

# Attention and cross-modal processing: Evidence from heart rate analyses

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## Abstract

The study of cross-modal processing has generated two seemingly contradictory sets of findings. Studies examining cross-modal processing in infants often find evidence that auditory input interferes with visual processing, whereas studies with adults often find evidence for visual input interfering with auditory processing. However, in the absence of amodal measures of auditory processing, it is possible that visual input also interferes with auditory processing in young infants. The primary goal of the current study was to examine this issue by focusing on Heart Rate (HR) to assess discrimination of unimodal auditory stimuli (Experiment 1), and to examine how visual stimuli affect auditory discrimination (Experiment 2). The results indicate that the presence of visual stimuli facilitated, rather than interfered with, auditory processing.

**Keywords:** Cognitive Development, Attention, Heart Rate, Psychology, Human Experimentation.

## Introduction

There are many tasks that require people to integrate information across sensory modalities (e.g., associating words with objects and categories, learning the sounds that objects make, etc.). While simultaneously presenting information to different sensory modalities can sometimes facilitate learning, there are also many occasions when presenting stimuli to one modality interfere with learning in a different modality (i.e., modality dominance). Interestingly, the study of modality dominance has generated seemingly inconsistent findings.

On the one hand, there is more than 30 years of research on the Colavita effect in adults (Colavita, 1974; Colavita & Weisberg, 1979; Klein, 1977; Posner, Nissen, & Klein, 1976, see Sinnett, Spence, & Soto-Faraco, 2007 for a review). The main finding of these studies is that visual information often interferes with the detection of auditory input, hence the “visual dominance effect”. On the other hand, studies with infants and young children often demonstrate the opposite finding: auditory input often interferes with visual processing, hence the “auditory

dominance effect” (Lewkowicz, 1988a; 1988b; Robinson & Sloutsky, 2004; 2007; 2010; Sloutsky & Napolitano, 2003; Sloutsky & Robinson, 2008).

Although the asymmetry between infant and adult literatures may reflect genuine developmental differences, it is also possible that the asymmetry stems from a lack of appropriate measure of auditory processing. In particular, most infant studies use visual fixations to examine auditory and cross-modal processing. For example, infants in many of the studies reported above were familiarized or habituated to an auditory stimulus, visual stimulus, or to a cross-modal stimulus. Infants in the cross-modal condition often failed to increase looking to a novel visual stimulus when it was paired with an old sound, suggesting that they did not discriminate the visual stimuli. This finding is noteworthy given that infants ably discriminated the same visual stimuli when they were presented unimodally.

In contrast, there were no costs of cross-modal presentation on auditory processing: infants equally discriminated auditory stimuli when presented unimodally and cross-modally. However, auditory processing was never measured independently of visual processing (i.e., auditory processing was assessed by examining infants’ visual fixations). In the absence of a true measure of auditory processing, it is possible that visual dominance was missed, with visual input interfering more with auditory input than the reverse. The goal of the present research was to address this issue.

The achievement of this goal requires an amodal measure of auditory processing. While sucking procedures and ERP tasks can provide modality-independent measures of auditory processing (e.g., Eimas, Siqueland, Jusczyk, & Vigorito, 1971; Nelson & deRegnier, 1992), sucking procedures are not appropriate for older infants and children and ERP tasks often require a large amount of trials. The present study uses infants’ Heart Rate (HR) to

measure auditory and cross-modal processing. HR has provided researchers with a powerful tool for examining the dynamics of visual attention. The gist is that HR decelerates while participants are actively processing visual input, and combining HR and visual fixations can delineate various stages of visual attention (Colombo, et. al., 2004; Courage, Reynolds, & Richards, 2006; Richards & Casey, 1992). Panneton and Richards (2002) used HR to assess how 4- to 6-month-old infants attend to auditory, visual, and cross-modal stimuli. This study demonstrated that HR decelerates more to dynamic and cross-modal stimuli than to static and unimodal stimuli. The current study expands on this research by using HR to examine the effects of visual input on auditory processing. In Experiment 1, we presented participants with unimodal auditory stimuli and measured auditory oddball detection. In Experiment 2, we examined how visual input affected the detection of auditory oddballs.

## Experiment 1

### Method

**Participants** Twenty-four 10-month-olds (16 boys and 8 girls,  $M = 301$  days,  $SD = 49.94$  days) participated in this experiment. A majority of infants were Caucasian and none of the infants had auditory or visual deficits, as reported by parents. No infants were excluded from the final sample.

**Apparatus** Infants sat on parents' laps 100 cm away from a 52" Sony LCD television. Two Boston Acoustics 380 speakers were 76 cm apart from each other and mounted in the wall (concealed by black felt). A pan-tilt-zoom camera was mounted above the television to capture a video stream of the infant, and a Sony DCR-TRV40 camcorder was located behind the infant to capture the AV stimulus presentation. These two video streams were overlaid using a Kramer PIP 200 picture and picture mixer, and videos were saved as mpg video files on a Dell Optiplex 755 computer.

In an adjacent room, a Dell Optiplex 745 computer with *E-prime* software was used to present stimuli to the infants, and a Dell Optiplex 755 computer with Mindware software was used to record electrocardiograms. Two Ag-AgCl electrodes were placed on the infants' right collar bone and left, lower rib, and a reference electrode was placed on the infants' right, lower rib. Electrocardiograms were collected using a BioNex acquisition unit with a BioNex Impedance Cardiograph and GSC amplifier. Electrocardiograms were time-locked with stimulus presentation and saved on the Dell Optiplex 755 computer.

**Stimuli** Auditory stimuli were seven nonsense words (e.g., vika, luru, kuna, etc.) that were recorded by a female speaker using infant-directed speech. Each nonsense word was edited in CoolEdit 2000 and saved as a 44.1 kHz, 16-

bit stereo wav file. Nonsense words were each 1 s in duration and were presented to infants at approximately 68-70 dB. One nonsense word served as the standard (presented 60% of the time) and the remaining nonsense words served as oddballs. While infrequent stimuli were presented for the remaining 40% of the experiment, six different oddballs were presented throughout the experiment. Thus, across the entire experiment the same standard was presented for approximately 60 s, whereas each individual oddball was only presented for 7 s.

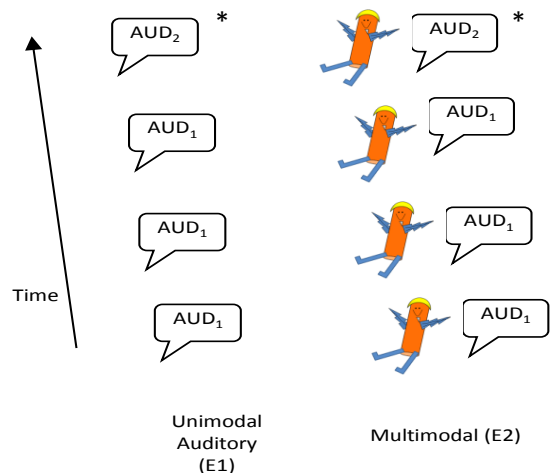


Figure 1: Overview of stimulus presentation in Experiments 1 and 2. Standards were presented five times in a row, followed by four oddballs. Note: “\*” denotes an example of oddball in both experiments.

**Procedure** Infants sat on parents' lap in a quiet, dimly lit room. A picture of a baby playing with toys was presented on the LCD television while the experimenter attached the electrodes to the infant. The experimenter left the room and started the experiment by pressing the spacebar on the Dell Dimension 8200 computer. At this point, the picture of the baby and toys disappeared and a white screen was presented throughout the entire experiment. Infants were presented with alternating standards and oddballs until the infant either became fussy or until all of the stimuli were presented (approximately 1.5 minutes). Stimuli were presented in Trials (i.e., Trial 1 = five presentations of standard → four presentations of oddball 1, Trial 2 = five presentations of standard → four presentations of oddball 2, etc.), such that the same standard was presented throughout the entire experiment and the oddballs changed on every trial. Auditory stimuli were presented for 1 s with a 0.75 s ISI. Thus, within each Trial, the standard was presented for 8.75 s (5 x 1.75 s) and then the oddball was presented for 7 s (4

x 1.75 ms). E-prime sent a pulse to BioNex every time the stimulus changed. For example, E-prime sent a pulse at the onset of the first standard presented in Trial 1. The next pulse was sent at the onset of the first oddball presented in Trial 1, etc. The experiment was not contingent on infants' looking, thus, auditory stimuli were presented as long as the infant was not fussy or interacting with the parent.

## Results and Discussion

Analyses focused on changes in infants' HR to standards and oddballs across time. Artifacts were corrected using Mindware software, and HR data were transformed to Inter-Beat-Interval (IBI). IBI is inversely related to HR. In particular, as HR slows down, the time between heart beats (distance between R waves) increases. Thus, longer IBIs correspond with slower HR. IBIs were computed by averaging IBIs within a one second bin and baseline corrected. For example, to determine how HR changed 1 s after stimulus onset, we subtracted baseline IBI (IBI 1 s pre-stimulus) from IBI at 1 s post stimulus. To examine how HR changed 2 s after stimulus onset, we subtracted baseline IBI from IBI at 2 s post stimulus. Thus, values greater than zero denote that HR slowed down after stimulus onset and values less than zero denote that HR sped up after stimulus onset.

To examine discrimination of standards and oddballs, we compared IBIs to standards and oddballs averaged across Trials 1-3 (Figure 2a) and averaged across Trials 4-6 (Figure 2b). Paired-sample *t* tests were conducted comparing IBIs to standards and oddballs at each point in time. Reliable differences between standards and oddballs are denoted with a "\*" on the x axis. For example, Figure 2a shows that IBIs to standards and oddballs only differed 3 s after stimulus onset,  $p < .05$ . However, as can be seen in Figure 2b, these differences became more pronounced in Trials 4-6. Furthermore, examination of Figure 2b also shows that the difference between standards and oddballs was not solely driven by greater deceleration to oddballs. Rather, HR also accelerated to standards. Examination of video streams suggests that this acceleration may be related to increased infant fidgeting rather than from auditory stimuli startling infants.

To examine how quickly oddballs engaged attention we identified the point for each infant when two consecutive IBIs exceeded baseline (zero). Eight of the 24 infants did not meet this criterion. Averaged across the remaining infants, it took approximately 2.3 s for HR to decelerate. Finally, we examined dwell time of attention to the oddballs (i.e., how long did the oddball hold infants' attention). For example, one of the infants' first of two consecutive IBIs exceeded zero 1 s after stimulus onset and returned to zero 6 s after stimulus onset. Thus, this infants' dwell time of attention was 5 s (HR was decelerated from 1 s – 5 s). On average infants' HRs were decelerated to oddballs for 5 s. However, it is important to

note that many of infants' HRs were still decelerated at the end of the trial. Thus, the value of 5 s underestimates how long the oddballs actually held infants' attention.

In summary, the findings from Experiment 1 demonstrate that HR can serve as a modality-independent measure of attention to assess auditory discrimination in a relatively short period of time, and these discriminations appeared to develop gradually across the experiment. In addition to providing time course information across trials, changes in HR can also provide a measure of speed of engagement and dwell time of attention within trials.

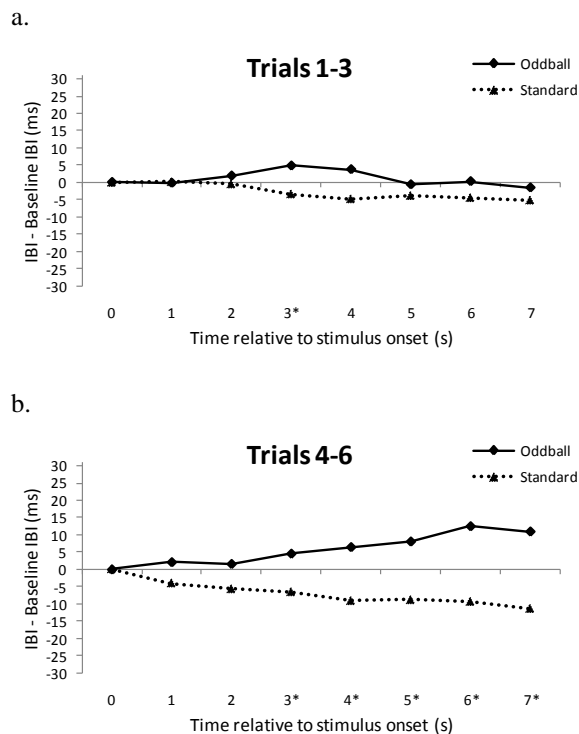


Figure 2: Change in IBI to standards and oddballs in Trials 1-3 (a) and Trials 4-6 (b). Note: "\*" on the x axis denote means at that point in time were reliably different,  $ps < .05$  (one-tailed).

## Experiment 2

The goal of Experiment 2 was to examine how visual input affects discrimination of the auditory stimuli presented in Experiment 1. More specifically, we examined how pairing an old visual stimulus with a novel auditory oddball would affect discrimination, speed of engagement, and dwell time of attention.

## Method

**Participants** Eight 10-month-olds (3 boys and 5 girls,  $M = 309$  days,  $SE = 56$  days) participated in this experiment. Demographics were identical to Experiment 1. Five infants were tested but were not included in the final sample due to fussiness ( $n=3$ ) and experimenter error ( $n = 2$ ).

**Stimuli and Procedure** The auditory stimuli were identical to Experiment 1, however, in the current experiment, auditory stimuli were paired with a visual stimulus (see Figure 1). The visual stimulus consisted of a novel creature that was created in PowerPoint and saved as a 400 x 400 pixel jpg. The visual stimulus was presented on the 52" Sony LCD and pulsed at the same rate as the auditory stimulus (1 s stimulus duration with a 0.75 s ISI). The procedure also differed from Experiment 1 in one important way. In the current experiment, the procedure paused and the screen darkened when infants looked away. The experiment started back up again when the infant looked to the darkened screen. This manipulation was important because we were interested in how the presence of an old visual stimulus affected auditory processing. Therefore, we only examined discrimination of auditory stimuli on those trials where the infants were looking to the visual stimulus. Trials where the infant looked away were discarded.

## Results and Discussion

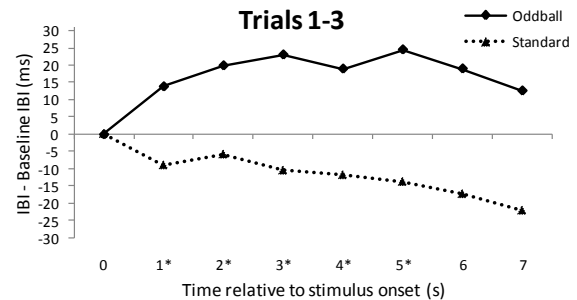
As in Experiment 1, we examined discrimination of standards and oddballs in Trials 1-3 (Figure 3a) and in Trials 4-6 (Figure 3b). Paired-sample  $t$  tests (one-tailed) were conducted to compare discrimination of standards and oddballs at each point in time. In contrast to Experiment 1, infants reliably discriminated auditory standards and oddballs in Trials 1-3 (see asterisks on the x axis to determine which means reliably differed from each other). This suggests that the presence of the visual stimulus actually facilitated auditory discrimination, with infants discriminating oddballs and standards early in the course of processing. Discrimination was also robust in the last three trials of the experiment (see Figure 3b).

As in Experiment 1, we also examined how quickly oddballs engaged attention and how long oddballs held attention. Two of the 8 infants never had two consecutive IBIs exceed zero. Averaged across the remaining infants, it took approximately 1.1 s for the oddballs to engage attention. Recall that infants in Experiment 1 took approximately 2.3 seconds. Therefore, the old visual stimulus did not appear to slow down the detection of the auditory oddballs. Furthermore, infants' HR in the current experiment was decelerated to oddballs for approximately 5.8 s, which was slightly longer than in Experiment 1. However, as in Experiment 1, many infants' HRs were still decelerated at the end of the trial. Therefore, it is

unclear if differences between Experiments 1 and 2 would have emerged if infants would have been given more time for HR to return to baseline levels.

In summary, Experiment 2 demonstrates that visual stimuli did not attenuate discrimination of auditory input or slow down the speed in which auditory oddballs engaged attention. Rather, cross-modal presentation in the current experiment actually facilitated auditory processing. Recall that infants in the current experiment (but not in Experiment 1) reliably discriminated standards from oddballs in Trials 1-3. Furthermore, these effects were much stronger in Experiment 2, with reliable discrimination occurring with a sample size of only eight infants. Finally, it is worth noting that all data reported in Experiment 2 came from trials when infants were looking throughout the entire trial. Therefore, analysis of looking data would suggest no discrimination of standards and oddballs, whereas HR data clearly demonstrate that infants discriminated these stimuli.

a.



b.

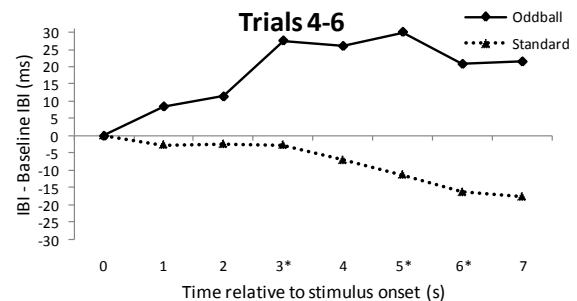


Figure 3: Change in IBI to standards and oddballs in Trials 1-3 (a) and Trials 4-6 (b). Note: “\*” on the x axis denotes mean at that point in time were reliably different,  $ps < .05$  (one-tailed).

## General Discussion

The current study reveals several important findings. First, Experiment 1 demonstrates that HR can provide a powerful tool for examining auditory processing. In particular, changes in HR to frequent and infrequent stimuli can provide a measure of auditory discrimination. Furthermore, speed of engagement and dwell time of attention can also be estimated by examining when HR decelerates compared to pre-stimulus levels and by examining how long HR remains decelerated. More importantly, Experiment 2 demonstrates that visual input facilitated, rather than interfered with, auditory processing.

These findings suggest that the differences in modality dominance between infants and adults do not stem from an underestimation of visual interference with auditory processing in infants. Rather, these findings suggest that the difference may actually reflect a real developmental phenomenon, with allocation of attention to multimodal stimuli changing in the course of development.

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