual cues specifying congruent motion trajectories in the first postnatal year, trying to reconcile the findings reported in the literature. Importantly, we looked at these abilities within the context of infants' motor development in the first year after birth: because of the tight intrinsic link between motion perception and action in the environment, and within peripersonal space in particular, we hypothesized that infants' motion perception could be influenced by the development of their motor skills, such as reaching and grasping. We suggested that infants' increasing ability to act purposefully on the environment, as well as their experience of successfully reaching and grasping moving stimuli, would support and enhance their understanding of motion events taking place within the same environment. Following this reasoning, we included in the current study infants aged 5 and 9 months: previous research indicates that infants can reliably reach both stationary and moving objects by 5 months (Thelen et al., 1996; Thelen & Spencer, 1998; von Hofsten, 1979, 1991, 2004) and can integrate reaching and grasping movements from around 9 months (Fagard et al., 2009; Konczak & Dichgans, 1997; Rochat & Goubet, 1995; von Hofsten & Rönnqvist, 1988).

Infants' interactions with the environment in the context of reaching and grasping moving objects provide them with an opportunity for learning about the space around them. This could likely contribute to building models of the world around them and support the formation of their predictive coding and prediction error mechanisms (Kayhan, Hunnius, et al., 2019; Kayhan, Meyer, et al., 2019; Köster et al., 2020; Orioli et al., 2023). In turn, infants' developing internal models of the environment may influence their visual preferences for audiovisual motion stimuli. We hypothesized that younger infants (5-month-olds), who are beginning to develop their internal models of the environment, would show a visual preference for audiovisual stimuli specifying a congruent direction of motion, given that this kind of stimulus pairing is familiar and frequently occurring in the environment. In fact, attending stimuli moving in congruent directions across different modalities could support and reinforce infants' developing internal models of the environment, constructed on the bases of their experience in ecological situations. On the contrary, we expected that older infants (9-month-olds) would show enhanced visual attention to audiovisual stimuli moving along incongruent motion directions: once rudimentary expectations on the familiar pairing of events in the environment are established, infants may become more interested in attending sources of stimulation that contradict their developing expectations.

Previous studies used ecological stimuli, such as moving trains, cars, faces, and toys: it is possible that the choice of the stimuli and their different salience could have had an impact on the different patterns of responses that have been observed. In the current study, instead we decided to present the infants with visual and auditory stimuli that were salient yet unlikely to have been experienced by the infants in their everyday lives: this allowed us to investigate infants' matching of crossmodal stimuli irrespective of their specific experience of those stimuli (Maier et al., 2004; Wilkie & Stockman, 2020). In particular, we chose to use the same stimuli employed in two recent studies conducted with newborns (1–3 days old), which showed that soon after birth humans discriminate motion toward the body, and match dynamic auditory and visual stimuli based on their motion direction with respect to the body (Orioli, Bremner, et al., 2018; Orioli, Filippetti, et al., 2018).

Method

Participants

The study involved two groups of 20 participants aged 5 and 9 months. The sample size for each age group (n = 20) was determined based on previous studies using similar stimuli and paradigms with newborn participants (Orioli, Bremner, et al., 2018; Orioli, Filippetti, et al., 2018) as well as on a power analysis. Based on the medium to large effect sizes indicated in the aforementioned studies, we calculated that 21 infants would be required to obtain an effect size of d = .75 given α = .05 and an expected power of .90. To obtain a more precise counterbalancing, we included 20 participants. The 5-month-old group participants (10 girls) were on average 21.2 weeks old (SD = 1.42). A further 15 5-month-old infants participated in the study but were excluded due to fussiness or excessive movement (n = 5), distraction or tiredness (looking for less than 15% of the total presentation time in at least one condition, n = 5), or a strong side bias (more than 80% of their looking time directed to the same side of the screen, n = 5). The 9-month-old group participants (10 girls) were on average 38.25 weeks old (SD = 1.84). A further 10 9-month-old infants participated in the study but were excluded due to fussiness or excessive movement (n = 4), distraction or tiredness (n = 2), or a strong side bias (n = 4).

The infants were recruited through the Pediatric Unit of the Hospital of Monfalcone (GO), where they were born and where the study was conducted. Testing took place when the infants were awake and alert, ideally at a time that suited their daily routine as advised by their parents. The parents were informed about the procedure and provided informed consent for their children's participation; ethical approval was obtained from the Psychology Ethical Committee of the University of Padova (Italy), and the study was conducted in accordance with the Declaration of Helsinki.

Design

The study presented visual stimuli approaching and receding from the infants simultaneously and side by side. We compared the infants' looking preferences for the approaching visual stimulus over the receding visual stimulus across three conditions: No Sound, Increasing Sound, and Decreasing Sound. The choice of using a parallel presentation looking paradigm was instrumental to trace the development of infants' behavioral responses to visual stimuli of different behavioral salience as well as the development of their crossmodal matching ability in the first year after birth. In addition, it was also in line with previous research (Morrongiello & Fenwick, 1991, Orioli, Bremner, et al., 2018, Orioli, Filippetti, et al., 2018, Walker-Andrews & Lennon, 1985). Several control measures were put in place to ensure that the results were reliable and unbiased (see "Procedure, stimuli, and apparatus" and "Looking behavior analyses" sections).

Each infant took part in all three conditions, each of which comprised two trials, across which the side of presentation of the approaching and receding visual stimuli was counterbalanced. The order of presentation of the three conditions and the two trials within each condition were counterbalanced between participants, with the No Sound condition always being either first or last.

In the No Sound condition, only the visual displays were presented. In the Increasing Sound condition, the visual displays were paired with a centrally presented sound (sinusoidal waveform) increasing in intensity and therefore simulating an approaching sound source. In the Decreasing Sound condition, they were paired with a centrally presented sinusoidal waveform decreasing in intensity and therefore simulating a receding sound source (see Supplementary Video 1 in the online supplementary material).

In each condition, the visual displays were located in the peripheral areas of the screen to ensure that infants' attention was engaged and to facilitate offline coding of their eye movements. The side of presentation of each visual display was counterbalanced between the two trials within each condition.

Procedure, stimuli, and apparatus

The experiment began as soon as the participant was seated and attending to the center of the screen: at this point, the experimenter triggered the presentation of the stimuli. The study included three conditions, each comprising two trials. Each trial lasted 44 s in total and comprised eight 4-s presentations of the stimuli, with a 1-s interval between two subsequent presentations and 4 s of blank screen before the first presentation. The full study, comprising the three conditions with two trials each, lasted about 5 min if no breaks were required.

The approaching and receding visual displays showed a black-and-white-striped ball moving within a black frame positioned over a gray background (Orioli, Bremner et al, 2018a; Orioli, Filippetti et al, 2018b). The approaching visual display depicted the ball moving from the background toward the infant's body along a colliding pathway. The Receding visual display was the approaching visual display played backward. During the motion, the diameter of the ball on the screen varied from 7.2 to 13.8 cm and the visual angle of the ball varied from $23.54° \times 23.54°$ to $37.70° \times 37.70°$. On average, the width of the stripes varied from 0.91 cm (2.94°) to 1.72 cm (4.71°). In each visual display, the motion of the ball lasted 3.33 s and was preceded and followed by 333 ms where the ball stood still (during the last frame the contrast was reduced, favoring a fading effect), for an overall display duration of 4 s (Orioli, Bremner et al., 2018a; Orioli, Filippetti et al., 2018b).

In the Increasing Sound or Decreasing Sound condition, the visual displays were paired with an auditory stimulus that conveyed the impression of a sound source that was either approaching the participant or receding toward the background, respectively. The impression of the sound source moving was obtained by modulating the intensity of the sound: intensity is described as the feature that better accounts for the motion of a sound source in space (Canzoneri et al., 2012; Maier & Ghazanfar, 2007; Middlebrooks & Green, 1991; Neuhoff, 1998; Rosenblum et al., 1987; Seifritz et al., 2002; Wilkie & Stockman, 2020). The auditory stimuli were two samples of a sinusoidal waveform of 4000 ms duration with constant frequency (8000 Hz) and presenting a variation in intensity of 15 dB SPL, from 55 to 70 dB and vice versa. The intensity was measured from the infant's position at the average conditions of the room during testing (environmental noise and setup). The sounds used had the same qualities (type of sound and frequency) and intensity variation as those used in a previous study that implemented the present paradigm with newborns (Orioli, Bremner et al., 2018a). In addition, the intensity interval chosen was the same one used in previous studies investigating peripersonal space in adults (Canzoneri et al., 2012; Romei et al., 2009).

Throughout the study, the infant sat on the experimenter's lap in a dimly lit room and attended to the stimuli presented on a 24-inch monitor in front of them. The infant's head was about 90 cm away from the monitor, and the infant's eye level was aligned to the center of the screen, which was surrounded by a black curtain to minimize distractions. The auditory stimuli were delivered through three different loudspeakers: two were positioned under the left and right portions of the screen, and the third one was on the floor, right below the horizontal center of the screen. The two loudspeakers under the screen conveyed the higher-frequency components of the sound, which allowed for better spatial localization of the sound, and the loudspeaker on the floor conveyed the lower-frequency components of the sound, which did not contain spatial location information (Ihlefeld & Shinn-Cunningham, 2011; Middlebrooks & Green, 1991). In this way, we created the impression of a sound source at the center of the screen between the two visual stimuli (Maier et al., 2004). A video camera located on top of the screen recorded the infant's eyes, allowing the experimenters to subsequently code the eye movements offline. The experimenter who was holding the infant was unaware of the order of presentation of the conditions and was unable to see the stimuli because the experimenter was constantly focusing on an additional small monitor (placed outside the infant's view) that showed the infant's mirrored head position to allow the experimenter to keep it in view. The stimuli were presented using E-Prime 2.0.10 (Psychology Software Tools, Pittsburgh, PA, USA).

Looking behavior analyses

The infants' eye movements were recorded throughout the study to allow an expert observer to subsequently code them offline while blind to the order of presentation of the conditions and trials. Two additional observers coded the looking time for 50% of the 5-month-olds (n = 10) and 50% of the 9-month-olds (n = 10), respectively. For the 5-month-olds, the average intraclass correlation coefficient (absolute agreement) between the two observers was $ICC(2,2)$ = .970, whereas Pearson's correlation coefficient was r = .948; for the 9-month-olds, the average intraclass correlation coefficient (absolute agreement) between the two observers was $ICC(2,2)$ = .991, whereas Pearson's correlation coefficient was r = .982.

For each infant and condition, we computed the proportion of looking time toward the approaching visual display, dividing (for each condition) the time spent by each infant attending the approaching display by that same infant's total looking time in the same condition.

For each age group, we explored the data to identify any influential observations. We computed a model estimating the proportions of looking time to the approaching visual stimulus based on condition (No Sound, Increasing Sound, or Decreasing Sound) and calculated Cook's distance for each observation. We defined as influential those observations whose Cook's distance was larger than 4 times the mean Cook's distance. Based on this, we identified 3 influential observations in each age group: these were removed from the analyses, leaving each age group with a total of 17 included participants.

Motor development assessment

We decided to include infants aged 5 and 9 months in the study based on the hypothesis that motor development might influence infants' looking behaviors toward visual and audiovisual moving stimuli in the space surrounding them. In particular, we were interested in infants' mastering of reaching and grasping, given that we hypothesized that these abilities could have an impact on infants' perception of motion events in the space around them.

We decided to use two tools to assess the participating infants' reaching and grasping abilities: the Early Motor Questionnaire (EMQ; Libertus & Landa, 2013) and a "Reaching Assessment Task" (Libertus & Needham, 2010). These tools allowed us to ensure that all infants in each age group had reached a comparable level of motor development at the time of their participation in the study and that all of them could reach and grasp effectively at their respective ages of 5 and 9 months.

Early motor questionnaire

The EMQ is a research-focused (nonstandardized), parent-report measure of infants' early motor skills, focusing on those skills that develop in the first 2 years after birth and that play a critical role for overall development (Libertus & Landa, 2013). It is organized in three different sections investigating gross motor (GM), fine motor (FM), and perception–action integration (PA) skills. With the authors' permission, we translated the questionnaire into Italian.

To ensure that the participants in each age group had reached a comparable level of motor development at the time of their participation in the study, we analyzed their (raw) scores in each subscale. If participants scored less than 2 *SD* below the group mean on at least one scale, they would have been excluded from the analyses; however, this was never the case. The EMQ scores are summarized in Table 1.

Reaching assessment task

The task used to assess reaching and grasping abilities was introduced by Libertus and Needham (2010). It is a four-step assessment where a rattle is placed in four different positions and the infants' attempts to reach it and grasp it are recorded. The steps—(1) beyond reach, (2) far but within reach, (3) next to the hand, and (4) in the hand—are presented in a fixed order for approximately 30 s each. During every step, several behaviors are assessed: looking at the toy or at the experimenter, reaching for the toy, touching the toy, grasping the toy, bimanually exploring the toy, swatting at the toy, and mouthing the toy (Libertus & Needham, 2010).

Following Libertus and Needham (2014), we considered as a successful reaching unit the period from when the infants moved their hand toward the toy to when they touched it, and we considered as a successful grasping unit the period from when the infants touched and grasped the toy until when they released it. Reaching also included touching behaviors if the toy was not lifted. Grasping included every period when the infants engaged with the toy (e.g., lifting, shaking, mouthing) if the contact between the hand and the toy was maintained.

For the 5-month-old group, 15 of 20 recordings of the reaching and grasping task were available. Step 4 was never performed because all infants reached the toy already during Step 2 or 3. Most infants attempted to reach the toy during Steps 2 and 3, spending 29% and 43% of the time reaching

Table 1
Summary of Early Motor Questionnaire results.

	5-month-olds			9-month-olds		
	GM	FM	PA	GM	FM	PA
Mean	−62.55	−49.42	−19.80	−21.24	−15.06	−1.59
SD	8.95	8.08	6.88	21.38	17.06	12.79
Range	−76 to − 31	−60 to − 29	−28 to 2	−54 to 23	−49 to 12	−22 to 19
Mean – 2 *SD*	−80.44	−65.58	−33.56	−64.00	−49.18	−49.18

Note. For both age groups, the table summarizes the responses obtained by the participating infants in the Early Motor Questionnaire. For each scale—gross motor (GM), fine motor (FM), and perception action (PA)—the table indicates the mean raw score along with its standard deviation (*SD*) and range. We also indicate the value of the mean − 2 *SD* because this was chosen as a criterion for infants' inclusion in the final sample.

for it and touching it, respectively. Overall, all 15 infants showed effective reaching when the toy was close enough to their body (Step 3). Averaged proportions of time spent performing each of the seven assessed behaviors during each step are represented in Fig. 1A.

For the 9-month-old group 15 of 20 recordings were available. Steps 3 and 4 were never performed because all infants successfully grasped the toy already during Step 2. In 3 cases, only Step 1 was performed because the infants successfully grasped the toy already when it was beyond reach. The infants in this group spent 23% of the time during Step 1 and 20% of the time during Step 2 reaching for the object and touching it, and they spent 13% of the time during Step 1 and 64% of the time during Step 2 grasping the object, mouthing it, and exploring it with both hands. Overall, all 15 infants showed successful grasping when the toy was far from the body but within reach, and some of them also grasped it when it was still beyond reach. Averaged proportions of time spent performing each of the seven assessed behaviors in each step are represented in Fig. 1B.

Results

First of all, we verified that the total amount of looking time to both visual displays was comparable across age groups and conditions (Fig. 2): age, $F(1, 32) = 1.827$, $p = .186$, $\eta^2 = .036$; condition, $F(2, 64) = 1.057$, $p = .354$, $\eta^2 = .01$; age*condition, $F(2, 64) = 1.189$, $p = .311$, $\eta^2 = .011$ [Mauchly's test indicated that the assumption of sphericity had not been violated, $\chi^2(2) = .984$, $p = .785$]. Given that there were no significant differences in the total amount of looking time across ages and conditions, we decided to analyze the two age groups and three conditions together.

We ran a preliminary mixed analysis of variance (ANOVA) on the proportion of looking time to the approaching visual display, including condition as a within-participants factor and age, gender, and order of presentation of the conditions as between-participants factors. Neither the main effects of gender and order of presentation nor their interaction with age and condition proved to be significant; therefore, these factors were excluded from further analyses. We then ran a second mixed ANOVA on the proportion of looking time to the approaching visual display, including condition as a within-participants factor and age as a between-participants factor [Mauchly's test indicated that the assumption of sphericity had not been violated, $\chi^2(2) = .972$, $p = .645$]. The ANOVA revealed significant main effects of age, $F(1, 32) = 10.632$, $p < .01$, $\eta^2 = .095$, and condition, $F(2, 64) = 10.539$, $p < .001$, $\eta^2 = .114$, and a significant interaction between age and condition, $F(2, 64) = 14.481$, $p < .001$, $\eta^2 = .157$.

These effects were in line with our hypotheses, and to better characterize them we ran three planned one-sample *t* tests within each age group, one per condition (Fig. 3). The results (Table 2) showed that in the No Sound condition the participants in both age groups looked significantly longer than chance at the approaching visual display. In the Increasing Sound condition, the average proportion of looking time to the approaching visual display did not differ significantly from chance in either age group. Finally, in the Decreasing Sound condition, the 5-month-olds' proportion of looking time to the approaching visual display was significantly lower than chance (mean proportion of looking time = .400, *SE* = .019), whereas in the 9-month-olds the proportion of looking time to the approaching visual display was significantly higher than chance (mean proportion of looking time = .561, *SE* = .017).

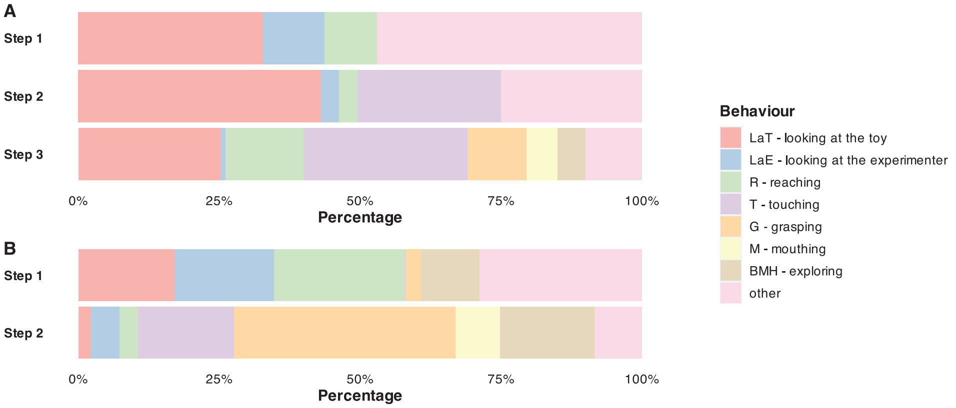

Fig. 1. Graphic representation of infants' responses in the reaching task. The figure represents, for each age group (A: 5-month-olds; B: 9-month-olds), the percentage of time that the infants spent showing each of the seven assessed behaviors in each step of the task.

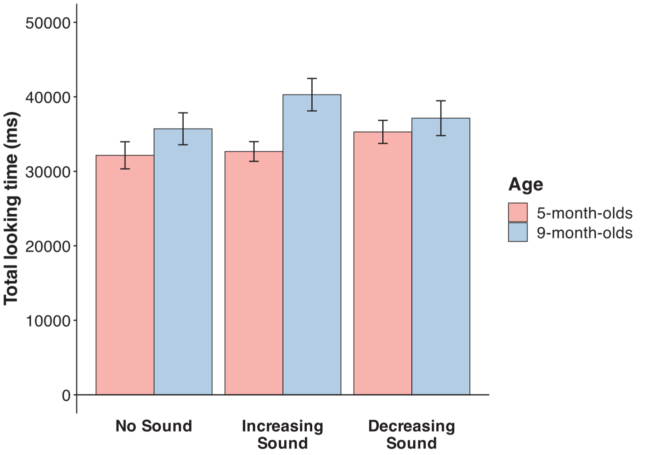

Fig. 2. Total amount of looking time to both visual displays in the two age groups. Error bars indicate the standard error of the mean.

This pattern of results is further supported by nonparametric tests that highlight the consistency of the effect across participants, confirming (a) in the No Sound condition, a visual preference for the approaching display in both age groups, and (b) in the Decreasing Sound condition, a visual preference for the receding display in 5-month-olds and for the approaching display in 9-month-olds (Table 3).

Discussion

Our findings show that 5- and 9-month-old infants' looking behavior is modulated by the cross-modal congruency of audiovisual looming stimuli as well as by the salience of visual and auditory information in the environment. Previous research investigating 5-month-olds' visual preferences for audiovisual moving stimuli (congruent and incongruent) is sparse and led to mixed findings:

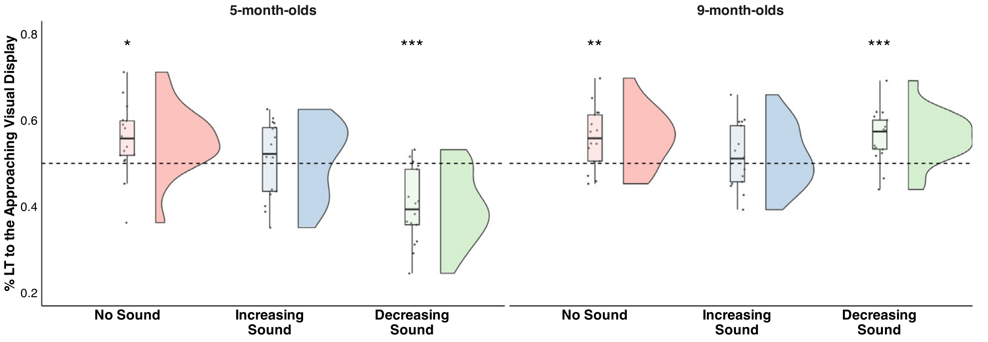

Fig. 3. Proportion of looking time (LT) to the approaching visual display in the three sound conditions in both age groups. Significant comparisons are indicated (*p < .50; **p < .01; ***p < .001).

Table 2
Summary of results of comparisons of proportion of looking time to the approaching visual display in the three conditions for the two age groups.

Condition	Age	*W*	*p*	*df*	*t*	*p*	d
No Sound	5-month-olds	.971	.831	16	2.818	.012	.683
	9-month-olds	.975	.903	16	3.611	< .01	.876
Increasing Sound	5-month-olds	.919	.140	16	.511	.617	.124
	9-month-olds	.968	.790	16	.914	.374	.222
Decreasing Sound	5-month-olds	.960	.626	16	−4.882	< .001	1.184
	9-month-olds	.971	.829	16	4.192	< .001	1.017

Note. Kolmogorov–Smirnov W statistics identifying significant deviations from normality in the distributions of the proportions of looking time are also included; α = .05 for all comparisons.

Table 3
Summary of results of nonparametric tests.

Condition	Age	*z* value	*p* value	*r*	Positive ranks	Negative ranks	*p* value
No Sound	5-month-olds	−2.378	.017	−.408	15	2	.002
	9-month-olds	−2.841	.005	−.487	14	3	.013
Increasing Sound	5-month-olds	−.142	.887	−.024	11	6	.332
	9-month-olds	−.835	.404	−.143	9	8	1
Decreasing Sound	5-month-olds	−3.407	.001	−.584	3	14	.013
	9-month-olds	−2.891	.004	−.496	15	2	.002

Note. Positive ranks: Infants showing a preference for the approaching visual display. Negative ranks: Infants showing a preference for the receding visual display.

one study found a visual preference for congruent audiovisual motion (Walker-Andrews & Lennon, 1985), whereas another showed the opposite pattern (Schiff et al., 1989). A third study (Morrongiello & Fenwick, 1991) suggested an extended and progressive development of infants' ability to match audiovisual cues about static and moving stimuli from 5 to 9 months of age, whereas more recent findings (Orioli et al., 2018a) indicate crossmodal matching of congruent audiovisual moving stimuli shortly after birth. Here we traced the changes in infants' visual preferences for both visual and audiovisual motion toward or away from the body throughout the first year of postnatal life, taking into account how infants' visual preferences change alongside motor development.

To this aim, we measured our participants' looking preferences when presented with visual stimuli approaching them and receding from them across three conditions: the visual stimuli presented alone (No Sound), paired with an approaching auditory stimulus (Increasing Sound), and paired with a receding auditory stimulus (Decreasing Sound). The study yielded to two main findings. First, we showed that when the moving stimuli are conveyed only in the visual modality, infants in both age groups show a visual preference for the stimulus approaching the body compared with the one moving away from it. Infants' ability to discriminate between visual approaching and receding stimuli was not surprising: a study with newborn participants demonstrated that even in the first few days after birth newborns can discriminate between stimuli moving along different trajectories with respect to the body (Orioli, Filippetti, et al., 2018). Our findings confirmed that throughout the first postnatal year infants not only discriminate between approaching and receding stimuli but also maintain a visual preference for approaching ones. This is particularly relevant considering the behavioral importance of approaching motion. As infants develop their motor abilities, such as reaching and grasping in the first instance and crawling and walking later on, they become progressively more able to interact with objects and people in their environment. Therefore, it is important that infants develop and maintain the ability to identify and pay more attention to those stimuli, such as approaching stimuli, that are behaviorally more salient given that they may anticipate an upcoming interaction between their body and an external object or agent.

It may be argued that infants' looking time responses in the No Sound condition also could have been influenced by low-level features of the stimuli (e.g., size of the moving stimulus). However, this is unlikely to explain the current results for two reasons. On the one hand, the two visual stimuli change between identical sizes (smallest and biggest) at the same rate. Therefore, if size was driving infants' attention, they would be looking longer at the receding visual stimulus for the first half of the trial and at the approaching visual stimulus for the second half of the trial, leading to comparable looking times to the two stimuli overall, which is not what the current findings suggest. On the other hand, a previous study using the same stimuli with newborn participants (Orioli, Filippetti, et al., 2018) investigated the potential effect of optical size on looking times by comparing the time spent attending each visual stimulus in the first versus second half of each of the presentations included in each trial and showed that the approaching visual stimulus was attended for longer periods of time in both halves of each presentation (i.e., also when its optical size was smaller). Because trajectory, rather than size, has been shown to drive newborns' (1–3 days old) looking behavior, it is unlikely that older infants' looking behavior may be affected by lower-lever features of the stimuli.

Our second finding concerns the pattern of results shown in the two conditions where multisensory audiovisual stimuli were presented. When the visual displays were paired with an increasing sound, specifying approaching motion, neither group of infants showed a visual preference for either visual stimulus. On the contrary, when the visual displays were paired with a decreasing sound, specifying receding motion, the younger infants showed a visual preference for the congruent receding visual trajectory, whereas the older infants showed a visual preference for the incongruent approaching visual trajectory.

Recent findings with newborn infants (1–3 days after birth) demonstrated that shortly after birth infants show a visual preference for an approaching visual display when this is presented together with a congruent sound increasing in intensity (Orioli, Bremner, et al., 2018). Based on this, we believe that the lack of visual preference shown by the infants in the Increasing Sound condition of the current study should not be attributed to a lack of the ability to discriminate between the two visual stimuli presented, as was also confirmed by the results of the No Sound condition. On the contrary, we speculate that the lack of visual preference in the Increasing Sound condition could be related to the infants' increasing motor abilities. We know that by 5 months of age infants have started to learn that they might need to respond to an approaching stimulus, for example, trying to reach for it (Thelen et al., 1996; Thelen & Spencer, 1998; von Hofsten, 1979, 1991, 2004). We also know that auditory information is predominant over other sensory information when it comes to monitoring of the space around the body, for example, detecting approaching stimuli (Ferri et al., 2015). Based on these two considerations, we speculate that when presented with a sound increasing in intensity, the infants in our sample could have focused their attention on the auditory information to prepare themselves to respond to the approaching source of the sound and therefore could have dedicated less attentional resources to process the visual information presented to them, leading to a lack of visual preference for either visual display.

In the Decreasing Sound condition, we found a visual preference in both groups, albeit in the opposite direction: younger infants showed a preference for the visual display depicting a trajectory congruent to that specified by the sound (i.e., receding away from the body), whereas older infants looked longer at the visual display depicting a trajectory incongruent to that conveyed by the sound (i.e., approaching the body). This pattern on results further reconfirms that the lack of visual preference in the Increasing Sound condition was unlikely to be due to infants' inability to discriminate between the two visual displays or to match crossmodal information. Most importantly, we speculate that when infants were presented with a decreasing sound, which is less relevant than an increasing sound from a behavioral point of view and therefore does not trigger the need to prepare a response, they were able to use their attentive resources to also take into account and process the visual stimuli presented to them.

It is interesting that infants' visual preferences in the Decreasing Sound condition are in opposite directions in the two age groups. We speculate that this pattern of visual responses may be driven by infants' emerging motor abilities and their developing predictive processing mechanisms supporting and influencing each other. At 5 months of age, infants are learning to reach for objects (Thelen et al., 1996; Thelen & Spencer, 1998; von Hofsten, 1979, 1991, 2004), both static objects and moving ones. Dedicating more visual attention to those stimuli that convey information about motion in the same direction across two visual modalities could support the development of infants' reaching skills. At the same time, it may reinforce their experience that decreasing sounds usually accompany the sight of an object or a person receding away from them. Repeated experience with visual and auditory information specifying motion in the same direction contributes to the development of infants' internal models of the environment and of typical events within it, which in turn will support the development of their predictive mechanisms (Kayhan, Hunnius, et al., 2019; Kayhan, Meyer, et al., 2019; Köster et al., 2020). We speculate that by 9 months of age infants' internal models of motion events could already be developed enough to lead the infants to expect that an increasing sound should be accompanied by an approaching visual stimulus, whereas a decreasing sound should be accompanied by a receding visual stimulus. In turn, they may already perceive an approaching visual stimulus paired with a decreasing sound as contradicting the experience of moving objects and people that they accumulated up to that point. The unexpectedness of such pairing could be driving them to devote more attention to it, as shown by longer looking times. This could be a sign of the development of the early precursors of prediction error processes (Kayhan, Hunnius, et al., 2019; Kayhan, Meyer, et al., 2019; Köster et al., 2020; Orioli et al., 2023). Interestingly, this switch in visual preferences from congruent to incongruent multisensory stimuli has been shown by other studies suggesting that younger infants may show a familiarity preference for multisensory pairings normally happening together in everyday life, that later shifts to a novelty preference for unfamiliar crossmodal matches that are not typically experienced in an ecological situation (Begum Ali et al., 2020; Freier et al., 2016; Thomas et al., 2018).

Further research will be needed to support our speculation of the reciprocal influence between motor development and the emergence of predictive processing mechanisms, integrating measures of motor development, electrophysiological measures indicating anticipatory brain activity (Kayhan, Meyer, et al., 2019; Mento et al., 2022), and looking behaviors in response to predictable and unpredictable multisensory stimuli.

In sum, our study traced infants' ability to discriminate unisensory and multisensory (visual and audiovisual) motion toward and away from the body during the first year of postnatal life. Our results provide some clarity among the mixed findings already available on infants' matching of crossmodal looming stimuli (Morrongiello & Fenwick, 1991; Schiff et al., 1989; Walker-Andrews & Lennon, 1985). We demonstrated that infants aged 5 and 9 months show a consistent visual preference for approaching visual stimuli. We also showed that infants' looking behavior in response to multisensory motion stimuli is influenced both by the salience of the auditory stimuli presented and by the infants' developing crossmodal matching abilities. The latter in particular may be influenced by infants' developing motor abilities as well as their emerging predictive processing mechanisms. These findings extend and complement the findings shown by a few recent studies with newborns (Orioli, Bremner, et al., 2018;

Orioli, Filippetti, et al., 2018) and suggest that infants' visual behavior in the first year after birth is influenced by, and at the same time supports, many different aspects of their cognitive and motor development.

CRediT authorship contribution statement

Giulia Orioli: Writing – review & editing, Writing – original draft, Visualization, Software, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Danica Dragovic:** Resources. **Teresa Farroni:** Writing – review & editing, Supervision, Resources, Methodology, Funding acquisition, Conceptualization.

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Data availability

The datasets analyzed in this article and the scripts used to perform the analyses are available online on the Open Science Framework website (Orioli & Farroni, 2020) and can be retrieved from osf.io/578vs. A version of this article was posted as a preprint (Orioli et al., 2023) and can be retrieved from psyarxiv.com/7u6hw. The design and analysis plans for this study were not preregistered.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jecp.2024.105921.

References

Ball, W., & Tronick, E. (1971). Infant responses to impending collision: Optical and real. *Science, 171*(3973), 818–820. https://doi.org/10.1126/science.171.3973.818.

Begum Ali, J., Thomas, R. L., Raymond, S. M., & Bremner, A. J. (2020). Sensitivity to visual–tactile colocation on the body prior to skilled reaching in early infancy. *Child Development, 92*(1), 21–34. https://doi.org/10.1111/cdev.13428.

Bower, T. G. R., Broughton, J. M., & Moore, M. K. (1971). Infant responses to approaching objects: An indicator of response to distal variables. *Perception & Psychophysics, 9*(2), 193–196. https://doi.org/10.3758/BF03212627.

Canzoneri, E., Magosso, E., & Serino, A. (2012). Dynamic sounds capture the boundaries of peripersonal space representation in humans. *PLoS One, 7*(9) e44306. https://doi.org/10.1371/journal.pone.0044306.

Cappe, C., Thelen, A., Romei, V., Thut, G., & Murray, M. M. (2012). Looming signals reveal synergistic principles of multisensory integration. *Journal of Neuroscience, 32*(4), 1171–1182. https://doi.org/10.1523/JNEUROSCI.5517-11.2012.

Cappe, C., Thut, G., Romei, V., & Murray, M. M. (2009). Selective integration of auditory–visual looming cues by humans. *Neuropsychologia, 47*(4), 1045–1052. https://doi.org/10.1016/j.neuropsychologia.2008.11.003.

Fagard, J., Spelke, E., & von Hofsten, C. (2009). Reaching and grasping a moving object in 6-, 8-, and 10-month-old infants: Laterality and performance. *Infant Behavior and Development, 32*(2), 137–146. https://doi.org/10.1016/j.infbeh.2008.12.002.

Farroni, T., Menon, E., Rigato, S., & Johnson, M. H. (2007). The perception of facial expressions in newborns. *European Journal of Developmental Psychology, 4*(1), 2–13. https://doi.org/10.1080/17405620601046832.

Ferri, F., Tajadura-Jiménez, A., Väljamäe, A., Vastano, R., & Costantini, M. (2015). Emotion-inducing approaching sounds shape the boundaries of multisensory peripersonal space. *Neuropsychologia, 70*, 468–475. https://doi.org/10.1016/j.neuropsychologia.2015.03.001.

Freier, L., Mason, L., & Bremner, A. J. (2016). Perception of visual–tactile colocation in the first year of life. *Developmental Psychology, 52*(12), 2184–2190. https://doi.org/10.1037/dev0000160.

Ihlefeld, A., & Shinn-Cunningham, B. G. (2011). Effect of source spectrum on sound localization in an everyday reverberant room. *Journal of the Acoustical Society of America, 130*(1), 324–333. https://doi.org/10.1121/1.3596476.

Johnson, M. H., Senju, A., & Tomalski, P. (2015). The two-process theory of face processing: Modifications based on two decades of data from infants and adults. *Neuroscience and Biobehavioral Reviews, 50*, 169–179. https://doi.org/10.1016/j.neubiorev.2014.10.009.
Kayhan, E., Hunnius, S., O'Reilly, J. X., & Bekkering, H. (2019a). Infants differentially update their internal models of a dynamic environment. *Cognition, 186*, 139–146. https://doi.org/10.1016/j.cognition.2019.02.004.
Kayhan, E., Meyer, M., O'Reilly, J. X., Hunnius, S., & Bekkering, H. (2019b). Nine-month-old infants update their predictive models of a changing environment. *Developmental Cognitive Neuroscience, 38* 100680. https://doi.org/10.1016/j.dcn.2019.100680.
Konczak, J., & Dichgans, J. (1997). The development toward stereotypic arm kinematics during reaching in the first 3 years of life. *Experimental Brain Research, 117*(2), 346–354. https://doi.org/10.1007/s002210050228.
Köster, M., Kayhan, E., Langeloh, M., & Hoehl, S. (2020). Making sense of the world: Infant learning from a predictive processing perspective. *Perspectives on Psychological Science, 15*(3), 562–571. https://doi.org/10.1177/1745691619895071.
Libertus, K., & Landa, R. J. (2013). The Early Motor Questionnaire (EMQ): A parental report measure of early motor development. *Infant Behavior and Development, 36*(4), 833–842. https://doi.org/10.1016/j.infbeh.2013.09.007.
Libertus, K., & Needham, A. (2010). Teach to reach: The effects of active vs. passive reaching experiences on action and perception. *Vision Research, 50*(24), 2750–2757. https://doi.org/10.1016/j.visres.2010.09.001.
Libertus, K., & Needham, A. (2014). Encouragement is nothing without control: Factors influencing the development of reaching and face preference. *Journal of Motor Learning and Development, 2*(1), 16–27. https://doi.org/10.1123/jmld.2013-0019.
Maier, J. X., & Ghazanfar, A. A. (2007). Looming biases in monkey auditory cortex. *Journal of Neuroscience, 27*(15), 4093–4100. https://doi.org/10.1523/JNEUROSCI.0330-07.2007.
Maier, J. X., Neuhoff, J. G., Logothetis, N. K., & Ghazanfar, A. A. (2004). Multisensory integration of looming signals by rhesus monkeys. *Neuron, 43*(2), 177–181. https://doi.org/10.1016/j.neuron.2004.06.027.
Mento, G., Duma, G. M., Valenza, E., & Farroni, T. (2022). Face specific neural anticipatory activity in infants 4 and 9 months old. *Scientific Reports, 12*(1) 12938. https://doi.org/10.1038/s41598-022-17273-1.
Middlebrooks, J. C., & Green, D. M. (1991). Sound localization by human listeners. *Annual Review of Psychology, 42*(1), 135–159. https://doi.org/10.1146/annurev.ps.42.020191.001031.
Morrongiello, B. A., & Fenwick, K. D. (1991). Infants' coordination of auditory and visual depth information. *Journal of Experimental Child Psychology, 52*(3), 277–296. https://doi.org/10.1016/0022-0965(91)90064-Y.
Náñez, J. E. (1988). Perception of impending collision in 3- to 6-week-old human Infants. *Infant Behavior and Development, 11*(4), 447–463. https://doi.org/10.1016/0163-6383(88)90005-7.
Neuhoff, J. G. (1998). Perceptual bias for rising tones. *Nature, 395*(6698), 123–124. https://doi.org/10.1038/25862.
Orioli, G., Bremner, A. J., & Farroni, T. (2018a). Multisensory perception of looming and receding objects in human newborns. *Current Biology, 28*, R1294–R1295. https://doi.org/10.1016/j.cub.2018.10.004.
Orioli, G., & Farroni, T. (2020). Infants' perception of visual and audiovisual looming stimuli. *OSF*. https://osf.io/578vs/.
Orioli, G., Filippetti, M. L., Gerbino, W., Dragovic, D., & Farroni, T. (2018b). Trajectory discrimination and peripersonal space perception in newborns. *Infancy, 23*(2), 252–267. https://doi.org/10.1111/infa.12207.
Orioli, G., Parisi, I., van Velzen, J. L., & Bremner, A. J. (2023). Visual objects approaching the body modulate subsequent somatosensory processing at 4 months of age. *Scientific Reports, 13*(1) 19300. https://doi.org/10.1038/s41598-023-45897-4.
Rochat, P., & Goubet, N. (1995). Development of sitting and reaching in 5–6 month old infants. *Infant Behavior and Development, 18*(1), 53–68. https://doi.org/10.1016/0163-6383(95)90007-1.
Romei, V., Murray, M. M., Cappe, C., & Thut, G. (2009). Preperceptual and stimulus-selective enhancement of low-level human visual cortex excitability by sounds. *Current Biology, 19*(21), 1799–1805. https://doi.org/10.1016/j.cub.2009.09.027.
Rosenblum, L. D., Carello, C., & Pastore, R. E. (1987). Relative effectiveness of three stimulus variables for locating a moving sound source. *Perception, 16*(2), 175–186. https://doi.org/10.1068/p160175.
Schiff, W., Benasich, A. A., & Bornstein, M. H. (1989). Infant sensitivity to audiovisually coherent events. *Psychological Research, 51*(3), 102–106. https://doi.org/10.1007/BF00309304.
Schmuckler, M., Collimore, L. M., & Dannemiller, J. L. (2007). Infants' reactions to object collision on hit and miss trajectories. *Infancy, 12*(1), 105–118. https://doi.org/10.1111/j.1532-7078.2007.tb00236.x.
Seifritz, E., Neuhoff, J. G., Bilecen, D., Scheffler, K., Mustovic, H., Schächinger, H., Elefante, R., & Di Salle, F. (2002). Neural processing of auditory looming in the human brain. *Current Biology, 12*(24), 2147–2151. https://doi.org/10.1016/S0960-9822(02)01356-8.
Tham, D. S. Y., Rees, A., Bremner, J. G., Slater, A., & Johnson, S. (2019). Auditory information for spatial location and pitch–height correspondence support young infants' perception of object persistence. *Journal of Experimental Child Psychology, 178*, 341–351. https://doi.org/10.1016/j.jecp.2018.05.017.
Thelen, E., Corbetta, D., & Spencer, J. P. (1996). Development of reaching during the first year: Role of movement speed. *Journal of Experimental Psychology: Human Perception and Performance, 22*(5), 1059–1076. https://doi.org/10.1037/0096-1523.22.5.1059.
Thelen, E., & Spencer, J. P. (1998). Postural control during reaching in young infants: A dynamic systems approach. *Neuroscience and Biobehavioral Reviews, 22*(4), 507–514. https://doi.org/10.1016/S0149-7634(97)00037-7.
Thomas, R. L., Misra, R., Akkunt, E., Ho, C., Spence, C., & Bremner, A. J. (2018). Sensitivity to auditory–tactile colocation in early infancy. *Developmental Science, 21*(4) e12597. https://doi.org/10.1111/desc.12597.
Tyll, S., Bonath, B., Schoenfeld, M. A., Heinze, H. J., Ohl, F. W., & Noesselt, T. (2013). Neural basis of multisensory looming signals. *NeuroImage, 65*, 13–22. https://doi.org/10.1016/j.neuroimage.2012.09.056.
von Hofsten, C. (1979). Development of visually directed reaching: The approach phase. *Journal of Human Movement Studies, 5* (3), 160–178 https://www.researchgate.net/profile/Claes-Hofsten/publication/243766154_Development_of_visually_directed_reaching_The_approach_phase/links/54fd84a90cf2c3f52424ec81/Development-of-visually-directed-reaching-The-approach-phase.pdf.
von Hofsten, C. (1991). Structuring of early reaching movements: A longitudinal study. *Journal of Motor Behaviour, 23*(4), 280–292. https://doi.org/10.1080/00222895.1991.9942039.

von Hofsten, C. (2004). An action perspective on motor development. *Trends in Cognitive Sciences, 8*(6), 266–272. https://doi.org/10.1016/j.tics.2004.04.002.

von Hofsten, C., & Rönnqvist, L. (1988). Preparation for grasping an object: A developmental study. *Journal of Experimental Psychology: Human Perception and Performance, 14*(4), 610–621. https://doi.org/10.1037/0096-1523.14.4.610.

Walker-Andrews, A. A. S., & Lennon, E. M. (1985). Auditory–visual perception of changing distance by human infants. *Child Development, 56*(3), 544–548. https://doi.org/10.2307/1129743.

Wilkie, S., & Stockman, T. (2020). The effect of audio cues and sound source stimuli on the perception of approaching objects. *Applied Acoustics, 167* 107388. https://doi.org/10.1016/j.apacoust.2020.107388.

Yonas, A., Bechtold, A. G., Frankel, D., Gordon, F. R., McRoberts, G., Norcia, A., & Sternfels, S. (1977). Development of sensitivity to information for impending collision. *Perception & Psychophysics, 21*(2), 97–104. https://doi.org/10.3758/BF03198713.