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Brief Report

Effects of multimodal presentation and stimulus familiarity on auditory and visual processing

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ABSTRACT

Two experiments examined the effects of multimodal presentation and stimulus familiarity on auditory and visual processing. In Experiment 1, 10-month-olds were habituated to either an auditory stimulus, a visual stimulus, or an auditory–visual multimodal stimulus. Processing time was assessed during the habituation phase, and discrimination of auditory and visual stimuli was assessed during a subsequent testing phase. In Experiment 2, the familiarity of the auditory or visual stimulus was systematically manipulated by prefamiliarizing infants to either the auditory or visual stimulus prior to the experiment proper. With the exception of the prefamiliarized auditory condition in Experiment 2, infants in the multimodal conditions failed to increase looking when the visual component changed at test. This finding is noteworthy given that infants discriminated the same visual stimuli when presented unimodally, and there was no evidence that multimodal presentation attenuated auditory processing. Possible factors underlying these effects are discussed.

Introduction

Infants live in a multimodal world where they frequently encounter information presented to multiple sensory modalities. In some situations, infants ably process and integrate information across sensory modalities. For example, young infants can associate words with arbitrarily paired objects, they can integrate auditory and visual input when perceiving speech, and auditory input can even facilitate visual processing (e.g., Kuhl & Meltzoff, 1982; Schafer & Plunkett, 1998; Sloutsky & Robinson, 2008;

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see also Lewkowicz, 2000; Lickliter & Bahrick, 2000, for reviews). At the same time, there are also many situations when presenting stimuli to multiple sensory modalities interferes with learning. For example, in many situations, infants and young children are often better at processing the details of a stimulus when it is presented unimodally than when the same stimulus is presented multimodally (Lewkowicz, 1988a, 1988b; Napolitano & Sloutsky, 2004; Robinson & Sloutsky, 2004; Sloutsky & Napolitano, 2003; Sloutsky & Robinson, 2008). The current study examines possible factors that might account for young infants' difficulties in processing multimodal information.

There are at least three possible reasons why multimodal presentation might attenuate (or delay) learning. First, multimodal stimuli often contain more information than unimodal stimuli. For example, in a unimodal visual task infants are required to encode and store a visual stimulus, whereas in a multimodal task (e.g., word learning) infants are often required to encode and store a simultaneously presented word and object and also to form associations across sensory modalities. This increase in processing demands, or "cognitive load", in a multimodal task may make it difficult for infants to process the details of a stimulus (e.g., Casasola & Cohen, 2000; Stager & Werker, 1997).

Second, the intersensory redundancy hypothesis also makes predictions concerning how multimodal stimuli are processed. In many situations, multimodal stimuli can provide amodal or redundant information. For example, the rate at which a ball is bouncing can be experienced both visually and auditorily. According to the intersensory redundancy hypothesis (Bahrick & Lickliter, 2000; see Bahrick, Lickliter, & Flom, 2004, for a review), when infants are presented with multimodal stimuli, such that each modality expresses the same amodal relation, this redundant information is particularly salient. Infants direct their attention to the amodal information before processing information that can be experienced only in a single modality (e.g., the color of an object). Because modality-specific information is initially pushed to the background of attention when it is presented multimodally, the intersensory redundancy hypothesis predicts that multimodal stimuli containing amodal relations should be acquired first, followed by learning of modality-specific information (but see Lewkowicz & Schwartz, 2002).

Finally, auditory dominance may also account for some infants' difficulties in processing multimodal information (Robinson & Sloutsky, 2004; Sloutsky & Napolitano, 2003). The auditory dominance account makes several assumptions. First, because auditory input is typically more transient than visual input, it seems adaptive to first allocate attention to these dynamic stimuli. Second, the auditory dominance account assumes that attention is allocated to multimodal stimuli in a serial manner, with infants first encoding the details of the auditory (or dynamic) stimulus before encoding the details of a visual stimulus. Finally, this account predicts that auditory stimuli that are faster to release attention (e.g., simple or familiar stimuli) should exert less interference than auditory stimuli that are slower to release attention (e.g., complex or unfamiliar stimuli).

Increased processing demands, intersensory redundancy, and auditory dominance all make predictions concerning how multimodal presentation should affect learning; however, the accounts differ in several important ways. For example, whereas increased cognitive load and intersensory redundancy are agnostic to the direction of interference effects, the auditory dominance account predicts that multimodal presentation will attenuate visual processing more than auditory processing. The three accounts also make different predictions concerning which type of multimodal stimuli will attenuate learning. For example, whereas the intersensory redundancy hypothesis makes it explicit that infants presented with multimodal stimuli consisting of amodal relations should first process the amodal information before processing the modality-specific information, the cognitive load and auditory dominance accounts do not discriminate between multimodal stimuli that contain amodal and arbitrary relations. Finally, both the cognitive load and auditory dominance accounts predict that increasing the familiarity of the stimuli should decrease processing demands and attenuate interference effects. The primary aim of the current study was to compare the ability of these accounts to explain phenomena associated with multimodal presentation of stimuli.

A second goal of the current study was to test the generalizability of auditory dominance. Although several methodologies have been used to examine processing of arbitrary auditory–visual pairings, most of the infant studies supporting auditory dominance have employed fixed-trial familiarization procedures (Robinson & Sloutsky, 2004, 2007a, 2007b, 2008; Sloutsky & Robinson, 2008). One potential concern is that fixed-trial duration procedures may be biased in favor of the auditory modality because infants could accumulate more exposure to auditory stimuli in the course of familiarization. In particular, although looking away from the screen in fixed-trial duration procedures terminates processing of the visual stimulus, infants can still hear the auditory stimulus. It could also be argued that processing of multimodal stimuli is more complex than processing of unimodal stimuli, therefore, an experimental procedure should be used to equate differential processing demands. Both of these issues were addressed in the current study by using an infant-controlled habituation procedure (see Horowitz, Paden, Bhana, & Self, 1972, for a description of the paradigm).

The current study employed an infant-controlled habituation procedure to examine how multimodal presentation affects auditory and visual processing in 10-month-olds. In Experiment 1, encoding of the same auditory and visual stimuli was assessed under three different stimulus conditions: (a) multimodal condition, (b) unimodal auditory condition, and (c) unimodal visual condition. According to the auditory dominance account, interference effects should be asymmetrical, with multimodal presentation attenuating visual processing more than auditory processing. In Experiment 2, we manipulated the familiarity of the auditory and visual stimulus prior to the experiment proper. Increasing the familiarity of the auditory and visual components should decrease processing demands and attenuate interference effects (Fennell, 2006; Robinson & Sloutsky, 2007b; Sloutsky & Robinson, 2008).

Experiment 1

Method

Participants

In total, 64 10-month-olds (33 boys and 31 girls, mean age = 300.86 days, $SD = 61.48$) participated in this experiment. Parents' names were collected from local birth announcements, and contact information was obtained through local directories. All children were full-term (>2500 g birth weight) with no auditory or visual deficits, as reported by parents. The majority of infants were Caucasian. An additional 36 infants were tested but not included in the current experiment due to fussiness ($n = 18$) or because they failed to reach the habituation criterion ($n = 18$).

Materials and design

Infants in the current study were presented with either two auditory stimuli ($n = 16$), two visual stimuli ($n = 17$), or two auditory–visual pairings ($n = 31$). The auditory components were melodies (each presented for a total duration of 1 s), with each melody consisting of a sequence of three musical notes (either D–F#–A or D–B–G). Melodies were generated using Creative SoundFont Bank Manager and were saved as 16-bit, 44.1-kHz WAV files. These stimuli were presented to infants at 65–70 dB. Visual stimuli (also presented for 1 s) were three-dimensional pictures of shapes created in Microsoft Word and saved as 400 × 400-pixel JPEG files (see Fig. 1 for visual stimuli). The same auditory and visual stimuli were used across unimodal and multimodal conditions, and the selection of the training

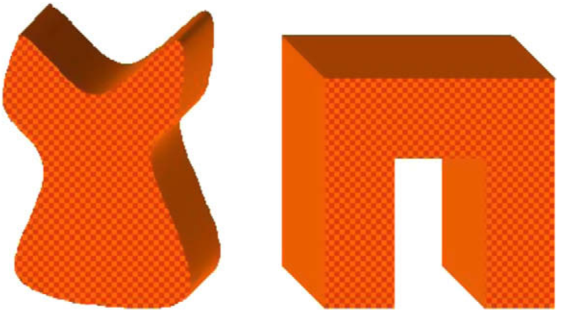

Fig. 1. Visual stimuli presented in Experiments 1 and 2.

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and testing stimuli was counterbalanced across participants (e.g., half of the infants in the unimodal visual condition were habituated to V1 and tested on V2, and the remaining infants were habituated to V2 and tested on V1).

Apparatus

Infants sat on their parents' laps approximately 100 cm away from a 152 × 127-cm projection screen. An NEC GT2150 LCD projector presented images to infants and was mounted on the ceiling approximately 30 cm behind infants (130 cm away from the projection screen). Two Boston Acoustics 380 speakers presented auditory stimuli to infants. These speakers were 76 cm apart from each other and mounted in the wall at infants' eye level. The projector and speakers received visual and auditory input from a Dell Dimension 8200 computer, which was controlled by custom-designed software created in Macromedia Director MX. This computer was also used to record visual fixations. Fixations were recorded online by pressing the space bar when infants looked at the stimulus and by releasing the space bar when infants looked away from the stimulus. Test trials from a random sample of 25% of the infants were coded offline. Reliability between online and offline raters across all reported experiments was $r = .97$.

Procedure

Infants in the multimodal condition were habituated to an auditory–visual compound stimulus. Each habituation trial began with a fixation stimulus (i.e., a red pulsating circle with a corresponding beeping sound), which was presented centrally on the projection screen. When infants looked at the fixation stimulus, it disappeared and the habituation stimulus was presented. To ensure that differences in encoding auditory and visual stimuli did not stem from infants accumulating more exposure to one modality, stimulus duration was equated by synchronizing the timing and duration of auditory and visual images. Auditory and visual stimuli were presented simultaneously for 1 s with a 0.5-s interstimulus interval. The combined 1.5-s iteration (stimulus plus interstimulus interval) looped continuously until infants looked away for a consecutive 2 s or until infants accumulated 120 s of looking on a single trial. The habituation phase continued until infants reached the habituation criterion or until infants accumulated 12 habituation trials. The habituation criterion was met when the mean looking on three consecutive trials dropped to 50% of initial looking (i.e., averaged looking on the first three trials). Only infants who met the habituation criterion were included in the final sample.

After reaching the habituation criterion, infants immediately moved into the testing phase. There were four test trials, and the order was randomized for each infant. One test trial was identical to the habitation stimulus in that the auditory and visual components were the same as the habituation components (i.e., *old target*). The other three test stimuli consisted of novel stimuli. On *changed visual* trials, only the visual component changed (i.e., changed visual/old auditory). On *changed auditory* trials, only the auditory component changed (i.e., changed auditory/old visual). On *changed both* trials, both components changed (i.e., changed auditory/changed visual). As in previous research (Robinson & Sloutsky, 2004; Sloutsky & Robinson, 2008), infants were briefly refamiliarized to the habituation stimulus during the testing phase. In particular, during the testing phase, the computer randomly presented infants with two of the four test trials. The next three trials were always identical to the habituation stimulus. The computer then randomly presented the remaining two test trials.

Infants in the unimodal visual condition were habituated and tested on the same pulsating images; however, visual stimuli were not paired with sounds during the habituation phase or during the testing phase. As in the multimodal condition, each trial began with a fixation stimulus (pulsating red circle and sound). When infants looked to the fixation stimulus, it disappeared and was replaced by the habituation stimulus. After reaching the habituation criterion, infants were given two test trials (i.e., old target and changed visual) that were randomized for each infant.

Infants in the unimodal auditory condition were habituated and tested on the same sounds that were presented in the multimodal condition; however, auditory stimuli were not paired with the visual images presented in Fig. 1. Each habituation and testing trial began with a fixation stimulus (a pulsating red circle and sound). When infants looked to the fixation stimulus, the red circle stopped pulsating and the auditory stimulus was presented. Auditory processing during the habituation phase and auditory discrimination during the testing phase were assessed by recording infants' looking to

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the static red circle. After reaching the habituation criterion, infants were given two test trials (i.e., old target and changed auditory) that were randomized for each infant.

Results and discussion

Analyses focused on infants' processing times during the habituation phase and on infants' discrimination of auditory and visual stimuli during the testing phase. Accumulated looking time during the habituation phase served as a measure of processing time (see Table 1 for means and standard errors). A one-way analysis of variance (ANOVA) with condition as a between-participants factor revealed that infants' accumulated looking times differed across the three conditions, $F(2, 61) = 4.37$, $p = .05$. An independent-sample t test revealed that infants in the multimodal condition accumulated more overall looking than infants in the unimodal auditory condition, $t(45) = 2.73$, $p = .01$. No other effects reached significance.

Test trials were analyzed to assess discrimination of auditory and visual stimuli across the different conditions. Recall that infants in the multimodal condition were randomly presented with four test items: old target, changed visual, changed auditory, and changed both. Three difference scores were created by subtracting accumulated looking to old target from accumulated looking to each of the three changed trials. If infants discriminated visual stimuli, then looking to changed visual should exceed looking to old target, thereby resulting in difference scores greater than zero. If infants discriminated auditory stimuli, then looking to changed auditory should exceed looking to old target, thereby resulting in difference scores greater than zero.

Difference scores in the multimodal condition were submitted to a one-way ANOVA with test trial as a repeated measure (see Table 1 for mean difference scores and standard errors). The analysis revealed an effect of test trial, $F(2, 60) = 3.97$, $p = .02$. A paired t test revealed that infants increased looking more when both components changed at test (i.e., changed both trials) than when only the visual component changed, $t(30) = 2.51$, $p = .02$. Difference scores were also submitted to one-sample t tests to determine which test items differed from zero. Difference scores on changed auditory trials, $t(30) = 3.03$, $p = .005$, and on changed both trials, $t(30) = 3.65$, $p = .001$, significantly differed from zero, whereas difference scores on changed visual trials did not differ from zero, $t(30) = 1.23$, $p = .23$.

Although discrimination analyses suggest that infants in the multimodal condition did not discriminate the visual stimuli, they did discriminate these stimuli when presented unimodally (see Table 1 for means and standard errors). Difference scores in the unimodal visual condition were calculated by subtracting looking times to old target from looking times to changed visual. Infants in this condition significantly increased looking when the visual component changed at test, with difference scores significantly different from zero, $t(16) = 1.87$, $p = .04$. Difference scores in the unimodal auditory condition were calculated by subtracting looking times to old target from looking times to changed auditory. Difference scores in this condition were also significantly different from zero, $t(15) = 2.04$, $p = .03$. Furthermore, an independent-sample t test revealed comparable discrimination across the unimodal conditions, $t(31) = 0.28$, $p = .78$.

In summary, although infants discriminated auditory and visual stimuli when presented unimodally, analyses of discrimination data suggest that multimodal presentation attenuated visual processing

Table 1
Mean accumulated looking during habituation phase and difference scores (vs. old target) during testing phase.

Stimulus condition	Habituation phase	Testing phase		
	Accumulated looking	Changed auditory	Changed visual	Changed both
Unimodal visual (Experiment 1)	82.99 (7.67)	–	3.64* (1.95)	–
Unimodal auditory (Experiment 1)	64.73 (7.41)	2.95* (1.45)	–	–
Unfamiliar sounds/unfamiliar visual (Experiment 1)	101.06 (8.73)	4.12* (1.36)	1.79 (1.45)	8.14* (2.23)
Prefamiliarized sounds/unfamiliar Visual (Experiment 2)	134.86 (16.68)	7.11* (1.62)	2.03* (0.27)	17.46* (3.57)
Prefamiliarized visual/unfamiliar sounds (Experiment 2)	112.56 (14.71)	7.42* (1.95)	0.46 (0.95)	5.16* (2.79)

Note. All difference scores are presented in seconds, and standard errors are reported in parentheses. An asterisk (*) denotes a difference score greater than zero ($p < .05$).

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but not auditory processing. Therefore, results of Experiment 1 point to asymmetric costs of multimodal presentation; whereas processing of visual input decreased compared with the unimodal baseline, processing of auditory input remained robust. The presence of costs could be explained by all three accounts of multimodal processing; however, only the auditory dominance account can explain the fact that the costs are asymmetric. The goal of Experiment 2 was to further examine the ability of the auditory dominance account to explain multimodal processing.

Experiment 2

According to the increased processing load account, giving infants an opportunity to process the auditory or visual component prior to presenting it multimodally should reduce processing demands and facilitate learning. For example, there is some evidence that prefamiliarizing infants to visual stimuli before pairing them with auditory stimuli appears to help infants make fine phonetic discriminations and retain word–object pairings (Fennell, 2006; Kucker & Samuelson, in press). According to the auditory dominance account, infants often allocate attention to the auditory stimulus before shifting attention to the visual stimulus. Prefamiliarizing infants to the sounds prior to pairing them with a visual stimulus should result in the auditory modality releasing attention earlier in the course of processing, thereby speeding up the onset of visual processing (Robinson & Sloutsky, 2007b).

The primary goal of Experiment 2 was to examine the role of auditory and visual familiarity during multimodal processing. The experiment was identical to the multimodal condition of Experiment 1 except that we prefamiliarized infants to either the auditory or visual component prior to the experiment proper. Both the processing load and auditory dominance predict that infants in the current experiment should be more likely to discriminate auditory and visual stimuli than infants in the multimodal condition of Experiment 1. However, the serial processing assumption of the auditory dominance account (i.e., auditory input is processed prior to visual input) predicts that prefamiliarizing infants to auditory input may have greater effects than prefamiliarizing infants to visual input. No such prediction is made by the processing load account.

Method

Participants, stimuli, and procedure

In total, 48 10-month-olds (29 boys and 19 girls, mean age = 299.19 days, $SD = 60.01$) participated in this experiment. Participant recruitment and demographics were identical to those of Experiment 1. An additional 22 infants were tested but not included in the current experiment due to fussiness ($n = 11$) or because they did not reach the habituation criterion ($n = 11$). The stimuli and experiment were identical to the multimodal condition of Experiment 1 except that the familiarity of the auditory or visual stimulus was manipulated prior to the experiment.

In the current experiment, infants were either given an opportunity to hear the auditory stimuli prior to the experiment proper ($n = 21$) or given an opportunity to see the visual images prior to the experiment proper ($n = 27$). During the prefamiliarization phase, infants either heard each auditory stimulus 15 times or saw each visual stimulus 15 times. Stimuli were presented unimodally during the prefamiliarization phase. After prefamiliarization, infants were given a short 2- to 3-min break and then participated in the experiment proper, which was identical to the multimodal condition of Experiment 1.

Results and discussion

Analyses focused on infants' processing times during the prefamiliarization and habituation phases and on infants' discrimination of auditory and visual stimuli during the testing phase. An independent-sample t test revealed that accumulated looking times during the habituation phase did not differ between the two conditions (see Table 1 for means and standard errors). Furthermore, infants' looking to the screen during the auditory prefamiliarization phase ($M = 27.45$ s, $SE = 2.46$) did not differ from infants' looking to the screen during the visual prefamiliarization phase ($M = 23.64$ s, *SE* = 2.40), and there was no evidence that preexposure to the auditory or visual input decreased processing time; infants in Experiment 2 did not require less time to process multimodal stimuli than infants in the multimodal condition of Experiment 1 (where both components were unfamiliar).

Difference scores at test were created by subtracting looking times to old target from looking times to the three changed trials (see Table 1 for means and standard errors). A Condition (prefamiliarized visual or prefamiliarized auditory) × Test Trial (changed visual, changed auditory, or changed both) ANOVA revealed an effect of test trial, $F(2, 92) = 14.53$, $p = .001$, an effect of condition, $F(1, 46) = 4.22$, $p = .046$, and a Condition × Test Trial interaction, $F(2, 92) = 6.06$, $p = .003$. In the prefamiliarized sound condition, paired-sample *t* tests confirmed that difference scores on changed both trials exceeded those on changed auditory trials, $t(20) = 3.02$, $p = .004$, and those on changed visual trials, $t(20) = 4.32$, $p = .001$. Furthermore, difference scores on changed auditory trials were greater than those on changed visual trials, $t(20) = 3.20$, $p = .003$.

In the prefamiliarized visual condition of Experiment 2, paired-sample *t* tests confirmed that difference scores on changed auditory trials exceeded those on changed visual trials, $t(26) = 3.79$, $p = .001$, and that difference scores on changed both trials were marginally greater than those on changed visual trials, $t(26) = 1.80$, $p = .084$.

Difference scores were also submitted to one-sample *t* tests to determine which test items differed from zero. In the prefamiliarized auditory condition, difference scores exceeded zero on changed auditory trials, $t(20) = 4.38$, $p = .001$, on changed visual trials, $t(20) = 3.01$, $p = .006$, and on changed both trials, $t(20) = 4.90$, $p = .001$. In contrast, in the prefamiliarized visual condition, difference scores exceeded zero only on changed auditory trials, $t(26) = 3.80$, $p = .001$, and on changed both trials, $t(26) = 1.96$, $p = .06$, whereas difference scores on changed visual trials did not differ from zero, $t(26) = 0.48$, $p = .66$.

These findings further extend earlier reported effects of auditory familiarity on visual processing (Robinson & Sloutsky, 2007b; Sloutsky & Robinson, 2008) and support the auditory dominance account; prefamiliarizing infants to the auditory input had greater effects on visual processing than prefamiliarizing infants to the visual input.

General discussion

The current study reveals several important findings concerning the effects of multimodal presentation on auditory and visual processing. First, discrimination data suggest that multimodal presentation had asymmetric costs for auditory and visual processing; whereas multimodal presentation attenuated discrimination of the visual input, it did not attenuate discrimination of auditory input. Second, infants in the multimodal condition took longer to reach the habituation criterion than infants in the unimodal auditory condition (Experiment 1). This finding suggests that some aspects of the visual stimulus (or multimodal stimulus) were attended to during the habituation phase. Finally, whereas prefamiliarizing infants to the auditory input attenuated auditory dominance effects, prefamiliarizing infants to the visual input did not appear to help infants discriminate the visual stimuli (Experiment 2).

Cognitive load, intersensory redundancy, and auditory dominance all predict that multimodal presentation can affect learning; however, only the auditory dominance account predicts that costs of multimodal presentation should be asymmetrical. Furthermore, auditory dominance can also account for the differences across the prefamiliarized auditory and prefamiliarized visual conditions. In particular, the auditory dominance account assumes that infants process the details of the auditory component prior to shifting their attention to the visual component. Increased familiarity with an auditory stimulus should correspond with faster processing (i.e., faster release of attention), which should allow for more time to process the visual stimulus. Although familiarity with the auditory stimulus did not have any significant effect on accumulated looking during the habituation phase, it did correspond with better discrimination of visual stimuli. Recall that this was the only multimodal condition where infants significantly increased looking on changed visual trials.

Infants in the multimodal conditions were trained and tested on multimodal stimuli; thus, it is unclear in the current study whether interference occurs during the encoding phase, during the testing

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phase, or during both of these phases. Although this issue awaits resolution, our previously published findings indicate that auditory dominance effects persist when infants are trained on multimodal stimuli and tested on unimodal visual stimuli (Robinson & Sloutsky, 2007a, 2008). This suggests that at least some of the interference occurs during the encoding stage of processing. In addition, to determine the robustness of auditory dominance, future research will need to manipulate the dynamic nature of auditory and visual stimuli. Will auditory dominance still persist when visual stimuli are dynamic and auditory stimuli are static?

In summary, the current study tested the ability of three different accounts to explain phenomena associated with multimodal presentation of stimuli. The auditory dominance account can explain why multimodal presentation attenuated visual processing more than auditory processing and can also account for the finding that prefamiliarized auditory and visual stimuli had different effects on multimodal processing.

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