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Developmental changes in the perception of visuotactile simultaneity

Yi-Chuan Chen [a,b,c], Terri L. Lewis [a], David I. Shore [a], Charles Spence [b], Daphne Maurer [a,*]

[a] Department of Psychology, Neuroscience & Behaviour, McMaster University, Hamilton, Ontario L8S 4K1, Canada
[b] Department of Experimental Psychology, University of Oxford, Oxford OX2 6GG, UK
[c] Department of Medicine, Mackay Medical College, New Taipei City 252, Taiwan

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A B S T R A C T

A simultaneity judgment (SJ) task was used to measure the developmental trajectory of visuotactile simultaneity perception in children (aged 7, 9, 11, and 13 years) and adults. Participants were presented with a visual flash in the center of a computer monitor and a tap on their right index finger (located 20° below the flash) with 13 possible stimulus onset asynchronies (SOAs). Participants reported whether the flash and tap were presented at the same time. Compared with the adult group, children aged 7 and 9 years made more simultaneous responses when the tap led by more than 300 ms and when the flash led by more than 200 ms, whereas they made fewer simultaneous responses at the 0 ms SOA. Model fitting demonstrated that the window of visuotactile simultaneity became narrower with development and reached adult-like levels between 9 and 11 years of age. Response errors decreased continuously until 11 years of age. The point of subjective simultaneity (PSS) was located on the tactile-leading side in all participants tested, indicating that 7-year olds (the youngest age tested) are adult-like on this measure. In summary, the perception of visuotactile simultaneity is not fully mature until 11 years of age. The protracted development of visuotactile simultaneity perception may be related to the need for crossmodal recalibration as the body grows and to the developmental improvements in the ability to optimally integrate visual and tactile signals.

* Corresponding author.
E-mail address: maurer@mcmaster.ca (D. Maurer).

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Introduction

Many daily activities involve visuotactile integration. For example, learning to dribble a basketball involves both tracking the ball visually and feeling the touch of the ball against the hand so that the correct force can be applied at the right time. The development of visuotactile integration in humans starts early in life and continues until late in childhood (for reviews, see Bremner & Spence, 2017; Burr & Gori, 2012; Streri, 2012). This prolonged trajectory results not only from the gradual neural maturation of each sensory system and its associated brain areas (e.g., Pihko, Nevalainen, Stephen, Okada, & Lauronen, 2009) but also from the continuous coordination and recalibration among sensory systems as the body itself grows (Ernst, 2008; Gori, 2015).

By 6 months of age, and perhaps even at birth, infants appear to match primitive features (such as smooth vs. nubby texture and oval vs. cross shape) presented tactilely in the mouth or on the hand to the same features presented visually (Meltzoff & Borton, 1979; Rose, Gottfried, & Bridger, 1981; Sann & Streri, 2007; but see Maurer, Stager, & Mondloch, 1999). Newborn infants are also sensitive to the spatial and temporal contingency between visual and tactile signals: when their face was stroked by a paintbrush, they looked longer at a synchronized video showing an infant's face being stroked by a paintbrush than at the same video desynchronized by 5 s (Filippetti, Johnson, Lloyd-Fox, Dragovic, & Farroni, 2013; see also Filippetti, Lloyd-Fox, Longo, Farroni, & Johnson, 2015; Zmyj, Jank, Schütz-Bosbach, & Daum, 2011).

Even though visuotactile interactions start early in life, adult-like levels of integration are not reached until late in childhood. For example, when estimating the shape of an object using both vision and touch, children older than 8 years, like adults, integrate optimally (i.e., weight information in each sensory modality according to its reliability; see Ernst & Banks, 2002; Gori, Del Viva, Sandini, & Burr, 2008). In contrast, younger children do not integrate but rather use only the information presented to *either* vision *or* touch (Gori et al., 2008; McGurk & Power, 1980). When judging the temporal order of a visual stimulus and a tactile stimulus, by 10 years of age children, like adults, are more accurate when the two stimuli are presented at different locations in space than when they are presented at the same location (e.g., Spence, Baddeley, Zampini, James, & Shore, 2003; Spence, Shore, & Klein, 2001); in contrast, younger children show no such spatial modulation (Röder, Pagel, & Heed, 2013). By 12 years of age, children show adult-level precision in judging the temporal order of visual and tactile stimuli (Röder et al., 2013).

Perceiving simultaneity has long been proposed as a critical factor modulating the interaction/integration of multisensory signals (see Welch & Warren, 1980, for an early review). At the neural level, Stein and Meredith (1993) demonstrated that the response of multisensory neurons in the superior colliculus of the cat to the presentation of visual and tactile (or visual and auditory) stimuli is stronger than the sum of responses to individual unisensory stimuli. More critically, such super-additive multisensory neuronal responses occur only when the multisensory stimuli are presented within a certain temporal window, typically spanning a few hundred milliseconds (Meredith, Nemitz, & Stein, 1987). In human behavior, the presentation of a tactile stimulus can improve the processing of a simultaneously presented visual stimulus, as indicated by higher accuracy and/or shorter response latencies (Ngo & Spence, 2010; van der Burg, Olivers, Bronkhorst, & Theeuwes, 2009). The simultaneous presentation of multisensory signals constitutes a highly compelling situation suggesting that these stimuli plausibly originate from the same object/event (i.e., the unity assumption; see Warren, Welch, & McCarthy, 1981; Welch & Warren 1980; see Chen & Spence, 2017, for a recent review). Hence, perceiving multisensory simultaneity increases the likelihood of integration of these sensory signals.

Röder et al. (2013) used temporal order judgments (TOJs) to examine developmental changes in spatial modulations of visuotactile temporal processing during childhood. In the TOJ task, the participants have to judge whether the visual or tactile stimulus came first. However, the study by Röder et al. did not provide precise measurements of the development of visuotactile simultaneity perception for two reasons. First, in order to manipulate the spatial congruency between the stimuli, the visual and tactile stimuli were presented randomly 32° to the left and/or right of center, presumably resulting in the participants' attention being distributed over a wide spatial area. Such a design likely