Journal of Experimental Child Psychology 102 (2009) 315–322

Contents lists available at ScienceDirect

Journal of Experimental Child Psychology

journal homepage: www.elsevier.com/locate/jecp

Sound enhances detection of visual target during infancy: A study using illusory contours

Yuji Wada [a,*], Nobu Shirai [b,c], Yumiko Otsuka [c,d], Akira Midorikawa [e], So Kanazawa [f], Ippeita Dan [a], Masami K. Yamaguchi [e,g,*]

[a] Sensory and Cognitive Food Science Laboratory, National Food Research Institute, 2-1-12 Kannondai, Tsukuba, Ibaraki 305-8642, Japan
[b] Department of Psychology, Tokyo Metropolitan University, Tokyo 192-0397, Japan
[c] Japan Society for the Promotion of Science, Tokyo 102-8472, Japan
[d] Department of Infants' Brain and Cognitive Development, Tokyo Women's Medical University, Tokyo 162-8666, Japan
[e] Department of Psychology, Chuo University, Tokyo 192-0393, Japan
[f] Department of Psychology, Japan Women's University, Kanagawa 214-8565, Japan
[g] Precursor Research for Embryonic Science and Technology, JST (JST-PRESTO), Saitama 351-0198, Japan

ARTICLE INFO

Article history:
Received 20 December 2007
Revised 7 July 2008
Available online 27 August 2008

Keywords:
Multisensory perception
Illusory contours
Infant perception
Audio–visual enhancement
Visual detection
Human development

ABSTRACT

In adults, a salient tone embedded in a sequence of nonsalient tones improves detection of a synchronously and briefly presented visual target in a rapid, visually distracting sequence. This phenomenon indicates that perception from one sensory modality can be influenced by another one even when the latter modality provides no information about the judged property itself. However, no study has revealed the age-related development of this kind of cross-modal enhancement. Here we tested the effect of concurrent and unique sounds on detection of illusory contours during infancy. We used a preferential looking technique to investigate whether audio–visual enhancement of the detection of illusory contours could be observed at 5, 6, and 7 months of age. A significant enhancement, induced by sound, of the preference for illusory contours was observed only in the 7-month-olds. These results suggest that audio–visual enhancement in visual target detection emerges at 7 months of age.

Introduction

In our perceptual system, external events independently input from different senses can result in a unified single phenomenon. During the past few decades, a number of factors that can facilitate mul-

* Corresponding authors. Fax: +81 29 838 7319 (Y. Wada), +81 42 674 3843 (M.K. Yamaguchi).
E-mail addresses: yujiwd@affrc.go.jp (Y. Wada), ymasa@tamacc.chuo-u.ac.jp (M.K. Yamaguchi).

0022-0965/$ - see front matter © 2008 Elsevier Inc. All rights reserved.
doi:10.1016/j.jecp.2008.07.002

tisensory binding, such as spatial and temporal coincidence, have been identified in adults (e.g., Calvert, Spence, & Stein, 2004; Spence, Sanabria, & Soto-Faraco, 2007; Wada, Kitagawa, & Omori, 2007). Recent studies revealed that functional interactions among senses can alter the perceptual phenomena even when each distinct modality provides independent information (Driver & Spence, 2000). For example, Vroomen and de Gelder (2000) reported that a visual display that temporally coincides with a salient high-pitched tone in a sequence of monotonous low-pitched tones appears to be segregated from other visual displays; it seems "frozen" in spite of the fact that the sound includes no information on the target's appearance. This visual freezing effect was apparent only when the tone could easily be segregated from a sequence of tones. The effect was greatly attenuated when the same tone was less abrupt or presented as part of a melody. The effect disappeared when an abrupt salient tone preceded the visual target in spite of the possibility that the tone could serve as a cue. Moreover, the effect was persistently observed whether the onset of the target was predictable or not. This suggests that the visual freezing effect is due to cross-modal enhancement caused by the perceptual organization in audition rather than to the attentional cuing provided by the salient tone. A leading explanation for achieving this kind of cross-modal enhancement is the functional interaction between differentiated sensory cortices; multimodal levels of representation may act as feedback to influence primary sensory cortex levels, which were traditionally considered as unimodal (Driver & Spence, 2000).

The emergence of multisensory binding remains a fundamental question dating from the earliest days of psychology (Berkeley, 1709; Gibson, 1969), and finding behavioral evidence for the emergence of functional connections among differentiated cortices in infants is essential for understanding the developmental process of the human brain. Previous developmental studies have indicated that even very young infants can react to corresponding cross-modal stimuli having common properties such as temporal coherence and stimulus intensity (Bahrick & Lickliter, 2000; Lewkowicz, 1996; Lewkowicz, 2000; Spelke, Born, & Chu, 1983). Specifically, Lewkowicz (1996), Lewkowicz (2000) reported that even 2-month-olds can perceive the spatiotemporal relation between very similar moving visual stimuli and sounds. This phenomenon suggests that young infants can pick up audio–visual synchrony in an ever-changing stream of stimuli. However, such early cross-modal coherency is likely to reflect undifferentiated sensory pathways in young infants (Lewkowicz & Lickliter, 1994; Maurer & Mondloch, 2004), unlike the hypothesis derived from adults' multisensory phenomena as above.

Other studies have demonstrated that older infants come to learn arbitrary associations between distinct sensory inputs (Bahrick, 1994; Patterson & Werker, 2002; Reardon & Bushnell, 1988). For example, 7-month-olds could make an association between the color of a cup and the taste of the food in the cup (Reardon & Bushnell, 1988). These results probed infants' ability, by learning within the context of the experiment, of association learning between distinct sensory inputs. However, these studies did not focus on infants' ability for instant integration of arbitrary information from multisensory inputs without learning the relation between multisensory information during the experimental session.

Recently, Scheier, Lewkowicz, and Shimojo (2003) examined the stream/bounce illusion, a typical example of immediate functional multisensory interaction during early infancy. This illusion occurs when an observer looks at two disks moving toward each other from opposite directions and then passing through each other. When the two disks overlapped concurrent with a brief sound, the disks were frequently perceived as bouncing. In contrast, the two disks tended to be perceived as streaming when they overlapped without sound (Sekuler, Sekuler, & Lau, 1997). Scheier and colleagues (2003) reported that 6- and 8-month-olds distinguished between events during which a brief sound (100 ms) was presented 1.3 s before or after the coincidence of disks and an event during which a sound was presented simultaneously with the coincidence, and these authors concluded that the infants perceived the visual bouncing event induced by the brief sound. They discussed that the phenomenon reflects not only developmental change in attentional mechanisms but also object knowledge. These findings suggest that infants older than 6 months of age can instantly integrate arbitrary information from multisensory inputs without learning within the context of the experiment.

Here we present another approach for assessing the functional and momentary multisensory integration in infants by measuring audio enhancements in visual detection. We used illusory contours (Kanizsa, 1979) as visual targets because previous studies have consistently shown that infants prefer