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Multisensory perception of looming and receding objects in human newborns

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When newborns leave the enclosed spatial environment of the uterus and arrive in the outside world, they are faced with a new audiovisual environment of dynamic objects, actions and events both close to themselves and further away. One particular challenge concerns matching and making sense of the visual and auditory cues specifying object motion [1–5]. Previous research shows that adults prioritise the integration of auditory and visual information indicating looming (for example [2]) and that rhesus monkeys can integrate multisensory looming, but not receding, audiovisual stimuli [4]. Despite the clear adaptive value of correctly perceiving motion towards or away from the self — for defence against and physical interaction with moving objects — such a perceptual ability would clearly be undermined if newborns were unable to correctly match the auditory and visual cues to such motion. This multisensory perceptual skill has scarcely been studied in human ontogeny. Here we report that newborns only a few hours old are sensitive to matches between changes in visual size and in auditory intensity. This early multisensory competence demonstrates that, rather than being entirely naïve to their new audiovisual environment, newborns can make sense of the multisensory cue combinations specifying motion with respect to themselves.

Newborns can discriminate between visual displays depicting different motion trajectories in the depth plane, showing a visual preference for trajectories approaching their body [6]. Here, we used an intersensory matching task (for example [4,7]) to investigate if this visual preference would be altered by concurrent auditory cues specifying the motion of a sound source towards or away from the body. Given prior evidence of intersensory matching in human infants and macaques [4,7], we predicted that, if newborns can match changes in auditory intensity and visual size according to their motion direction, then they should look longer at the display matching the auditory presentation: the looming display if the sound intensity increased and the receding one if it decreased. But because newborns show a preference for looming over receding visual displays [6], the visual preference for the intersensory match might also be reduced when the sound intensity decreased [4].

Twenty newborns (19–90 hours old) took part in the study, including two sound conditions, each comprising two trials. In both conditions, we presented the newborns with two simultaneous, side by side visual displays, each presenting the same object, one looming towards and the other receding from the newborn. Each trial lasted 44 s and included eight repetitions of the looming/receding displays. A centrally presented sound (8 kHz sine wave) accompanied the visual displays. The sound either increased or decreased in intensity (from 55 to 70 dB or vice versa), respectively

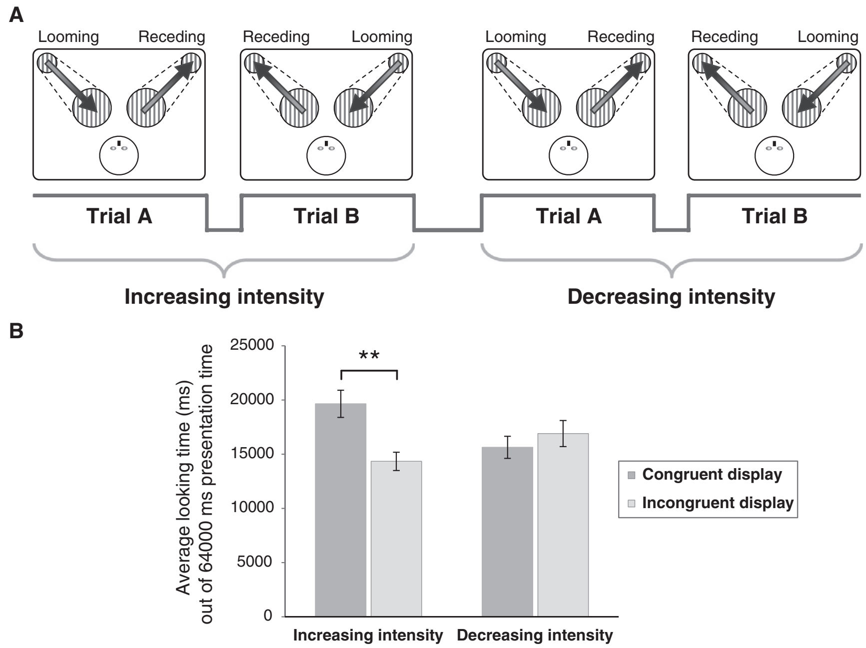

Figure 1. Experimental procedure and results.
(A) Description of the intersensory matching task. The experiment comprised two different sound conditions (sounds were always presented centrally), each including two trials. One condition presented a sound increasing in intensity, simulating a looming sound source, and the other presented a sound decreasing in intensity, simulating a receding sound source. During those auditory presentations, the newborns saw, side by side, looming and receding visual displays. The audiovisual stimuli were repeated eight times in each trial, with a 1-second interval between two subsequent stimuli and 4 s of blank screen before the first one, for an overall trial duration of 44 s. The positions of the two visual displays were counterbalanced across trials. The order of presentation of the two sound conditions and the two trials within each condition was counterbalanced across participants. (B) Looking durations (ms) towards the congruent and incongruent visual displays in each sound condition. Error bars indicate the standard error of the mean. Significant comparisons are indicated (** = $p < 0.01$). When the newborns were presented with a sound that increased in intensity (specifying an approaching sound source), they showed a visual preference for the congruent (looming) visual display. No visual preference was observed when the sound decreased in intensity. We measured the looking durations to each visual display in both sound conditions. A 2 x 2 repeated measures ANOVA (Congruency: Congruent/Incongruent; Sound condition: Increasing intensity/Decreasing intensity) revealed a significant effect of the Interaction, $F(1,19) = 6.652$, $p = 0.018$, $\eta^2 = 0.133$. No significant main effects of Congruency, $F(1,19) = 3.916$, $p = 0.063$, $\eta^2 = 0.055$, or Sound condition, $F(1,19) = 0.809$, $p = 0.380$, $\eta^2 = 0.008$, were observed. The absence of a significant main effect of Sound indicates that the sounds did not affect differently newborns' alertness and attentiveness. The newborns looked longer at the congruent visual display in the Increasing intensity condition, $t(19) = 3.562$, $p = 0.002$, $d_z = 0.796$, but not in the Decreasing intensity condition, $t(19) = -0.653$, $p = 0.521$, $d_z = 0.146$.

simulating approach or withdrawal of a sound source [8] (Figure 1A and Supplemental Experimental Procedures).

In both sound conditions, we recorded the newborns' looking durations to each visual display and compared these across conditions, according to whether the simulated motion directions of the visual and auditory stimuli were congruent or incongruent. We found a significant interaction between the congruency of the motion direction of the stimuli and the sound condition (Figure 1B). This interaction was explained by the newborns showing a visual preference for the congruent (looming) visual display when the sound intensity increased, but comparable looking durations at the two visual displays when it decreased.

To investigate if and how the presence of a sound influenced the newborns' looking to the visual stimuli, we compared the results from each condition of the current study with those of a previous one presenting unisensory looming and receding visual displays identical to those shown here [6]. The results of this comparison suggest that the presence of a sound decreasing in intensity led to an increase in the newborns' visual attention only towards the receding display, specifying motion in the same direction as the sound (Figure S1), reducing the preference for visual looming that newborns typically demonstrate [6].

Overall, these results show that newborns are able to match dynamic auditory and visual stimuli based on whether they specify motion towards or away from the infant. We found that newborns showed a visual preference for the looming visual display when a congruent sound, increasing in intensity, was presented. But we cannot rely on this condition alone to draw any conclusions about newborns' early multisensory competence, as they might have preferred the looming visual display irrespective of the sound, as shown in previous research [6]. However, the previous findings, obtained with visual looming and receding stimuli, highlighted newborns' preference for looming visual displays in absence of sound and therefore ruled out the possibility that the visual preference found here could be simply due to an arousal state driven by the presentation of a sound increasing in intensity [6]. If newborns' preference for the looming display was driven solely by visual information and they were not taking into account the sound, we would have expected them to show a visual preference for the looming display also in the Decreasing intensity condition. Conversely, when the sound decreased the newborns showed no significant visual preference. This demonstrates that newborns' pattern of looking durations is influenced by the simulated motion direction of a concurrent sound and, therefore, it supports the claim that they are able to match auditory and visual displays specifying a common motion direction towards or away from themselves. The absence of a significant preference in this condition suggests that the newborns' visual preferences result from a trade-off between a preference for intersensory matches and a preference for the ethological salience of the looming visual display.

The striking early multisensory competence that newborns showed here demonstrates that humans arrive in the world well prepared to perceive their audiovisual environment in depth. Further studies are needed to determine precisely how newborns make sense of their new audiovisual world (which cues they match across the senses). Do they match looming visual and auditory cues based on changing size/intensity, is looming perceived in common via changes in the total energy of stimulation, or are links made between changing sound intensity and other visual depth cues such as changes in surface reflection? All of these possibilities raise provocative questions about the early origins of multisensory abilities because current influential accounts of multisensory development argue that newborns are largely limited to perceiving redundant intersensory properties [9]. Changes in size and intensity are not specified redundantly across modalities, and it is even questionable whether such a basic sense property as intensity is coded in a common format in the nervous system [10]. Irrespective of the specific cues used to perceive multisensory motion trajectories, this ability at birth represents an important point of access for making sense of the multisensory world. The prenatal origins of this ability certainly deserve further study.

SUPPLEMENTAL INFORMATION

Supplemental Information includes experimental procedures, one table, one figure and one video, and can be found with this article online at https://doi.org/10.1016/j.cub.2018.10.004.

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AUTHOR CONTRIBUTIONS

Conceptualization, G.O. and T.F.; Methodology, G.O. and T.F.; Software, G.O.; Formal Analysis, G.O. and A.B.; Investigation, G.O.; Resources, G.O.; Data Curation, G.O.; Writing – Original Draft, G.O., A.B. and T.F.; Writing – Review & Editing, G.O., A.B. and T.F.; Visualization, G.O.

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