Cognitive, Affective, & Behavioral Neuroscience
2004, 4 (2), 133-136

Do small white balls squeak? Pitch–object correspondences in young children

CATHERINE J. MONDLOCH
McMaster University, Hamilton, Ontario, Canada
and Brock University, St. Catharines, Ontario, Canada

and

DAPHNE MAURER
McMaster University, Hamilton, Ontario, Canada

Adults with auditory–visual synesthesia agree that higher pitched sounds induce smaller, brighter visual percepts. We have hypothesized that these correspondences are remnants of cross-modal neural connections that are present at birth and that influence the development of perception and language even in adults and children without synesthesia. In this study, we explored these correspondences in preschoolers (30–36 months; $n = 12$ per experiment). The children were asked to indicate which of two bouncing balls was making a centrally located sound. The balls varied in size and/or surface darkness; the sound varied in pitch. The children reliably matched the higher pitched sound to a smaller and lighter (white) ball (Experiment 1), to a lighter (white) ball (Experiment 2), and in one of two groups, to a smaller ball (Experiment 3). Children's matching of pitch and size cannot be attributed to intensity matching or to learning. These data support the hypothesis that some cross-modal correspondences may be remnants of the neural mechanisms underlying neonatal perception.

Synesthesia, a condition in which stimulation in one modality evokes not only the "correct" perception, but also a specific perception in a second, "wrong" modality (Harrison & Baron-Cohen, 1997), involves both idiosyncratic correspondences that vary across synesthetes and correspondences on which synesthetes generally agree. The latter may reflect fundamental cross-modal correspondences that may have been present at birth. In the most common form of synesthesia, sounds evoke not only auditory, but also visual perceptions (e.g., Baron-Cohen, Wyke, & Binnie, 1987; Cytowic, 2002; Marks, 1975). Although the specific correspondences vary across individuals (e.g., whether *p* is green or blue), there is general agreement among synesthetes that high-frequency sounds produce smaller, brighter percepts than do low-frequency sounds (e.g., a higher pitched *p* is a brighter green or a brighter blue; Marks, 1974; Marks, Hammeal, & Bornstein, 1987). Brain imaging with adult synesthetes has revealed two unusual patterns of brain activity during their synesthetic perceptions: deactivation of large parts of the cortex (Cytowic, 1989) and activation of the visual cortical areas by sound (Aleman, Rutten, Sitskoorn, Dautzenberg, & Ramsey, 2001; Gray, Williams, Nunn, & Baron-Cohen, 1997; Nunn et al., 2002; Paulesu et al., 1995). Both patterns are likely to occur in newborns—because the cortex is immature and because its limited functioning may be influenced by transient connections between sensory cortical areas (Maurer & Mondloch, 1996, in press). Thus, we hypothesized that synesthesia may represent the failure to prune cross-modal connections that were present at birth and that influence neonatal perception (i.e., neonatal synesthesia).

Although young children and adults without synesthesia do not experience visual percepts in response to auditory stimuli, they do report cross-modal correspondences that parallel the commonalities reported by synesthetes. Normal adults match higher pitched tones with smaller lights, brighter lights (Marks et al., 1987), and the lighter of two gray squares (Marks, 1974). They also match louder tones with brighter lights (Marks et al., 1987) and larger objects (Smith & Sera, 1992). Some of these cross-modal correspondences can be attributed to intensity matching. This explanation can be invoked whenever participants are asked to match stimuli that vary along dimensions we describe in *more-end* terms (i.e., *prothetic* dimensions), such as size and loudness (Smith & Sera, 1992; Stevens, 1957): Bigger objects, louder sounds, and brighter lights may match because they are at the "more" end of prothetic dimensions. However, intensity matching cannot be invoked if one of the dimensions is *metathetic* and, thus, cannot be described in more-end terms. Although *big* is more than *small*, *loud* is more than *quiet*, and *bright* is more than *dim*, adults do not describe either achromatic color (surface darkness) or pitch in more-end

---

Correspondence concerning this article should be addressed to C. J. Mondloch, Department of Psychology, Brock University, 500 Glenridge Ave., St. Catharines, ON, L2S 3A1 Canada (e-mail: cmondloch@brocku.ca; mondloch@mcmaster.ca).

terms. Dark gray, for example, is not "more than" light gray, and adults vary in whether they match dark gray to the larger or the smaller of two objects (Smith & Sera, 1992). Similarly, higher pitch (treble) is not "more than" lower pitch (bass). Thus, the correspondences that both synesthetes and normal adults report between pitch and surface darkness (both metathetic dimensions) and between pitch and size (one metathetic and one prothetic dimension) cannot be attributed to intensity matching. We hypothesize that these correspondences are remnants of the intrinsic wiring of the nervous system underlying neonatal perception and, hence, that they will be observable in young children who have not yet learned much of the metaphorical aspects of language. In this study, we investigated the perceived correspondence between pitch and size and between pitch and surface darkness in children 30–36 months old.

Previous research has indicated that there are developmental changes in perceived correspondences among dimensions, both within and between modalities. Unlike adults and older children, 2-year-olds treat surface darkness as a prothetic dimension: They consistently report that dark gray is "more" than light gray and match it to the larger of two objects (Smith & Sera, 1992). Smith and Sera speculated that in its initial state, surface darkness may be a prothetic dimension and only later become a metathetic dimension, as the child's acquisition of language modifies matching based earlier on sensory physiology. There are also reported developmental changes in auditory–visual correspondences, with younger children failing to show the correspondences reported by older children and adults: Two-year-olds did not match the larger of two objects with the louder of two sounds (Smith & Sera, 1992), and even 9-year-old children did not match a larger light with a lower pitch in a perceptual matching task; nor did they understand cross-modal metaphors involving pitch and size (Marks et al., 1987).

Our goal was to test correspondences between pitch and both surface darkness and size, using a procedure designed for young children. We first used common animals and objects, such as a lion and an elephant, to train the child to "play the game" of indicating which one was making the accompanying sound. We then showed the child a movie of two balls bouncing in synchrony with each other and with a central sound that varied in auditory frequency. The child was asked to point to the ball that was "making" the sound. In Experiment 1, the balls differed in both size and surface darkness; in Experiments 2 and 3, the balls differed only in surface darkness (Experiment 2) or only in size (Experiment 3). Because one or both of the dimensions being varied was metathetic, matching of a sound to one of the visual stimuli cannot be attributed to intensity matching. Rather, if these children match the visual and auditory stimuli in a manner analogous to adults with and without synesthesia, it would support the hypothesis that some cross-modal correspondences have their origin in the initial wiring of the nervous system underlying neonatal perception, some of which is preserved after infancy.

EXPERIMENT 1

Method

Participants. Twelve children (6 boys and 6 girls) ranging in age between 30:0 and 35:11 months participated. In this and subsequent experiments, parents were contacted from our file of volunteers recruited through hospital visits shortly after birth. No children had to be excluded from any of the experiments for failure to pass the training task (see below).

Stimuli. All the stimuli were presented on a color video monitor. Sounds emanated from a speaker centered directly above the monitor. Training stimuli consisted of four pairs of objects (lion–elephant; train–car; cow–horse; and sheep–pig) accompanied by a sound appropriate to one member of each pair. The stimuli used to test intermodal correspondences consisted of two bouncing balls—one smaller (4.8 cm in diameter; 3.44º from 80 cm) and white (93 cd/m^2), one larger (9.8 cm in diameter; 7º from 80 cm) and gray (42 cd/m^2)—that bounced in synchrony with each other and with a tone that was presented as the balls reversed their trajectory at the bottom of the screen. The frequency of the tone was higher (512 Hz) or lower (256 Hz). To reduce the likelihood of the children's responding on the basis of correspondences between loudness and either brightness or size, we varied the volume randomly across bounces between 66 and 74 db, in 2-db steps.

Procedure. The experimenter greeted the child and his/her parents, explained the study to the parents and obtained informed consent. The experimenter then played with the child until the child was willing to "play a game." Each test began with a training task designed to facilitate the children's comprehension of our intermodal task. We showed each child the video of four pairs of familiar animals/objects accompanied by a sound appropriate to one member of each pair. The observer, who stood behind the child to minimize cuing, asked the child to point to the animal/object that was "making" the sound. To be included in the final sample, the child had to point correctly on three of the four training trials; all the children passed this criterion.

After the training phase, the observer played a videotape of the two bouncing balls. We presented four demonstration trials in which the two balls bounced three times in synchrony with each other and with a tone that was presented as the balls reversed their trajectory at the bottom of the screen. On alternating trials, the frequency of the tone was higher (512 Hz) or lower (256 Hz). For half of the children, the sequence began with the higher frequency tone, and for the other half, it began with the lower frequency tone. We then presented a single test trial in which the two balls bounced 10 times in synchrony with each other and one of the two tones. After the first three bounces, the observer instructed the child to point to the ball that was making the sound. Half of the children were tested with the higher frequency tone, and the remaining half were tested with the lower frequency tone.

Results and Discussion

Eleven out of 12 children matched in the predicted direction (one-tailed binomial test, $p < .01$): They said that the smaller, white ball was making the higher frequency sound or that the larger, gray ball was making the lower frequency sound. This experiment cannot distinguish whether children were matching pitch only with size, only with surface darkness, or with both size and surface darkness, because the smaller ball was also white. Marks et al. (1987) reported that 88% of 3.5- to 5.5-year-old children match higher pitch with brighter lights but that only 54% of 9-year-olds match higher pitch with smaller lights. We expected, then, that the children in our experiment were responding on the basis of surface darkness alone—that is, that they were matching two metathetic dimensions that cannot be described in more–less terms. To test this hypothesis directly, in the next experiments, we tested separate groups of children with visual stimuli varying only in surface darkness (Experiment 2) or only in size (Experiment 3).

EXPERIMENT 2

Method

Twelve children ranging in age from 33:26 to 35:19 months participated. The stimuli and procedure were identical to those in Experiment 1, with one exception: The balls were the same size (7° from 80 cm), but one was white (93 cd/m^2) and the other gray (42 cd/m^2).

Results and Discussion

As was predicted, children less than 3 years old matched lower pitch to darker balls. Every child matched in the predicted direction (one-tailed binomial test, $p < .01$): They said that the white ball was making the higher frequency sound and that the gray ball was making the lower frequency sound. This is the same correspondence as that reported by synesthetic adults with colored hearing (Marks, 1975) and as the correspondence shown in the pattern of perceptual matching by nonsynesthetic adults (Marks, 1974). Moreover, the visual discriminations of nonsynesthetic adults are influenced by this correspondence, so that they respond faster and more accurately when the brighter of two lights is accompanied by an irrelevant sound of higher pitch than if the match is opposite (Marks, 1987; Melara, 1989).

Because pitch and surface lightness are both metathetic, this correspondence cannot be attributed to intensity matching. Furthermore, these two attributes are not reliably related in the real world: Darker objects do not make lower pitched sounds. It is unlikely, therefore, that the correspondence can be attributed to postnatal learning of auditory–visual correspondences that are prevalent in the environment.

EXPERIMENT 3

Method

Two groups of 12 children, ranging in age from 34:15 to 35:26 months (Group 1) and from 33:9 to 35:22 months (Group 2), participated. The stimuli and procedure were identical to those in Experiment 1, with one exception: Both balls were white (93 cd/m^2), but one was smaller (7° from 80 cm) than the other (3.44° from 80 cm).

Results and Discussion

Only 9 of the 12 children in the first group matched in the predicted direction. Because this result approached significance ($p = .07$), we tested a second group of 12 children. Ten of these children matched in the expected direction (one-tailed binomial test, $p < .05$): They said that the smaller ball was making the higher frequency sound or that the larger ball was making the lower frequency sound. These results suggest that children as young as 30–36 months tend to match higher frequency sounds with smaller objects but that this correspondence may be weaker than that between pitch and surface darkness.

GENERAL DISCUSSION

During the second half of their 3rd year, children match higher pitched sounds with more luminant objects and with smaller objects, although the latter association may be weaker. These data concur with Marks et al. (1987), who reported that slightly older children (3.5– 5.5 years) match higher pitch with brighter lights. Unlike Marks et al., however, we also found associations between pitch and size, perhaps because our task was more "child friendly." Because we varied loudness, these correspondences cannot be attributed to correspondences between loudness and size or loudness and surface darkness.

The correspondence between pitch and size reported in Experiment 3 cannot be based on intensity matching, because pitch is a metathetic dimension. However, higher pitch is reliably associated with smaller objects in the real world. Children's voices are higher pitched than those of their parents, and smaller musical instruments, such as a violin, make higher frequency sounds than do larger musical instruments, such as a cello. Therefore, we cannot rule out the possibility that these correspondences are based on postnatal learning of the types of auditory–visual pairings that occur frequently in the environment.

The correspondence between pitch and surface darkness reported in Experiment 2 also cannot be based on intensity matching, because both pitch and surface darkness are metathetic dimensions. More important, this correspondence is unlikely to have been learned from observing the statistical properties of the environment—lighter objects do not make higher pitched sounds in the real world. That young children match higher pitched sounds with lighter gray objects is consistent with the hypothesis that this same correspondence observed in nonsynesthetic adults is not the result of specific training by the environment. Rather, it may reflect the preservation of neural connections between sensory areas that were present at birth and that were not pruned: Those connections may continue to influence the child's perception and may come to influence the child's developing language.

Ramachandran and Hubbard (2001) have suggested that synesthetic correspondences between sensory dimensions may have "boot-strapped" the evolution of language. Adults rate angular nonsense figures as more aggressive, more tense, stronger, and noisier than rounded shapes (Marks, 1996); they are also more likely to label angular shapes *takete* or *kiki* and rounded shapes *maluma* or *bouba*—perhaps because there is a correspondence between the visual percept, the phonetic inflections, and the movement of the tongue on the palate that results from the same type of cortical connections among contiguous cortical areas that underlie synesthesia (Ramachandran & Hubbard, 2001). Future studies are needed to determine whether such synesthetic correspondences facilitate the toddler's learning to map words onto objects. This model would predict that toddlers would be more likely to select a rounded toy when an experimenter asks for the *maluma* but an angular toy when asked for the *takete*. Perceptual organization and language do appear to influence one another during development. Two-year-olds match darker gray with the bigger of two objects; however, subsequent comprehension of the four relevant adjectives—dark, light, big, and little—results in perceptual disorganization, so that older children no longer match these two dimensions consistently (Smith & Sera, 1992). Thus, rather than language learning initiating the child's understanding of auditory–visual correspondences, it may alter an already existing understanding based on cortical interconnections that exist in the immature brain.

Synesthetic correspondences between sensory dimensions also may facilitate the production and understanding of cross-modal metaphors. Systematic investigations have demonstrated that words denoting loudness, brightness, pitch, and surface lightness act in much the same way as sensory stimuli that vary on these dimensions. Adults rate *bright coughs* as louder than *dim coughs*, and *loud sunlight* as brighter than *quiet sunlight* (Marks, 1982), just as they match brighter lights with louder tones (Marks et al., 1987). Likewise, they rate *bright* sneezes as higher pitched than *dim* sneezes and violins as brighter than thunder (Marks, 1982)—just as they match higher pitched tones with lighter and brighter visual stimuli (Marks, 1974; Marks et al., 1987). Not only are sensory dimensions that adults match in laboratory studies mirrored in metaphors, but sensory dimensions that adults fail to match in laboratory tasks are not related metaphorically. Dark squares are not consistently matched with louder/quieter tones (Marks, 1974), and dark piano notes are not rated as much louder than bright piano notes (Marks, 1982).

Of course, although the present results are consistent with the hypothesis that newborns' perception is synesthetic, they do not prove it; nor do they clarify the precise nature of infants' perception. Newborns may resemble synesthetic adults in whom stimulation of one sensory modality evokes not only a percept in that modality (such as hearing a voice), but also a specific percept in a second modality (e.g., seeing a shape). Alternatively, newborns may fail to differentiate stimuli from different modalities and may respond on the basis of the total amount of energy, summed across all modalities (see also Zelazo, 1996), or they may have partially differentiated perceptions, the quality of which is altered by stimulation in a second modality. Nonetheless, a remnant of neonatal perception appears to be cross-modal correspondences between dimensions that are reported by preschool children and that cannot be explained by either intensity matching or specific postnatal learning. Such correspondences appear to contribute to metaphorical language (Marks, 1982; Marks et al., 1987) and may facilitate the development of language in individuals.

REFERENCES

Aleman, A., Rutten, G. J., Sitskoorn, M. M., Dautzenberg, G., & Ramsey, N. F. (2001). Activation of striate cortex in the absence of visual stimulation: An fMRI study of synesthesia. *NeuroReport*, **12**, 2827-2830.

Baron-Cohen, S., Wyke, M., & Binnie, C. (1987). Hearing words and seeing colours: An experimental investigation of a case of synaesthesia. *Perception*, **16**, 761-767.

Cytowic, R. E. (1989). *Synesthesia: A union of the senses*. New York: Springer-Verlag.

Cytowic, R. E. (2002). *Synesthesia: A union of the senses* (2nd ed.). Cambridge, MA: MIT Press.

Gray, J., Williams, S., Nunn, J., & Baron-Cohen, S. (1997). Possible implications of synaesthesia for the hard question of consciousness. In S. Baron-Cohen & J. Harrison (Eds.), *Synaesthesia: Classic and contemporary readings* (pp. 173-181). Oxford: Blackwell.

Harrison, J. E., & Baron-Cohen, S. (1997). Synaesthesia: An introduction. In S. Baron-Cohen & J. E. Harrison (Eds.), *Synaesthesia* (pp. 3-16). Oxford: Blackwell.

Marks, L. E. (1974). On associations of light and sound: The mediation of brightness, pitch, and loudness. *American Journal of Psychology*, **87**, 173-188.

Marks, L. E. (1975). On colored-hearing synesthesia: Cross-modal translations of sensory dimensions. *Psychological Bulletin*, **82**, 303-331.

Marks, L. E. (1982). Bright sneezes and dark coughs, loud sunlight and soft moonlight. *Journal of Experimental Psychology: Human Perception & Performance*, **8**, 177-193.

Marks, L. E. (1987). Auditory–visual interactions in speeded discrimination. *Journal of Experimental Psychology: Human Perception & Performance*, **13**, 384-394.

Marks, L. E. (1996). On perceptual metaphors. *Metaphor & Symbolic Activity*, **11**, 39-66.

Marks, L. E., Hammeal, R., & Bornstein, M. (1987). Perceiving similarity and comprehending metaphor. *Monographs of the Society for Research in Child Development*, 52 (Serial No. 215).

Maurer, D., & Mondloch, C. (1996). Synesthesia: A stage of normal infancy? In S. Masin (Ed.), *Proceedings of the 12th meeting of the International Society for Psychophysics* (pp. 107-112). Padua.

Maurer, D., & Mondloch, C. (in press). Neonatal synesthesia: A reevaluation. In L. Robertson & N. Sagiv (Eds.), *Attention on synesthesia: Cognition, development and neuroscience*. Oxford: Oxford University Press.

Melara, R. D. (1989). Dimensional interactions between color and pitch. *Journal of Experimental Psychology: Human Perception & Performance*, **15**, 69-79.

Nunn, J. A., Gregory, L. J., Brammer, M., Williams, S., Parslow, D., Morgan, M., Morris, R., Bullmore, E., Baron-Cohen, S., & Gray, J. (2002). Functional magnetic resonance imaging of synesthesia: Activation of V4/V8 by spoken words. *Nature Neuroscience*, **5**, 371-375.

Paulesu, E., Harrison, J., Baron-Cohen, S., Watson, J., Goldstein, L., Heather, J., Frackowiak, R., & Frith, C. (1995). The physiology of coloured-hearing: A PET activation study of colour–word synesthesia. *Brain*, **118**, 661-676.

Ramachandran, V. S., & Hubbard, E. M. (2001). Synaesthesia: A window into perception, thought and language. *Journal of Consciousness Studies*, **8**, 3-34.

Smith, L. B., & Sera, M. D. (1992). A developmental analysis of the polar structure of dimensions. *Cognitive Psychology*, **24**, 99-142.

Stevens, S. S. (1957). On the psychophysical law. *Psychological Review*, **64**, 153-181.

Zelazo, P. D. (1996). Toward a characterization of minimal consciousness. *New Ideas in Psychology*, **14**, 63-80.

(Manuscript received October 17, 2003;
revision accepted for publication April 4, 2004.)