Proceedings of the Annual Meeting of the Cognitive Science Society

Title

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Permalink

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Journal

Proceedings of the Annual Meeting of the Cognitive Science Society, 32(32)

ISSN

1069-7977

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Publication Date

2010

Evidence for auditory dominance in a passive oddball task

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Abstract

Simultaneous presentation of auditory and visual input can often lead to visual dominance. Most studies supporting visual dominance often require participants to make an explicit response, therefore, it is unclear if visual input disrupt encoding/discrimination of auditory input or results in a response bias. The current study begins to address this issue by examining how multimodal presentation affects discrimination of auditory and visual stimuli, while using a passive oddball task that does not require an explicit response. Participants in the current study ably discriminated auditory and visual stimuli in all unimodal and multimodal conditions. Furthermore, there was no evidence that visual stimuli attenuated auditory processing. Rather, multimodal presentation sped up auditory processing (shorter latency of P300) and slowed down visual processing (longer latency of P300). These findings are consistent with research examining modality dominance in young children and suggest that visual dominance effects may be restricted to tasks that require an explicit response.

Keywords: Attention, Cross-modal Processing, Electroencephalograph (EEG), Neurophysiology, Psychology.

Introduction

Most of our experiences are multimodal in nature. The objects and events that we encounter in the environment can be seen, touched, heard, and smelled. The fact that the brain can integrate this knowledge into a coherent experience is amazing given that each modality simultaneously receives different types of input, and this information is processed, at least in the early stages of processing, by dedicated sensory systems.

While multimodal presentation can sometimes facilitate learning, there are many occasions when presenting information to one sensory modality interferes with learning in a second modality. These modality dominance effects can occur on detection tasks and on more complex discrimination tasks, with auditory input often attenuating visual processing in young children (Sloutsky & Napolitano, 2003; Robinson & Sloutsky, 2004) and visual input often attenuating auditory processing in adults (Colavita, 1974; Colavita & Weisberg, 1979).

Support for visual dominance in adults comes from a long history of research examining how multimodal stimuli affect the detection of auditory and visual input (Colavita, 1974; Colavita & Weisberg, 1979; Klein, 1977; Posner, Nissen, & Klein, 1976; see also Sinnett, Spence, & Soto-Faraco, 2007; Spence, Shore, & Klein, 2001, for reviews). For example, in a classic study Colavita (1974) presented adults with a tone, a light, or the tone and light paired together. Participants had to press one button when they heard the tone and a different button when they saw the light. While participants were accurate when the tone and light were presented unimodally, they often responded to the visual stimulus when the stimuli were paired together, with many adults failing to detect the auditory stimulus. This finding has been replicated using a variety of stimuli and procedures, with little evidence demonstrating that auditory input attenuates visual processing in adults (see Sinnett, Spence, & Soto-Faraco, 2007 for a review).

There appears to be an attentional component underlying visual dominance (Posner, Nissen, & Klein, 1976). In particular, the underlying idea is that the auditory and visual modalities share the same pool of attentional resources. While auditory stimuli automatically engage attention, visual stimuli often have poor alerting abilities. To compensate for the poor alerting ability of visual input, adults endogenously direct attention to visual stimuli. This increased attention to the visual modality comes with a cost – attenuated auditory processing.

While there is much support for visual dominance, it is important to note that this support primarily comes from studies examining response latencies and response accuracies. Therefore, it is possible that visual input have no effect on encoding or discrimination of auditory stimuli. Rather, these effects may stem solely from visual input dominating the response. The current study begins to address this issue by examining processing of auditory, visual, and multimodal stimuli in a task that does not require an explicit response.

Participants in the current study were presented with a passive oddball task where they were presented with auditory, visual, or multimodal stimuli. Event Related Potentials (ERPs) were recorded as adults passively attended to frequent stimuli (standard) and infrequent stimuli (oddballs). The signature pattern of discrimination is a P300. P300 is a positive component with a peak latency occurring between 300-800 ms after stimulus onset and is strongest over the temporal, parietal, and fronto-central regions (see Polich & Criado, 2006 for a review). The amplitude of P300 is larger for novel or infrequent stimuli (Sutton, Braren, Zubin, & John, 1965), and the latency of P300 can be used as a measure of processing time (Kutas, McCarthy, & Donchin, 1977). In particular, experimental manipulations that affect the processing leading up to classification and responding should affect the latency of P300. The same underlying idea is guiding the current research: multimodal facilitation and interference should manifest themselves by affecting the latency (and possibly amplitude) of P300.

Previous studies have used oddball tasks to examine unimodal and multimodal processing and to examine effects of response on ERP components. However, these procedures differed from the ones reported here in several important ways. First, ERP studies that have directly compared unimodal and multimodal conditions either focused on early ERP components associated with stimulus detection or they required participants to make a response to oddballs (e.g., Brown, Clarke, & Barry, 2007; Fort, Delpuech, Pernier, & Giard, 2002; Giard & Peronnet, 1999; Vidal, Giard, Roux, Barthelemy, & Bruneau, 2008). In contrast, the current study focused exclusively on discrimination of standards and oddballs (P300), and participants did not make an explicit response to these stimuli. Second, the studies that have examined the effects of explicit response on oddball tasks were not interested in modality dominance, thus, they did not examine discrimination of the same auditory and visual stimuli when presented unimodally and multimodally (Mertens & Polich, 1997; Wronka, Kaiser, & Coenen, 2008).

Thus, to the best of our knowledge this is the first study to use a passive oddball task to examine how multimodal presentation affects auditory and visual processing. If visual stimuli interfere with the encoding and/or discrimination of auditory stimuli, then the latency of P300 should occur later in the multimodal condition than in the unimodal condition. However, if visual stimuli only affect the response, then no effects should be found or auditory input may attenuate visual processing (auditory dominance).

Methods

Participants

Thirty-nine undergraduate students from The Ohio State University (23 men and 16 women, *M* = 19.5 years, *SD* = 3.9 years) participated in this experiment for course credit. Prior to the experiment all participants gave informed consent and provided basic personal information (handedness, age, medical history). All participants had normal hearing and normal (or corrected to normal) vision.

Stimuli

The stimuli and cover story were designed for young children. The visual stimuli consisted of six novel creatures that were created in PowerPoint and exported as 400 x 400 pixel jpeg images (see Figure 1 for examples).

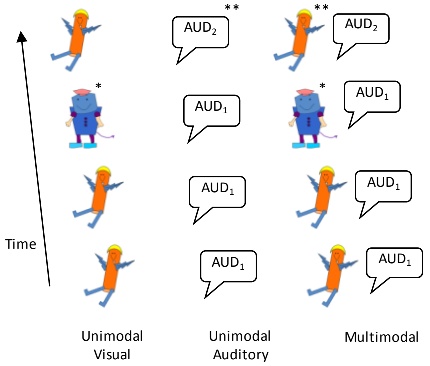

Figure 1: Example of stimuli and overview of the visual, auditory, and multimodal conditions. Note: "*" denotes visual oddball and "**" denotes auditory oddball.

Visual stimuli were presented centrally on a Dell 17" LCD monitor for 480 ms. The interstimulus interval (ISI) randomly varied from 1000 ms - 1520 ms. Auditory stimuli were also 480 ms in duration, with a 1000 ms - 1520 ms ISI. The auditory stimuli were dynamic sounds that changed in pitch and amplitude across time. The sounds were created in CoolEdit 2000 by using preset functions (e.g., DTMF signal, out of control, etc.). Stimuli in the multimodal condition were constructed by pairing the auditory and visual stimuli together (see Figure 1 and Table 1). Thus, the same stimuli were used in the unimodal and multimodal conditions, therefore, any differences found between these conditions cannot be accounted for by properties of the unimodal stimuli.

Procedure

Three different oddball tasks were used (see Figure 1 and Table 1), and task order was pseudo-randomized for each participant. Approximately half of the participants were presented with the unimodal oddball tasks (order of auditory and visual was randomized for each participant), and then they participated in the multimodal task. The remaining participants were presented with the multimodal task, followed by the two unimodal tasks (order randomized for each participant). The multimodal task took approximately 40 minutes, and each unimodal task took approximately 20 minutes.

As can be seen in Table 1, each task consisted of one standard (presented approximately 80% of the time), four oddballs (each presented approximately 4% of the time), and one novel (presented approximately 4% of the time). Participants were instructed to press a button every time they saw/heard the novel, and to not respond to the standards and oddballs (see cover story). The novel trials were presented to keep participants engaged, and ERPs from these trials were discarded. Four oddballs were used to keep the task interesting for participants and to maintain a low probability of oddballs (each oddball was only presented 4% of the time). In each of the unimodal conditions there were four oddballs, and in the multimodal condition, there were eight oddballs (four auditory and four visual). To examine how multimodal stimuli affect auditory processing, we compared auditory oddballs in the silent condition (e.g., A2, A3, etc.) with the same auditory oddballs in the multimodal condition (e.g., A2V1, A3V1, etc.). To examine how multimodal stimuli affect visual processing, we compared visual oddballs in the silent condition (e.g., V2, V3, etc.) with the same visual oddballs in the multimodal condition (e.g., A1V2, A1V3, etc.).

Prior to each task participants were told a short cover story. For example, in the unimodal visual task, participants were told: *You are going to see creatures from a far away place. Most of the creatures that you will see eat vegetables. However sometimes you will see this creature (novel was presented). This creature eats cookies. In this game you have to press a button every time you see this creature that eats cookies (novel was presented). Do not press any buttons when you see any of the other creatures.* In the auditory condition they were told that they would hear the sounds of creatures eating vegetables and cookies, and in the multimodal condition they were told that they would see creatures and hear the sounds that they make while eating vegetables and cookies.

	Unimodal Auditory	Unimodal Visual	Multimodal
Standard	A1 (280)	V1 (280)	A1V1 (560)
Oddballs (A)	A2 (16)		A2V1 (16)
	A3 (16)		A3V1 (16)
	A4 (16)		A4V1 (16)
	A5 (16)		A5V1 (16)
Oddballs (V)		V2 (16)	A1V2 (16)
		V3 (16)	A1V3 (16)
		V4 (16)	A1V4 (16)
		V5 (16)	A1V5 (16)
Novel	A6 (16)	V6 (16)	A6V6 (16)

Table 1. Overview of stimuli and tasks (frequency of each stimulus).

Participants were presented with a warm up task where they were given 10 standards and 3 novels. ERPs from the warm up task were not included in the final data. Feedback was provided throughout the entire experiment. Feedback was provided if participants: (a) responded to a standard or oddball or (b) failed to respond to a novel. All data were recorded with eyes open and participants in the unimodal auditory condition were asked to fixate on a square taped to the top of the LCD monitor.

Recording Conditions and Data Acquisition

Experiments were conducted in a sound-attenuated, illuminated, and well-ventilated presentation chamber which housed a Dell 17” monitor, two Polk PLKRC65I wall mount speakers, and a response pad. In the experimenter room, a Dell Optiplex 755 computer with E-prime software v.2.0.8.22 was used to present stimuli to participants, and a Harman Kardon AVR-154 receiver was used to amplify the sounds. Timing tests were conducted to ensure that auditory and visual stimuli were presented simultaneously. Offsets between trigger registration and stimuli presentation were measured for unimodal and multimodal conditions and were adjusted during analysis. A PowerPC G5 Mac with Netstation software was used to record and store ERP data.

ElectroEncephalography (EEG) brain activity was recorded using a 128-channel HydroCel Geodesic Sensor Net (Electrical Geodesics, Inc., Eugene, OR). Scalp-electrode impedances were kept below 50 kOhms. All channels were referenced to Cz during acquisition. EEG was recorded using a 0.1 to 100 Hz band-pass filter (3 dB attenuation), amplified at a gain of 1000, sampled at a rate of 250 Hz, and digitized with a 24-bit A/D converter.

Data analysis

Participants ably discriminated novels in all of the conditions (proportion of hits to novels – proportion of false alarms to standards + oddballs > .99). Because auditory and visual components both changed on novel trials and participants made a response, it is unclear if ERP waveforms reflect auditory discrimination, visual discrimination, or the response. Therefore, data from novel trials were not included in any of the analyses.

ERPs to standards and oddballs were processed using Netstation waveform tool. EEGs were band-passed between 0.1 Hz and 30 Hz and segmented between 100 ms pre-stimulus onset and 1000ms post stimulus onset. ERPs were referenced with respect to the average of all channels after correcting for bad trials using neighboring channels. Trials were then baseline corrected with respect to the 100 ms pre-stimulus and then exported to Matlab.

Initially, we looked at 8 different scalp regions, each comprising of 6 or 7 channels from the 10/20 system representing: F3, F4, P3, P4, T3, T4, Pz, and Oz. However, in the current study we focused exclusively on Pz; the region that provided the best measure of discrimination in all conditions (see Figure 2). In each of the unimodal conditions, participants provided two ERP waveforms (one for the standard and one for the oddball). To equate the number of standards and oddballs, we randomly picked and averaged 64 of the 280 standards and we averaged across the four different oddballs. In the multimodal condition, adults provided a waveform for the standard, a waveform for auditory oddballs, and a waveform for visual oddballs (see Table 1).

Results and Discussion

A reliable P300 was found at Pz, P3, and P4, however, as mentioned above, discrimination was most pronounced at Pz. Thus, analyses reported below focus on Pz between 250-650 ms after stimulus onset. Waveforms for the unimodal conditions are presented on the left side of Figure 2 and waveforms for the multimodal conditions are presented on the right side of Figure 2. As can be seen in Figure 2, participants ably discriminated auditory and visual stimuli when presented unimodally and multimodally. Mean averages were computed for each participant. For example, to assess discrimination of the auditory stimuli in the unimodal auditory condition, we computed a mean average for the standard (between 250-650 ms) and a mean average for the oddball (between 250-650 ms) for each participant. These means were then submitted to a one-way ANOVA with trial type (standards vs. oddball) as a repeated measure. The same analyses were conducted in the four conditions (i.e., Unimodal Auditory, Unimodal Visual, Multimodal Auditory, and Multimodal Visual). All ANOVAs were significant, *F*s > 20, *p*s < .0001.

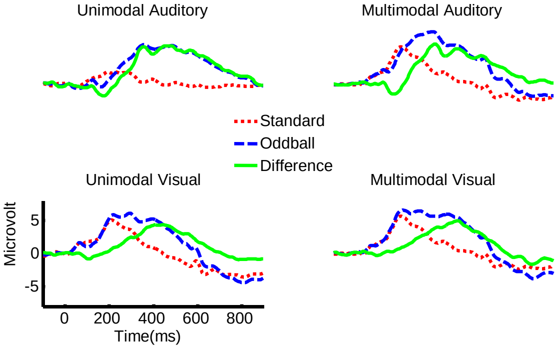

Figure 2. ERP waveforms for Standards and Oddballs across conditions. Solid line represents difference waves (Oddball – Standard).

To examine the effects of visual input on auditory discrimination, we compared the auditory difference waveform in the multimodal condition to the auditory difference waveform in the unimodal condition (see Figure 3a). A one-way AVOVA revealed that mean amplitude between 250-650 ms did not differ between the unimodal and multimodal conditions. We also examined how the presence of auditory input affected visual discrimination by comparing the visual difference waveform in the multimodal condition to the visual difference waveform in the unimodal condition (see Figure 3b). As in the auditory conditions, mean amplitude did not differ between the unimodal and multimodal conditions.

To statistically find and quantify any significant displacement of P300 between unimodal and multimodal conditions, we computed the fractional area latency. In particular, for a predefined window, we measured the area under the curve, and then we found the latency that divided that area into two equal parts (see Hansen & Hillyard, 1980). Using this measure for a window between 250 ms and 650 ms, we found that multimodal presentation sped up auditory discrimination by 26ms and slowed down visual discrimination by 12 ms.

However, as can be seen in Figure 3a, there are multiple peaks in both auditory conditions that could be the result of multiple underlying components. Therefore, we ran sliding windows of 200 ms, 300 ms, and 400 ms for each participant's data covering the whole time range of interest (250ms to 650ms). That is, for each window length, centered at a time sample, we computed the 50% area latency for both the multimodal difference waveform and for the unimodal difference waveform. We then calculated a difference wave (Difference Multimodal – Difference Unimodal) to denote the displacement. We kept doing this while sliding the window at 4ms increments. Figure 4a – 4c plot the displacement waveforms for the 200 ms, 300 ms, and 400 ms windows, respectively. Values greater than zero denote that multimodal presentation increased the latency of P300 and values less than zero denote that multimodal presentation shortened the latency of P300.

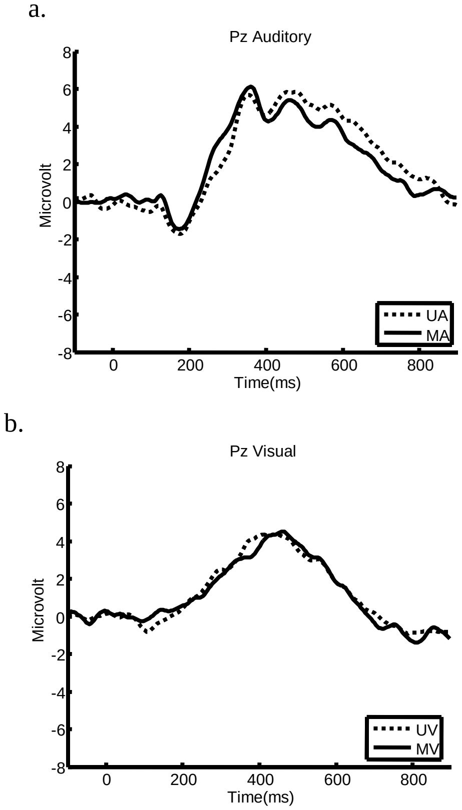

Figure 3. (a) Difference waves for Unimodal Auditory (UA) and Multimodal Auditory (MA), (b) Difference waves for Unimodal Visual (UV) and Multimodal Visual (MV). All data are averaged across participants.

As can be seen in Figures 4a-4c, across all windows, multimodal presentation sped up auditory processing and slowed down visual processing. ANOVAs were conducted for each window at every 4 ms increment. Using a window size of 200 ms, auditory and visual displacement waves differed from 370 ms to 514 ms, *p*s < .05. Using a window size of 300 ms, auditory and visual displacement waves differed from 362 ms to 534 ms, *p*s < .05. Finally, using a window size of 400 ms, auditory and visual displacement waves differed from 370 ms to 554 ms, *p*s < .05. These findings suggest the multimodal presentation had different effects on auditory and visual processing, with multimodal presentation increasing the latency of the visual P300 and shortening the latency of the auditory P300.

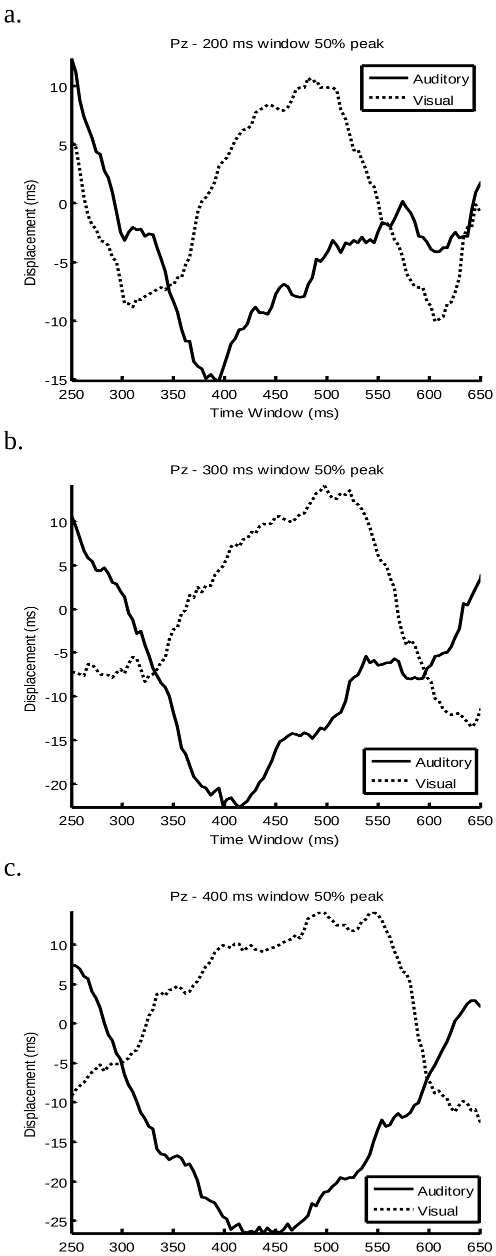

Figure 4. Displacement for (a) 200 ms window, (b) 300 ms window, (c) 400 ms window.

General Discussion

The current study used a passive oddball task to examine the time course of auditory and visual processing when stimuli were presented unimodally and multimodally. As can be seen in Figures 2, 3a, and 4a-4c, there was no evidence that visual input attenuated discrimination of auditory stimuli. Rather, multimodal presentation appeared to speed up auditory processing and slow down visual processing. These findings have important implications for understanding the underlying mechanisms and time course of modality dominance. In particular, the current findings suggest that some of the effects of visual dominance may stem from visual input dominating the response. However, future research will need to make direct comparisons on tasks that do and do not require explicit responses before any strong conclusions can be drawn.

The novelty of the current research is that we examined the time course of auditory and visual processing on a task that did not require an explicit response. The results replicate auditory dominance effects found in young children, with multimodal presentation attenuating visual processing, and having no effect or facilitating auditory processing (see Robinson & Sloutsky, 2010 for a review). This interaction suggests that effects cannot solely stem from increased tasks demands, otherwise processing in both modalities would have been delayed. Rather, we believe this interaction stems from the dynamics of cross-modal processing. According to this account (Robinson & Sloutsky, 2010), auditory stimuli quickly engage attention and processing of the details of a visual stimulus does not begin until the auditory modality releases attention. While this account has received some support in young children, the finding that auditory input can also slow down visual processing in adults is novel.

Acknowledgments

This research has been supported by grants from the NSF (BCS-0720135), NIH (R01HD056105) and from the US Department of Education (R305H050125 and R305B070407) to Vladimir Sloutsky and from NIH (RO3HD055527) to Chris Robinson.

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