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Different patterns of modality dominance across development

Wesley R. Barnhart[a], Samuel Rivera[b], Christopher W. Robinson[c,*]

[a] ID/ASD Research Group, Nisonger Center, University Center for Excellence in Developmental Disabilities, USA
[b] Department of Psychology, The Ohio State University, USA
[c] Department of Psychology, The Ohio State University Newark, USA

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A B S T R A C T

The present study sought to better understand how children, young adults, and older adults attend and respond to multisensory information. In Experiment 1, young adults were presented with two spoken words, two pictures, or two word-picture pairings and they had to determine if the two stimuli/pairings were exactly the same or different. Pairing the words and pictures together slowed down visual but not auditory response times and delayed the latency of first fixations, both of which are consistent with a proposed mechanism underlying auditory dominance. Experiment 2 examined the development of modality dominance in children, young adults, and older adults. Cross-modal presentation attenuated visual accuracy and slowed down visual response times in children, whereas older adults showed the opposite pattern, with cross-modal presentation attenuating auditory accuracy and slowing down auditory response times. Cross-modal presentation also delayed first fixations in children and young adults. Mechanisms underlying modality dominance and multisensory processing are discussed.

1. Introduction

Over the last forty years there has been a growing body of research examining how sensory modalities interact while processing multisensory information (e.g., sounds and pictures paired together). Under some conditions, presenting congruent information (e.g., stimuli provide converging details across modalities) to multiple sensory modalities facilitates processing (Fort, Delpuech, Pernier, & Giard, 2002; Giard & Peronnet, 1999; McGurk & MacDonald, 1976; Miller, 1982; see also Bahrick, Lickliter, & Flom, 2004; Spence & Driver, 2004 for reviews). However, there are many situations where multisensory information is incongruent in nature, with stimuli in one modality providing little to no details about stimuli presented to another modality. Research examining processing of incongruent information often shows modality dominance effects, with one sensory modality interfering with processing in a second modality (see Robinson & Sloutsky, 2010; Sinnett, Spence, & Soto-Faraco, 2007; Spence, 2009; Spence, Parise, & Chen, 2012, for reviews). Given that most of our experiences are multisensory in nature, it is important to examine how multisensory presentation affects processing of auditory and visual information at various points in development. The present study contributes to this research by investigating modality dominance effects across development.

There is a clear pattern within the young adult literature: when simultaneously presented with auditory and visual information, visual input often dominates (Colavita, Tomko, & Weisberg, 1976; Colavita & Weisberg, 1979; Egeth & Sager, 1977; Koppen, Alsius, & Spence, 2008; Ngo, Cadieux, Sinnett, & Soto-Faraco, 2011; Ngo, Sinnett, Soto-Faraco, & Spence, 2010; Sinnett et al., 2007; Sinnett, Soto-Faraco, & Spence, 2008). For example, in a typical Colavita task, participants are instructed to press one button when they see a light and press a different button when they hear a tone (Colavita, 1974). In said research, most trials are unimodal (only light or sound); however, some are cross-modal (light and sound are paired together). On these cross-modal trials, participants often respond incorrectly by only pressing the visual button as opposed to correctly pressing both buttons or a third button associated with cross-modal stimuli. Visual dominance has been extended to different tasks with a variety of attentional manipulations failing to reverse the effect (Ngo et al., 2010; see also Spence, 2009 for a review). While there is some evidence that auditory input can attenuate visual processing, these findings require significant modifications to the task or come from tasks that are temporal in nature and favor the auditory modality (Ngo et al., 2011; Robinson & Sloutsky, 2013; Shams, Kamitani, & Shimojo, 2000, 2002).

Numerous accounts have been put forward to explain visual dominance (see Sinnett et al., 2007; Spence, 2009; Spence et al., 2012, for reviews). For example, according to the modality appropriateness hypothesis, the modality that is most appropriate for a given task will

* Corresponding author at: Department of Psychology, The Ohio State University Newark, 1179 University Drive, Newark, OH 43055, USA.
E-mail address: robinson.777@osu.edu (C.W. Robinson).

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dominate, with the visual modality dominating spatial tasks and the auditory modality dominating temporal tasks (Welch & Warren, 1980). Attentional and sensory factors may also underlie modality dominance effects. For example, while auditory stimuli may automatically engage attention, an attentional bias to the visual modality might be needed to compensate for poor altering qualities of visual stimuli (Posner, Nissen, & Klein, 1976, but see Koppen & Spence, 2007a; Sinnett et al., 2007, which show that visual dominance cannot be reversed by directing adults' attention to the auditory modality). Other research has considered how quickly the auditory and visual stimuli engage attention, with the visual input possibly being detected first (Koppen & Spence, 2007b; Rutschmann & Link, 1964). More recent accounts posit sensory/network dominance, with interneurons between sensory systems being inhibitory in nature (i.e., activation of one inhibits the other and vice versa; Desimone & Duncan, 1995; Duncan, 1996; Spence et al., 2012). According to this view, visual dominance should be more likely to occur given that over half of the brain is devoted to processing visual information (Sereno et al., 1995), resulting in strong inhibition of other sensory systems.

However, it is unclear how the proposed mechanisms underlying visual dominance can account for developmental findings, which often show that auditory information often dominates processing of visual input (Lewkowicz, 1988a, 1988b; Nava & Pavani, 2013; Robinson & Sloutsky, 2004; Sloutsky & Napolitano, 2003; Sloutsky & Robinson, 2008). For example, using the Colavita visual dominance task with 6–7, 9–10, and 11–12 year-old children, 6–7 year-old's responses were consistent with auditory dominance (pressed sound button on cross-modal trials) while older children were consistent with visual dominance (pressed picture button on cross-modal trials). This shift from auditory to visual dominance (or increase reliance on visual information) dovetails with developmental research examining the McGurk effect (Massaro, 1984), Sound Induced Flash Illusion - SIFI (Nava & Pavani, 2013), Colavita-like task using semantically meaningful stimuli (Wille & Ebersbach, 2016), inductive generalization (Robinson & Sloutsky, 2004), and change detection (Napolitano & Sloutsky, 2004; Sloutsky & Napolitano, 2003).

While modality dominance effects appear to change across development, recent studies using more sensitive procedures show some support for auditory dominance in young adults (Dunifon, Rivera, & Robinson, 2016; Robinson, Chandra, & Sinnett, 2016; Robinson & Sloutsky, 2013). For example, using a modified oddball paradigm, Robinson et al. (2016) examined how quickly young adults discriminated a frequently presented AV pairing (standard) from infrequently presented auditory oddballs (auditory oddball paired with visual standard) and visual oddballs (visual oddball paired with auditory standard). When participants were instructed to quickly press the spacebar to any oddball, auditory dominance was found with cross-modal presentation slowing down visual but not auditory discrimination (Experiment 1). It is important to note that this effect reversed when participants had to not only detect a change, but also report what changed (i.e., press one button for visual oddball, a different button for auditory oddball, or a third button if both AV components changed (Experiment 2). This latter finding suggests that visual dominance might occur later in the course of processing by dominating the response/decision phase of processing, as opposed to disrupting early encoding of auditory information. However, one limitation of this study was that the auditory stimuli were simple tones paired with monochromatic and unfamiliar images.

Dunifon et al. (2016) extended these findings by using another variation of a change detection task while using semantically meaningful visual stimuli and more dynamic nonlinguistic sounds. Young adults had to quickly discriminate two visual stimuli (unimodal visual condition), two auditory stimuli (unimodal auditory condition), or two auditory-visual pairings (cross-modal condition). In addition to examining response times and accuracies, this study also examined visual fixations while participants were making discriminations. Simultaneously presenting the auditory and visual stimuli in the cross-modal condition was more likely to slow down visual response times (Experiments 1–3), even when participants were instructed to ignore the auditory stimuli (Experiment 2). Moreover, the presence of the sound also delayed the onset of first fixations to the visual stimulus (relative to the unimodal visual condition) and increased participants' mean fixation durations.

One potential explanation for auditory dominance is that sensory modalities may share a "pool" of available attentional resources and compete for these resources (see Duncan, Martens, & Ward, 1997; Eimer & Driver, 2000; Eimer & van Velzen, 2002; Pavani, Husain, Ládavas, & Driver, 2004; Sinnett et al., 2007; Wickens, 1984 for related discussions). Moreover, since auditory stimuli are often dynamic and transient in nature, it may be adaptive for the system to allocate greater attentional resources to auditory stimuli to ensure this information is processed before it disappears, especially early in stimulus presentation (see Robinson & Sloutsky, 2010 for a review). Thus, auditory dominance may stem from auditory stimuli automatically engaging attention early in the course of processing and attenuating or delaying visual processing. While this proposed mechanism predicts some of the developmental findings, it is unclear how to reconcile this account with the numerous studies that clearly show evidence of visual dominance (see Sinnett et al., 2007; Spence, 2009; Spence et al., 2012, for reviews) and if such an account can predict modality dominance effects in older adults.

It is well established that there are substantial changes to the sensory, motor, and cognitive systems into late adulthood (see Birren & Schaie, 2006, for a review), and it is unclear how these developmental/maturational changes affect multisensory processing and modality dominance. For example, previous research has documented that older adults are frequently outperformed by young adults on tasks of memory (e.g., Craik, 1994), motor response (e.g., Pratt, Chasteen, & Abrams, 1994), and executive control (e.g., Royall, Palmer, Chiodo, & Polk, 2004), and it is well established that there are also sensory declines in late adulthood (e.g., Corso, 1971; He, Dubno, & Mills, 1998; Schneider, Daneman, Murphy, & Kwong, 2000; Weale, 1975). However, to our knowledge, there is no research examining modality dominance effects in older adults. As such, it is unclear if the shift from auditory to visual dominance will continue, with older adults showing stronger visual dominance effects than children and young adults. However, it is also possible that visual dominance effects plateau, reverse to auditory dominance, or no dominance effects will be present. Pattern of dominance will shed light on how older adults prioritize different components of multisensory information and may predict which types of multisensory experiences facilitate or interfere with learning.

Potential support for a reversal to auditory dominance comes from multisensory integration research (DeLoss, Pierce, & Andersen, 2013; Laurienti, Burdette, Maldjian, & Wallace, 2006). For example, in DeLoss et al. (2013), young and older adults participated in the Sound Induced Flash Illusion task (SIFI) and had to ignore beeps and report how many flashes were presented on a computer screen. While the number of beeps presented influenced visual perception in both groups, the effect of beeps on visual perception was stronger in older adults. A parallel finding can be found when examining speeded responses to unimodal and cross-modal targets (Laurienti et al., 2006). Both young and older adults were faster to respond to cross-modal targets than visual targets, however, older adults appeared to benefit more from the presence of the sound. Thus, across both studies, auditory stimuli had a greater effect on visual processing and responding to targets in older adults. These effects might be related to the inhibitory deficit hypothesis, which posits that older adults may have difficulty filtering out cross-modal stimuli (Lustig, Hasher, & Zacks, 2007). Thus, auditory stimuli may be more likely to be combined with visual information (multisensory integration research) or facilitate/interfere with visual processing (modality dominance research) because these stimuli are more likely to be detected and encoded late in development (due to declines