



Brief report

Intersensory redundancy promotes visual rhythm discrimination in visually impaired infants



Viola Brenna^a, Elena Nava^{b,*}, Chiara Turati^b, Rosario Montiroso^a, Anna Cavallini^c, Renato Borgatti^c

^a 0-3 Centre for the Study of Social Emotional Development of At-Risk Infant, Scientific Institute, IRCCS Eugenio Medea, Bosisio Parini, LC, Italy

^b Department of Psychology, University of Milan-Bicocca, Milan, Italy

^c Department of Child and Adolescent Neurology and Psychiatry, Scientific Institute, IRCCS Eugenio Medea, Bosisio Parini, LC, Italy

ARTICLE INFO

Article history:

Received 15 September 2014

Received in revised form 4 February 2015

Accepted 10 February 2015

Available online 28 March 2015

Keywords:

Intersensory redundancy

Visual impairment

Development

Rhythm

Audio-visual information

ABSTRACT

Infants' attention is captured by the redundancy of amodal stimulation in multimodal objects and events. Evidence from this study demonstrates that intersensory redundancy can facilitate discrimination of rhythm changes presented in the visual modality alone in visually impaired infants, suggesting that multisensory rehabilitation strategies could prove helpful in this population.

© 2015 Elsevier Inc. All rights reserved.

Intersensory processing is considered to be a basic neural design feature that is found in most species (Stein & Meredith, 1990).

Researchers have demonstrated that young infants (Bahrick & Lickliter, 2012; Bahrick & Lickliter, 2014; Flom & Bahrick, 2007) learn to perceive multisensory events by detecting amodal properties of the stimuli, i.e., the information that is not specific to a particular sense but is conveyed by multiple senses and can thus provide redundant information (e.g., tempo, intensity, rhythm) during multimodal presentation. This early perceptual ability is considered to be the cornerstone of the adult capability of interacting with more complex multisensory information. In particular, according to the Intersensory Redundancy Hypothesis (IRH, Bahrick & Lickliter, 2012, for a recent review), multimodal events that share the same amodal information recruit greater selective attention to amodal properties at the expense particularly of unimodal processing. Indeed, when the same amodal property is perceived only from one sensory modality (e.g., hearing speech, watching others' actions), it will not be processed as efficiently as when it is multimodally presented. A wide range of infant studies have corroborated the IRH by showing that young infants are able to detect rhythm and tempo (Bahrick & Lickliter, 2004), as well as affect (Flom & Bahrick, 2007) when presented multimodally but not when presented unimodally (i.e., only visual stimulation). The IRH also predicts that, as attention becomes more efficient with experience, children become increasingly capable of detecting both amodal and modality specific properties also when non-redundant and unimodal stimulation is available.

* Corresponding author. Tel.: +39 02 64483863; fax: +39 02 64483705.
E-mail address: elena.nava@unimib.it (E. Nava).

More recently, [Bahrick, Lickliter, Castellanos, and Vaillant-Molina \(2010\)](#) have demonstrated that the effects of intersensory redundancy persist in older infants when the task is more difficult. For instance, the authors found that when presented with fine-grained tempo contrasts of high difficulty, 5-month-old infants' discrimination abilities are comparable to 3-month-olds abilities, suggesting that intersensory facilitation may persist across when the expertise of the perceiver is lower than the difficulty of the task.

The development of intersensory interactions is not only considered to emerge very early in life ([Lewkowicz & Lickliter, 1994](#)). Moreover, animal studies ([Wallace, Perrault, Hairston, & Stein, 2004](#)) have shown that visual deprivation during the first months of life (i.e., animals whose eye-lids were sutured from birth and re-opened later in development) permanently impairs the interactions between sensory systems, in that multisensory neurons in the superior colliculus cannot synthesise the information coming from different sensory modalities. An analogous result was found in human adult individuals, born with dense binocular cataracts that were removed within age 24 months. When tested on a multisensory interference task (i.e., a test for assessing temporal aspects of multisensory interaction using non-verbal stimuli), patients showed superior performance caused by their reduced multisensory capacities ([Putzar, Goerendt, Lange, Rösler, & Röder, 2007](#)). This evidence appears to be in line with the studies by Maurer and colleagues ([Lewis & Maurer, 2005](#)), demonstrating that early visual deprivation may cause subtle differences in the processing of visual stimuli. Overall, these findings point to the idea that there may well be critical periods during early development, in which vision plays an essential role for the typical development of both unimodal and multimodal processing.

While the development of multisensory processing has been investigated in animals ([Wallace et al., 2004](#)) and human adults ([Putzar et al., 2007](#)), who were born totally blind but regained sight early in development, to date no study has questioned whether multisensory development is impaired following congenital visual impairment. Visual impairment is defined in the *International Statistical Classification of Diseases, Injuries and Causes of Death*, 10th revision, ICD-10, as visual acuity of less than 6/18, but equal to or better than 3/60, or a corresponding visual field loss to less than 20 degrees in the better eye with best possible correction. Therefore, our goal was to examine whether poor visual information might constrain the development of multisensory abilities.

Furthermore, the possibility that congenital visual impairment may undermine the development of multisensory processing uncovers another fundamental and closely related issue, namely the ability to transfer amodal information learned through multimodal stimulation to unisensory processing. This important aspect was first evidenced by [Bahrick and Lickliter \(2000\)](#), who habituated infants to unimodal or audio-visual synchronous rhythm and tested them on the same unimodal visual rhythm. Because only those infants habituated to the audio-visual rhythm were able to discriminate a novel visual rhythm, the authors were able to show transfer of learning from audio-visual to unimodal visual stimulation. Interestingly, transfer of learning from multimodal to unimodal stimulation appears to occur in avian embryos too ([Lickliter, Bahrick, & Markham, 2007](#)), suggesting that this mechanism may represent a general developmental principle across species.

In this study, we investigated (i) whether visual impairment affects the early development of intersensory processing, and (ii) whether multisensory information aids visually impaired infants at discriminating changes that are provided in the unimodal visual modality. To this aim, we habituated a small group of congenitally visually impaired infants, ranging between the ages of 7 and 12 months (as well as a group of sighted infants) on an audio-visual and unimodal visual stimulus at different time points (i.e., in one session infants were habituated to an audio-visual stimulus, on a different session to a unimodal visual stimulus). The visually impaired (VI) infants had different gravity of visual impairment but all could use their visual residual for age-appropriate functional exchanges with the environment from both eyes.

All infants were habituated to one type of rhythm (R1), which could be presented bimodally (audio-visual) or unimodally (visual alone). The test phase consisted of a novel (R2) and a familiar rhythm (R1) that were presented in alternation (i.e., R1-R2-R1-R2, or R2-R1-R2-R1) and were always presented in the unimodal visual modality.

We hypothesised that if both typically developing (TD) and VI infants looked longer at the novel rhythm following audio-visual, but not unimodal visual habituation, that would indicate – in line with the IRH – that concurrent and synchronous presentation in two sensory modalities recruits attention and facilitates perceptual learning of amodal information to a greater extent than when information is presented in only one sensory modality (i.e., unimodal visual). For the VI infants though, there may be another possible outcome. Indeed, if typical visual acuity is necessary to process multisensory information, VI infants may prove insensitive to the change in rhythm, even if presented after audio-visual habituation.

Seven infants with visual impairment (mean age = 43.2 weeks, SD = 12.0, range = 24.3–60.1 weeks, 3 females) and nine healthy full-term 3-month-olds were tested (mean age = 14.5 weeks, SD = 0.8, range = 13.6–15.7 weeks, 2 females). VI infants were recruited from the Department of Child and Adolescent Neurology and Psychiatry, "E. Medea Scientific Institute", Bosisio Parini, (LC, Italy). VI infants presented no other sensory deficit (e.g., hearing impairment). The visual deficit had different etiologies and gravity among VI infants (see [Table 1](#) for further details), including four infants with central visual pathways damage and three infants with retinal damage. For all VI infants, inclusion criteria were a congenital deficit. Specifically, the visual acuity ranged between 0.8 and 2 decimals, the first indicating infants being able to recognize a 5 cm-object at 60 cm distance, the second indicating infants being able to recognize a 3 cm-object at 4 m distance. Note that TD infants with comparable age have a visual acuity that ranges between 1/15 and 3 decimals, which correspond to seeing a 7.5 cm-object at 4 m and a 2 cm-object at 4 m distance, respectively.

TD infants were recruited from community paediatricians and selected according to the following criteria: they were all healthy full-term infants, with no congenital abnormalities, and an uncomplicated prenatal, perinatal and postnatal course. In order to match as closely as possible the cognitive development between the two groups, TD infants were assessed at

Table 1

Clinical details of visually impaired infants.

ID	Gender	Age (weeks)	Type of visual impairment	Cause of visual impairment	Visual acuity (decimals)
1	m	22	Retinal	Ocular albinism	0.70
2	f	48	Optic nerve	Optic nerve atrophy	2.00
3	f	31	Cerebral	Periventricular leukomalacia	0.20
4	m	37	Cerebral	Congenital nystagmus	0.80
5	m	55	Retinal	Retinopathy of prematurity (third degree)	1.50
6	f	40	Retinal	Congenital nystagmus	1.00
7	m	45	Rerebral	Periventricular leukomalacia	0.20

3 months of chronological age. Developmental quotient (DQ) was assessed using the (Revised) Griffiths Mental Development Scale (Huntley, 1996). Normative values indicate a mean of 100.5 and a SD of 11.8, with a two SD cut-off. Scores below 76.9 were considered an indication of delay. TD infants showed a DQ mean of 99.8, SD = 6.0, range: 90–110. VI group had a DQ mean of 80.1, SD = 20.9, range: 55–105. Although VI's developmental score was lower than that for the healthy control group, VI infants demonstrated a DQ at the lower limit of the average range (i.e., borderline). The study was approved by the Ethical Committee of the Scientific Institute "E. Medea". All parents gave written informed consent prior to testing.

The experiment consisted of a habituation and a test phase. Stimulation in the habituation phase could be conveyed either audio-visually or unimodally visually, while stimulation in the test phase was always conveyed through unimodal visual stimulation. Note that there were only two rhythms, one (R1) presented during habituation in both audio-visual and unimodal visual stimulation, the other rhythm (R2) presented as novel rhythm in the test phase only.

During habituation to R1, conveyed by audio-visual stimulation, a ball moved horizontally and reversed its direction when hitting a vertical wall. The visual stimulus comprised a sequence of 16 frames (250 ms each) displayed on the screen (i.e., a–b–c–d–e–f–g–h and i–j–k–l–m–n–o–p). In each frame, there was a black and white ball (5.4 cm in diameter), moving horizontally with an arc of shifting of 22 degrees of visual angle at a viewing distance of 30 cm. The auditory stimulus consisted of a sound (50 ms, 900 Hz, 60 dB) that was presented together with the visual frame 'h', i.e., when the ball bounced against the wall (see Fig. 1a). Overall, one trial lasted 4 s. Habituation criterion was met when the infant showed a decrement in looking

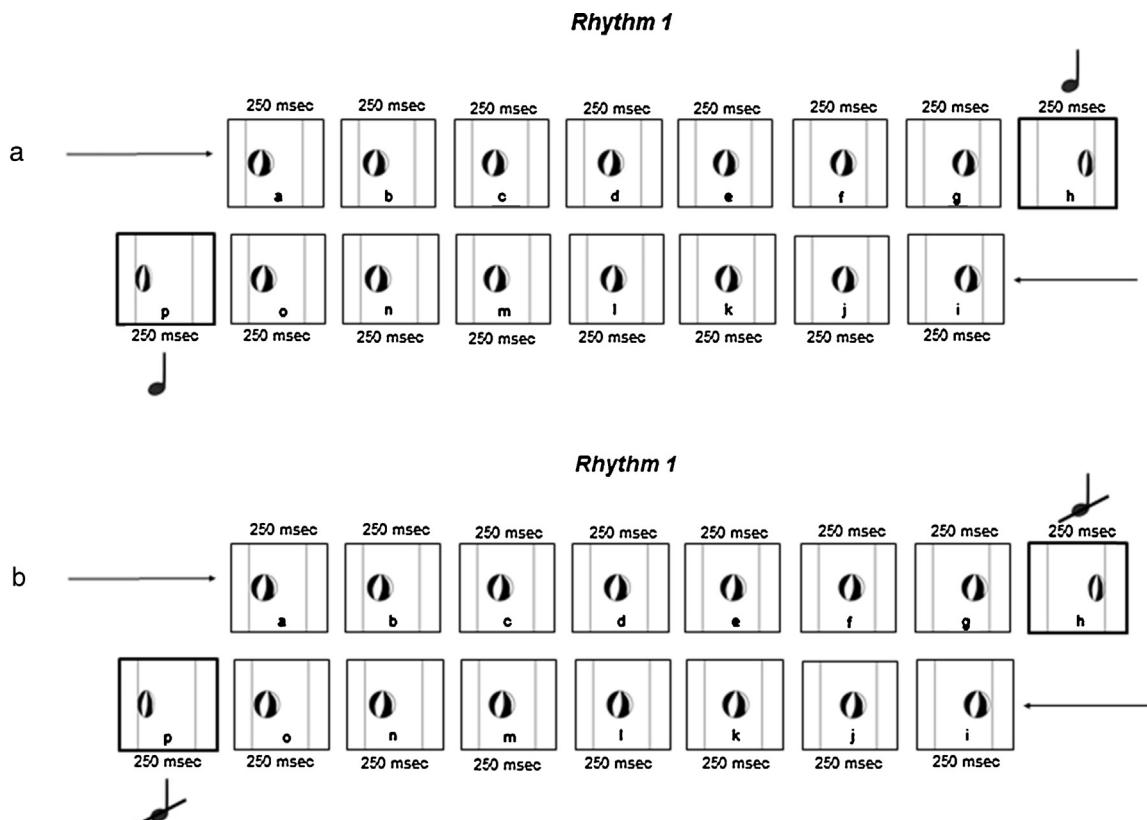


Fig. 1. Audio-visual (a) and unimodal visual (b) habituation to Rhythm 1 (R1). For audio-visual and visual habituation, one trial comprised a total of 16 frames (250 ms each), following this sequence: a–b–c–d–e–f–g–h, i–j–k–l–m–n–o–p. The only difference was the sound, which was presented only in correspondence to frames 'h' and 'p' following audio-visual habituation.

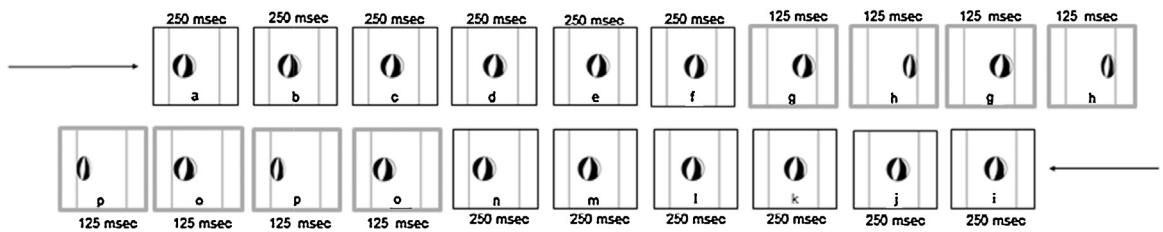
Rhythm 2

Fig. 2. Graphical illustration of R2. The visual stimulus comprised 20 frames: 6 frames of 250 ms each (i.e., a–b–c–d–e–f) and 4 frames of 125 ms each (i.e., g–h–g–h). Another 6 frames of 250 ms each (i.e., i–j–k–l–m–n) and 4 frames of 125 ms each (i.e., o–p–o–p) followed the first sequence in the opposite direction.

time of 50% or greater on three consecutive trials relative to the total looking time on the first three trials (Horowitz, Paden, Bhana, & Self, 1972). As in previous studies that addressed intersensory redundancy in infancy (Bahrick, Flom, & Lickliter, 2002), the habituation phase was followed by 4 test trials, 2 constituted by a novel (Rhythm 2) and 2 constituted by a familiar rhythm (Rhythm 1) presented in alternation (i.e., N–F–N–F or F–N–F–N). Note that R1 and R2 in the test phase were always presented in the unimodal visual modality. The order of presentation (i.e., novel or familiar first) was counterbalanced among infants.

Habituation to R1 conveyed by unimodal visual stimulation was identical to audio–visual habituation, with the only exception that the auditory stimulus was absent in this condition (see Fig. 1b).

In the test phase, infants were presented with 4 unimodal visual trials, 2 depicting the familiar rhythm (R1) and 2 depicting the novel rhythm (R2). R2 differed from R1 in that the ball bounced twice against the wall (see Fig. 2). For R2, the visual stimulus comprised 20 frames having different durations. More in detail, the first sequence (e.g., from the left to the right) was composed by 6 frames of 250 ms each (i.e., a–b–c–d–e–f) and 4 frames of 125 ms each (i.e., g–h–g–h). Another 6 frames of 250 ms each (i.e., i–j–k–l–m–n) and 4 frames of 125 ms each (i.e., o–p–o–p) followed the first sequence in the opposite direction.

All infants were tested at two different time points (sessions), i.e., one time they were tested in the audio–visual condition, the second time in the unimodal visual condition. In the first session, half the infants were habituated to the audio–visual R1 and the other half was habituated to the unimodal visual R1, followed by the test phase (only visual presentation of R1 alternated with R2). An infant-friendly image associated with varying sounds was used as fixation point and attention catcher before trial onset. The experimenter started the trial as soon as the infant looked at the fixation point by pressing a key on the keyboard.

The testing took place at the 0–3 Centre for the Study of Social Emotional Development of At-Risk Infant of the Scientific Institute IRCCS Eugenio Medea, Bosisio Parini (LC, Italy). Infants sat in a standard infant seat or on their mother's lap facing a 18-in. PC monitor at a distance of approximately 30 cm. The infant seat and monitor were surrounded by black curtains to prevent distractions. A trained observer, unaware of the infant's condition, monitored infants' visual fixations by pressing and holding a button that indicated that the infant was fixating the display, thus creating an on-line record of infant's visual fixations. The button box was connected to a 24-in. computer (Hp G7000); a programme (E-Prime 2.0) automatically calculated the end of each trial and the reaching of the habituation criterion. A second experimenter coded off-line the total duration of the looking times towards the stimuli for about one-third of the participants. Inter-coder agreement calculated by Pearson correlation was $r=0.75$ ($p=0.02$) for total looking time.

To examine whether infants were able to discriminate a change in rhythm, we compared mean total fixation time of R1 and R2, separately for VI and TD, and separately for first pair (i.e., presentation of first pair of novel and familiar stimuli) and second pair of trials (i.e., presentation of second pair of novel and familiar stimuli) using Wilcoxon signed-rank tests.

Under conditions of audio–visual habituation (Fig. 3), we found that VI infants were able to perceive a change in rhythm on the second ($z=-2.4$, $p=0.02$), but not on the first pair of trial ($z=0.2$, $p=0.9$). On the contrary, TD infants were able to perceive a change in rhythm on the first ($z=2.5$, $p=0.01$), but not on the second pair of trial ($z=1.1$, $p=0.3$).

Following visual habituation (Fig. 4), we found that both VI and TD infants were not able to discriminate a change in rhythm on neither of the two pairs of trials (all $p>0.7$).

Finally, to observe whether the chronological age of the VI infants could have influenced the results, we ran a correlation between the chronological age (in weeks) of the VI infants and the preference for novel stimuli following audio–visual habituation (calculated as the percentage of preference to novel stimuli), but no significant result was found ($p=0.6$).

In the present study, we investigated the consequences of congenital visual impairment in the early development of intersensory processing, and particularly whether multisensory information aids visually impaired infants at learning and discriminating amodal stimuli characteristics that are provided in the visual modality only. In other words, we observed whether learning of amodal properties (i.e., rhythm) bimodally (i.e., audio–visual) transfers to visual unimodal perception. Our participants were habituated to a rhythm presented in the audio–visual or the unimodal visual modality and were

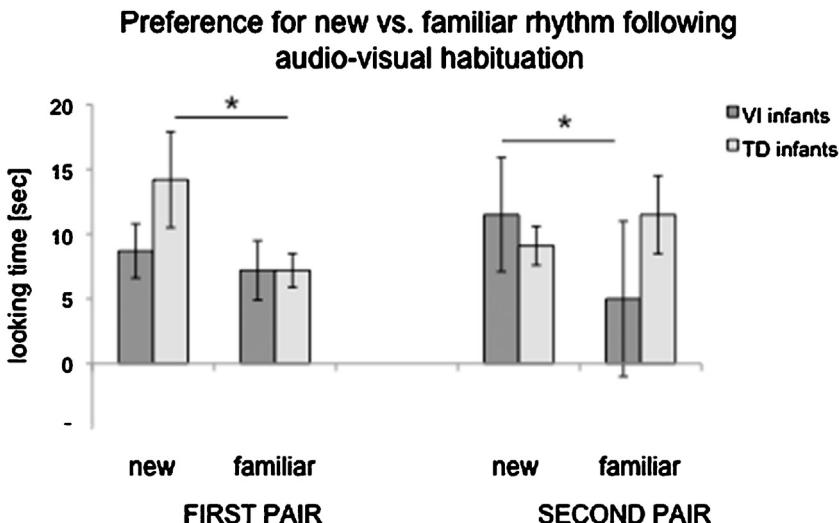


Fig. 3. Total looking time [s] for new vs. familiar rhythm following audio-visual habituation in the first and second pairs of trial for VI and TD infants. Error bars indicate standard error of the mean.

then tested on a novel rhythm presented only unimodally. Our main finding is that both VI and TD infants were able to discriminate the novel from the familiar rhythm only when habituated to the audio-visual, but not unimodal visual familiar rhythm. This suggests that synchronous audio-visual information facilitates visual processing of rhythmical information and that, most importantly, visual impairment does not constrain this ability. Our results are in line and extend previous literature (Bahrick & Lickliter, 2000; Bahrick & Lickliter, 2012; Bahrick & Lickliter, 2014), which have largely highlighted the importance of intersensory redundancy in guiding early perceptual development.

It is worth noting that because of a limited sample size, we were not able to counterbalance the two rhythms during the habituation phase, thus controlling for possible preferences for the rhythm itself. In particular, because R2 consisted of two bounces instead of a single bounce presented in the habituation phase (R1), it may be that infants preferred R2 because it was more salient and thus more arousing. However, because both TD and VI infants did not prefer the novel to the familiar rhythm following unimodal visual habituation, it well may be that it was not the salience of the rhythm to capture the infants' attention.

Also, because we only used unimodal visual stimulation to control for the claim that the infants were able to detect a change in rhythm when it is presented bimodally, we cannot exclude that particularly VI infants were relying on the auditory modality to detect such change. If this were true, it would also imply that VI infants were transferring the information about rhythm from the auditory to the visual modality.

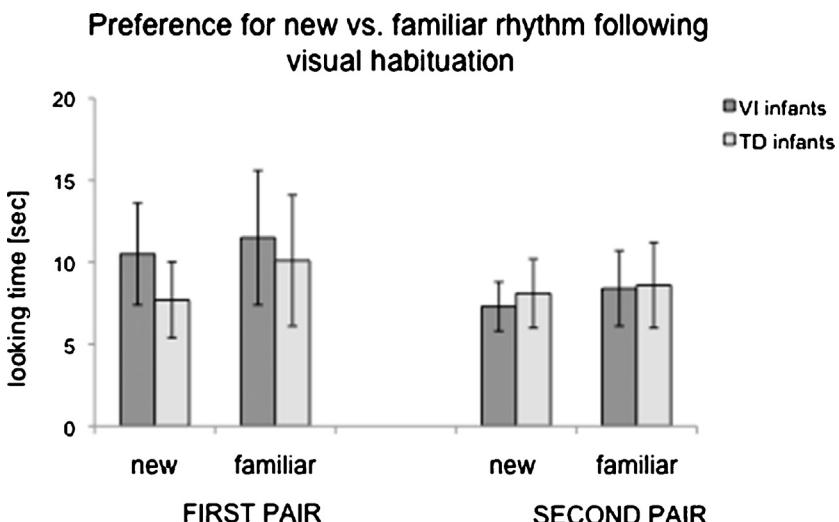


Fig. 4. Total looking time [s] for new vs. familiar rhythm following visual habituation in the first and second pairs of trial for VI and TD infants. Error bars indicate standard error of the mean.

Overall, in the current study both TD and VI infants proved to be able to transfer the information about the amodal property of the stimuli (i.e., rhythm) learned through bimodal stimulation (i.e., audio–visual habituation) to the unimodal visual stimulation. This finding is in accord with previous studies (Bahrick & Lickliter, 2000), which showed a similar audio–visual to unimodal visual transfer in 5-month-olds. The fact that multisensory learning facilitates unimodal learning has recently received much attention in studies addressing this issue in the adult population (Shams & Seitz, 2008; Shams, Wozny, Kim, & Seitz, 2011), and deserves more attention in the infant population for the implications it may have. For instance, Shams and Seitz (2008) suggested that unisensory benefits may occur due to an alteration, or formation, of multisensory representations of the stimuli. In other words, multisensory stimulation could boost visual or auditory processing and result in alterations of unisensory visual and/or auditory structures. Although further studies are needed to conclude whether these theories apply to young infants too, they indicate that learning mechanisms operate at best under multisensory conditions and may thus have direct implications for the atypical infant population (e.g., visually and auditory impaired infants).

Acknowledgments

We are grateful to all parents of the infants who took part in the study. Research was supported by funds from the Italian Health Ministry to Scientific Institute IRCCS Eugenio Medea, Bosisio Parini (LC), Italy (Ricerca Corrente 2009 “Early visual rehabilitation in infants with pre- or perinatal suffering”) and by an European Research Council Starting Grant to C.T. on a project entitled “The origins and development of the human mirror neuron system”—ODMIR No. 241176. A fuller report of the manuscript can be provided upon request.

References

- Bahrick, L. E., Flom, R., & Lickliter, R. (2002). Intersensory redundancy facilitates discrimination of tempo in 3-month-old infants. *Developmental Psychobiology*: *41*, 352–363.
- Bahrick, L. E., & Lickliter, R. (2014). Learning to attend selectively. The dual role of intersensory redundancy. *Current Directions in Psychological Science*: *23*, 414–420.
- Bahrick, L. E., & Lickliter, R. (2012). The role of intersensory redundancy in early perceptual, cognitive, and social development. In A. Bremner, D. J. Lewkowicz, & C. Spence (Eds.), *Multisensory development* (pp. 183–205). Oxford, UK: Oxford University Press.
- Bahrick, L. E., Lickliter, R., Castellanos, I., & Vaillant-Molina, M. (2010). Increasing task difficulty enhances effects of intersensory redundancy: Testing a new prediction of the intersensory redundancy hypothesis. *Developmental Science*: *13*, 731–737.
- Bahrick, L. E., & Lickliter, R. (2004). Infants' perception of rhythm and tempo in unimodal and multimodal stimulation: A developmental test of the intersensory redundancy hypothesis. *Cognitive, Affective, & Behavioral Neuroscience*: *4*, 137–147.
- Bahrick, L. E., & Lickliter, R. (2000). Intersensory redundancy guides attentional selectivity and perceptual learning in infancy. *Developmental Psychology*: *36*, 190–201.
- Flom, R., & Bahrick, L. E. (2007). The development of infant discrimination of affect in multimodal and unimodal stimulation: The role of intersensory redundancy. *Developmental Psychology*: *43*, 238–252.
- Horowitz, F. D., Paden, L., Bhana, K., & Self, P. (1972). An infant-control procedure for studying infant visual fixations. *Developmental Psychology*: *7*, 90.
- Huntley, M. (1996). *The Griffiths mental development scales from birth to two years: Manual*. Amersham: Association for Research in Infant and Child Development (ARICD).
- Lewis, T. L., & Maurer, D. (2005). Multiple sensitive periods in human visual development: Evidence from visually deprived children. *Developmental Psychobiology*: *46*, 163–183.
- Lewkowicz, D. J., & Lickliter, R. (Eds.). (1994). *The development of intersensory perception: Comparative perspectives*. Hillsdale, NJ: Lawrence Erlbaum Associates.
- Lickliter, R., Bahrick, L. E., & Markham, R. G. (2007). Intersensory redundancy educates selective attention in bobwhite quail embryos. *Developmental Science*: *9*, 604–615.
- Putzlar, L., Goerendt, I., Lange, K., Rösler, F., & Röder, B. (2007). Early visual deprivation impairs multisensory interactions in humans. *Nature Neuroscience*: *10*, 1243–1245.
- Shams, L., & Seitz, A. R. (2008). Benefits of multisensory learning. *Trends in Cognitive Sciences*: *12*, 411–417.
- Shams, L., Wozny, D. R., Kim, R., & Seitz, A. (2011). Influences of multisensory experience on subsequent unisensory processing. *Frontiers in Psychology*: *2*, 1–9.
- Stein, B. E., & Meredith, M. (1990). Multisensory integration. *Annals of the New York Academy of Sciences*: *608*, 51–70.
- Wallace, M. T., Perrault, T. J., Hairston, W. D., & Stein, B. E. (2004). Visual experience is necessary for the development of multisensory integration. *The Journal of Neuroscience*: *24*, 9580–9584.