

# **Preverbal Infants' Sensitivity to Synaesthetic Cross-Modality Correspondences**

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## **ABSTRACT**

Stimulation of one sensory modality can induce perceptual experiences in another modality that reflect synaesthetic correspondences among different dimensions of sensory experience. In visual-hearing synaesthesia, for example, higher-pitched sounds induce visual images that are brighter, smaller, higher in space, and sharper, than those induced by lower-pitched sounds. Claims that neonatal perception is synaesthetic imply that such correspondences are an unlearned aspect of perception. To date, the youngest children in whom such correspondences have been confirmed with any certainty were 2- to 3-year-olds. We examined preferential looking to assess 3- to 4-month-old preverbal infants' sensitivity to the correspondences linking auditory pitch to visuo-spatial height and visual sharpness. The infants looked longer at a changing visual display when this was accompanied by a sound whose changing pitch was congruent, rather than incongruent, with these correspondences. This is the strongest indication to date that synaesthetic cross-modality correspondences are an unlearned aspect of perception.

## **Preverbal Infants' Sensitivity to Synaesthetic Cross-Modality Correspondences**

Synaesthesia occurs when stimulation of one sensory channel induces perceptions normally associated with a different sensory channel. Though there is much that is idiosyncratic about the experiences of individual synaesthetes, their experiences are constrained by a set of underlying cross-modality correspondences. These correspondences reflect the alignment of different dimensions of sensory experience (e.g., between visual brightness and auditory pitch), and can also be observed in non-synaesthetes (where their influence is called *weak synaesthesia*, see Martino & Marks, 2001). Claims that neonatal perception is synaesthetic for all infants (James, 1890; Maurer, Pathman, & Mondloch, 2006; Mondloch & Maurer, 2004), suggest that these cross-modality correspondences are an innate aspect of perception.

Cross-modality correspondences qualify most clearly as synaesthetic either when at least one of the dimensions involved is a *metathetic*<sup>1</sup> dimension (i.e., a dimension concerned with a qualitative aspect of sensory experience), or when two *prothetic* dimensions (i.e., dimensions concerned with the 'amount' of sensory experience) are aligned in opposition to their *more-than* interpretation (e.g., when *less* size is aligned with *more* brightness and *more* speed, see Walker & Smith, 1985). When two *prothetic* dimensions are aligned according to their shared *more-than* interpretation (e.g., when *more* visual brightness is aligned with *more* auditory loudness), the cross-modality associations that arise need not be synaesthetic. Instead, they might reflect the fact that the two modalities are conveying equivalent (redundant) information about the same aspect of an object or event (as when vision and audition provide equivalent information about the strength of a stimulus). Lewkowicz and Turkewitz (1980) emphasized the latter

interpretation in their seminal study demonstrating that 3- to 4.5-week-old infants respond to the equivalence of different levels of visual brightness and auditory loudness.

As a metathetic dimension, auditory pitch is involved in cross-modality correspondences with visuo-spatial height (Melara & O'Brien, 1987; Miller, Werner, & Wapner, 1958; Roffler & Butler, 1967), visual sharpness (Marks, 1987; O'Boyle & Tarte, 1980), visual brightness (Collier & Hubbard, 2001; Marks, 1978; Walker & Smith, 1984, 1985; Ward, Huckstep, & Tsakanikos, 2006), lightness in weight (Walker & Smith, 1984), and smallness in size (Parise & Spence, 2008; Perrott, Musicant, & Schwethelm, 1980; Walker & Smith, 1984). Some of these studies confirmed the impact of cross-modality correspondences on perception (e.g., Miller, Werner, & Wapner, 1958; Parise & Spence, 2008; Roffler & Butler, 1967). Strong evidence for this also comes from visual-hearing synaesthesia, where higher-pitched sounds induce visual images that are brighter, smaller, higher in space, sharper, and more likely to be moving, than those induced by lower-pitched sounds (Karwoski & Odbert, 1938; Marks, 1987; Ward, Huckstep, & Tsakanikos, 2006).

If neonatal perception is synaesthetic, then infants should reveal their sensitivity to these cross-modality correspondences. Wagner, Winner, Cicchetti, and Gardner (1981) claimed to have shown that 9- to 13-month-olds appreciate the correspondence between visual height (specifically, an up and down pointing arrow) and auditory pitch (an ascending and descending tone). As noted by Wagner et al., however, arrows are conventional symbols whose significance needs to be learned, and their infants may not have interpreted them as representing ascending and descending change. Instead, Wagner et al. proposed that their infants should have looked at the top of an up arrow, and at the bottom of a down arrow, because these are the locations at which the highest density of visual information is found. They imply, therefore, that it is the difference in the elevation

of infants' fixations that is the critical factor entering into correspondence with the ascending/descending pitch of a sound. Wagner et al. offered no supporting evidence for the presence and significance of such a correspondence in adults, and did not monitor the elevation of their infants' fixations, and so we contend that the youngest children in whom synaesthetic cross-modality correspondences have been confirmed with any certainty were 2- to 3-year-olds (Maurer, Pathman, & Mondloch, 2006; Mondloch & Maurer, 2004).

This age range does not preclude mediation through postnatal learning. Such learning could be based on a child's exposure to language, because synaesthetic cross-modality correspondences find expression in the visible, spoken, and conceptual aspects of language (Marks, 1978). For example, across a range of languages, smaller, brighter, sharper, and faster things tend to have names with higher-pitched vowel sounds (Marks, 1978; Maurer, Pathman, & Mondloch, 2006). To test the perceptual innateness of synaesthetic cross-modality correspondences, while avoiding any learning based on language comprehension, we exploited a preferential looking procedure to assess 3- to 4-month-old preverbal infants' sensitivity to two synaesthetic correspondences involving auditory pitch.

In the first of two experiments, we examined the correspondence between auditory pitch and visuo-spatial height. In the second experiment, we examined the correspondence between auditory pitch and visual sharpness. The existence of these two perceptual correspondences has been confirmed with several observations. For example, when adults point to the perceived visual location of a sound whose source is hidden from view, the elevation of this location is determined by the pitch of the sound, and not by the actual location of the source of the sound (Roffler & Butler, 1967). And when an incidental sound rises and falls in pitch, it induces corresponding visual illusory movement (i.e., upward versus downward autokinetic movement, respectively) in a stationary spot of light (Miller,

Werner, & Wapner, 1958). In addition to being observed in visual-hearing synaesthesia, the correspondence between auditory pitch and visual sharpness emerges when adults judge the sharpness of auditory tones varying in pitch using a scale defined by the polar adjectives *sharp* and *blunt* (Walker & Smith, 1985). And when, in a preliminary phase of the present study, people rated pointed and curved variants of several geometric shapes (including those in Fig. 1B) on a scale with endpoints defined as *would make a high/low-pitched sound if it came to life or was struck by another object*, pointedness was again associated with higher pitch.

## METHOD

### Participants

Eight male and eight female infants completed the *pitch-height* experiment (mean age = 128 days, range = 114 to 145 days). A further two infants were unable to complete this experiment because of excessive restlessness. Eight male and eight female infants completed the *pitch-sharpness* experiment (mean age = 129 days, range = 91 to 150 days). A further three infants were unable to complete the experiment because of excessive restlessness.

### Materials and Procedure

A Barco monitor was integrated into one 'wall' of a 3 m<sup>2</sup> cubicle created from thick black curtaining. QuickTime animations appeared within a 48 x 48 cm screen area (25.6 x 25.6 deg), each lasting a maximum of 60 s. Each infant sat on her/his mother's knee, viewing the animations at eye level and from a distance of 1 m. Their mothers fixed their own gaze on the top of their child's head. An infant's eye fixations were monitored and recorded on video, and an animation was removed immediately they looked elsewhere for a single period of 2 s or more. The total length of time an infant looked directly at an animation was

later ascertained by two independent judges who were ignorant of the nature of the animation being observed by the infant.

In the *pitch-height* experiment, the infants watched a 7 cm (4 deg) diameter orange ball (average luminance = 39 cd/m<sup>2</sup>) move up and down a 32 cm vertical trajectory in front of a 20 x 20 grid of small white dots on an otherwise dark field (Fig. 1A). The deletion and accretion of the dots served to strengthen the impression that the ball was a solid object moving in its own depth plane. The ball moved at a constant speed of 12.8 cm/s, and paused momentarily (50 ms) at each endpoint. Each animation was accompanied by the sound of a sliding whistle, whose fundamental frequency changed at a constant rate, between 300 and 1700 Hz, over a period of time coinciding with an individual phase of the animation (2.5 s). The loudness of the sound increased and then decreased between 54 and 80 dB (against an uncontrolled ambient noise level of 42 dB) within each phase of the animation, peaking when the fundamental frequency of the sound was mid-range. The ‘natural’ sound of a sliding whistle has a loudness profile of this type, and this profile was retained during sound editing for two reasons: First, to preserve the naturalness of the sound (which we considered especially important for infants) and second, in the absence of individual equal loudness contours for our participants, to ensure that changes in perceived loudness were not confounded with changes in pitch. In the *congruent condition*, the pitch of the sound rose and fell as the ball rose and fell. In the *incongruent condition*, the pitch of the sound fell and rose as the ball rose and fell. Every infant viewed three congruent animations interleaved with three incongruent animations, with eight infants viewing a congruent/incongruent animation first.

In the *pitch-sharpness* experiment, the infants watched computerised animations of a static, uniformly grey (13 cd/m<sup>2</sup>) geometric shape morphing, at a constant rate, between two extreme forms of pointedness (Fig. 1B). The shape appeared against a beige, hopsack

background (average luminance = 28 cd/m<sup>2</sup>), and in its pointed and curved extreme forms had a surface area of 100.3 and 99.7 cm<sup>2</sup>, respectively. With this small difference in surface area, the overall size of the shape did not appear to change as it morphed (as judged by a set of independent adult judges in a preliminary study). The morphing was accompanied by the same sound used in the *pitch-height* experiment. Each phase of the animation (morphing from one extreme to the other) again lasted 2.5 s, with a brief 50 ms pause at each extreme. In the *congruent condition*, the pitch of the sound rose and fell as the shape became more and then less pointed. In the *incongruent condition*, the pitch of the sound fell and then rose as the shape became more and then less pointed. Other aspects of the method were identical to the *pitch-height* experiment.

## RESULTS

In both experiments, a high level of agreement was confirmed between the two judges in their estimates of each infant's individual viewing times across the six trials (mean Pearson  $r = .99, p < .01$ , in both cases).

### Auditory pitch and visuo-spatial height

Twelve of the sixteen infants looked longer at a congruent animation than at an incongruent animation ( $p = .038$  on a binomial test,  $p_{\text{rep}} = .90$ ). The average time infants looked at congruent and incongruent animations was 28.5 ( $SD = 10.5$  s) and 21.7 s ( $SD = 11.9$  s), respectively. Because the looking times were positively skewed, they were log-transformed before analysis of variance confirmed the significance of the effect of congruity [ $F(1,15) = 9.22, p = .008, p_{\text{rep}} = .94, \eta_p^2 = .38$ ].

### Auditory pitch and visual sharpness

Twelve of the sixteen infants looked longer at a congruent animation than at an incongruent animation ( $p = .038$  on a binomial test,  $p_{\text{rep}} = .90$ ). The average time infants looked at

congruent and incongruent animations was 20.1 ( $SD = 7.9$  s) and 15.9 s ( $SD = 6.3$  s), respectively. Analysis of variance of the log-transformed looking times confirmed the significance of the effect of congruity [ $F(1,15) = 7.57, p = .015, p_{\text{rep}} = .96, \eta_p^2 = .34$ ]. The percentage reduction in looking time caused by introducing incongruity was comparable across both experiments (i.e., 24% and 21% for the *pitch-height* and *pitch-sharpness* experiments, respectively).

## DISCUSSION

Our results confirm young infants' sensitivity to the correspondences linking auditory pitch with visuo-spatial height and visual sharpness. They provide the strongest indication to date that synaesthetic cross-modality correspondences are an unlearned aspect of perception, and are consistent with claims that neonatal perception is synaesthetic.

Some might wish to argue that our infants were old enough to have learned the correspondences. This raises two questions. First, where might the correspondences originate, if not in language? Second, could there be sufficient exposure to these origins to allow the correspondences to be learned within the first three or four months of life? It is possible that relevant co-occurrences exist in the real world, and exposure to these ensures perceptual learning of the underlying dimensional correspondences. For example, when they hear people/animals vocalise (Bee, Perrill, & Owen, 2000; Davies & Halliday, 1978; Harrington, 1987), and objects strike each other (Grassi, 2005; Perrott, Musicant, & Schwethelm, 1980), infants will encounter co-occurrences reflecting the correspondence between size and pitch, and these encounters might be sufficient to establish perceptual expectations linking size and pitch. It is difficult, however, to identify natural co-occurrences capable of supporting other correspondences, including the two correspondences examined here. With regard to sharpness and pitch, a potentially relevant co-occurrence might be mediated by the hardness of natural materials. Sharp/pointed

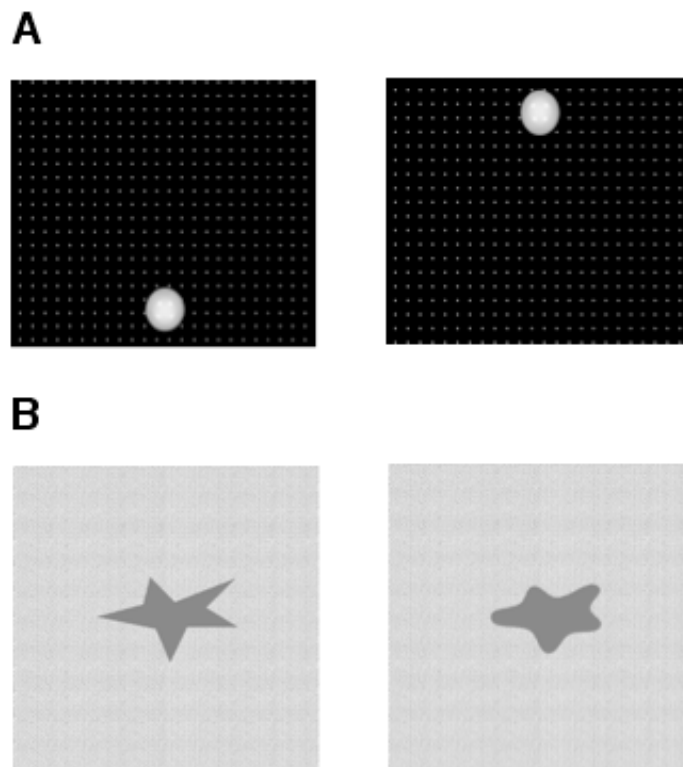
objects tend to be formed from hard materials, for which reason the objects are also likely to make relatively high-pitched sounds when struck (Freed, 1990; Klatzky, Pai, & Krotkov, 2000; van den Doel & Pai, 1998). Future research must explore the incidence of natural co-occurrences to determine if the typical environment to which young infants are exposed could support perceptual learning of the synaesthetic cross-modality correspondences observed in adulthood. Confirmation would not, of course, mean that sensitivity to the correspondences is acquired during infancy. Indeed, we doubt very much that infants' encounters with objects within the first 3 to 4 months could support such learning, in part because any relevant co-occurrences will not be in evidence with complete consistency (e.g., objects that look sharp will sometimes make a low-pitched sound, and *vice versa*). Furthermore, as implied by the claim that neonatal perception is synaesthetic, acquisition of the correspondences could be phylogenetic, rather than ontogenetic, with appropriate neural circuitry in place at birth (Maurer & Mondloch, 2006).

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**Fig. 1** Animations involving visuo-spatial height and pointedness: **(A)** The moving ball as seen at the extremes of its vertical trajectory in the *pitch-height* experiment. **(B)** The extreme forms of pointedness of the static morphing shape as seen in the *pitch-sharpness* experiment. Reproduced to scale.

## Notes

1. The distinction between *prothetic* and *metathetic* dimensions (continua) of sensory experience is, in essence, a distinction between quantity and quality (Stevens, 1957). Prothetic dimensions are concerned with how much of a type of sensation is being experienced (e.g., how loud), and have been linked to variations in the level of excitation within a sensory channel. Metathetic dimensions deal with qualitative differences in sensory experience, and have been linked to variations in the location of maximum excitation in a sensory channel.