

Auditory Dominance: Overshadowing or Response Competition?

Christopher W. Robinson (robinson.777@osu.edu)

Center for Cognitive Science
The Ohio State University
208F Ohio Stadium East, 1961 Tuttle Park Place
Columbus, OH 43210, USA

Vladimir M. Sloutsky (sloutsky.1@osu.edu)

Center for Cognitive Science
The Ohio State University
208C Ohio Stadium East, 1961 Tuttle Park Place
Columbus, OH 43210, USA

Abstract

The ability to process simultaneously presented auditory and visual information is a necessary component underlying many cognitive tasks. While this ability is often taken for granted, previous research has demonstrated that there are many occasions where infants and young children are better at discriminating a visual stimulus when it is presented in isolation than when paired with an auditory stimulus. The current study expands on this research by examining whether this attenuated discrimination stems from overshadowing (auditory stimulus disrupts encoding of visual stimulus) or from response competition (auditory input interferes with visual processing during the decision or response phase). While attenuated discrimination in the current study stemmed from response competition, we argue that both overshadowing and response competition underlie auditory dominance effects.

Keywords: Cognitive Development, Attention, Language Acquisition, Psychology, Human Experimentation.

Introduction

The ability to process simultaneously presented auditory and visual information is a necessary component underlying many cognitive tasks. For example, word learning and effects of linguistic labels on categorization, induction and object individuation all hinge on the ability to encode and store arbitrary, auditory-visual pairings (Balaban & Waxman, 1997; Sloutsky & Fisher, 2004; Sloutsky, Lo, & Fisher, 2001; Welder & Graham, 2001; Xu, 2002). The current research can shed light on many different aspects of cognitive development by examining how children process simultaneously presented auditory and visual stimuli more generally.

The research that has examined infants' and young children's processing of arbitrary auditory-visual pairings has documented several important findings. First, infants and young children are often better at discriminating a visual stimulus when it is presented in isolation than when paired with an auditory stimulus (Napolitano & Sloutsky,

2004; Robinson & Sloutsky, 2004; in press-a; in press-b; Sloutsky & Napolitano, 2003). Second, there is an auditory dominance effect: While the presence of an auditory stimulus often hinders visual discrimination, the presence of a visual stimulus often has little or no effect on auditory discrimination (Sloutsky & Robinson, in press). Third, auditory dominance decreases in the course of development (Robinson & Sloutsky, 2004; Sloutsky & Napolitano, 2003). Fourth, auditory dominance can be reversed or attenuated by manipulating the familiarity of the auditory and visual stimuli (Napolitano & Sloutsky, 2004; Robinson & Sloutsky, in press-a; Sloutsky & Robinson, in press). Finally, while unfamiliar sounds and words often have different effects on visual tasks, familiar sounds and words often have comparable effects on visual tasks (Robinson & Sloutsky, in press-a; Sloutsky & Robinson, in press).

Although auditory dominance is well documented, the mechanism(s) underlying these effects need further examination. For example, one mechanism that can result in auditory dominance is overshadowing. According to this account, poor visual discrimination in bimodal conditions stems from the auditory stimulus pulling attention away from the visual stimulus and, thus, attenuating the encoding of visual input. However, it is also possible that some of these effects stem from response competition. According to this account, children encode both modalities, however, the auditory input interferes with or is preferred when making a decision or response. The primary goal of the current research is to distinguish between these two possible mechanisms that may underlie auditory dominance.

The current study employed a variation of the immediate recognition task recently used by Napolitano and Sloutsky (2004). Children were first presented with a target stimulus, which was followed by a test stimulus. Children were instructed to say

“same” if the target and test stimuli were exactly the same and say “different” if the target and test stimuli differed in any way.

In the first experiment both the target stimulus and the test stimulus consisted of arbitrary, auditory-visual pairings (e.g., AUD-VIS → AUD-VIS). Children were instructed to say “same” if the target and test stimuli were exactly the same (i.e., if the auditory and visual stimuli were in agreement) and say “different” if either the auditory component changed, the visual component changed or both components changed. Given that the auditory stimulus was present in the target stimulus as well as in the test stimulus, auditory dominance could stem from overshadowing or from response competition.

In Experiment 2, children were also shown an auditory-visual target stimulus. However, this time either the auditory stimulus was removed at test (e.g., AUD-VIS → VIS) or the visual stimulus was removed at test (e.g., AUD-VIS → AUD). In the former trial types (visual trials), children had to determine if the two pictures were exactly the same or different. In the latter trial types (auditory trials), children had to determine if the two auditory stimuli were exactly the same or different. Because the auditory stimulus was not present at test to interfere with a response on visual trials, any attenuated discrimination in Experiment 2 could be directly attributed to the auditory stimulus attenuating the encoding of the visual stimulus. Thus, by manipulating whether the auditory stimulus is present or absent at test, the current study will shed light on children’s processing of simultaneously presented auditory and visual stimuli, which has implications for higher-level tasks that hinge on this process.

Experiment 1

The goal of Experiment 1 was to first identify conditions that result in auditory dominance. Based on Napolitano and Sloutsky’s (2004) findings, it was expected that familiar auditory stimuli (e.g., familiar sounds and human speech) would be more likely to attenuate visual discrimination than unfamiliar sounds. Thus, familiar auditory stimuli were used in the current experiments.

Method

Participants Twenty-three four-year olds (13 girls and 10 boys, $M = 4.5$ years, $SD = .30$ years) participated in this experiment. Ten children heard familiar sounds during the experiment and 13 children heard words. Children were recruited through local day-care centers located in middle- and upper-middle-class suburbs of Columbus, Ohio. The majority of children were Caucasian.

Stimuli The auditory and visual stimuli consisted of 12 familiar sounds (e.g., car horn, telephone ring, etc.), 12 nonsense labels (e.g., vika, toma, etc.) and 12 novel

animal-like creatures (see Figure 1 for examples of visual stimuli). Although children did not know the referents for the nonsense words, the words are familiar to children in the sense that they can ably identify the source of these stimuli (i.e., a person produced the words). The auditory and visual stimuli were presented on a Dell Inspiron laptop computer with Presentation software. Visual stimuli were approximately 10 cm by 10 cm in size. Auditory stimuli consisted of child-directed labels, which were produced by a female experimenter. Both the familiar sounds and nonsense labels were edited using Cool Edit 2000 to ensure that auditory stimuli were equal in duration (1 s) and presented at 65-70 dB.

Procedure The experiment consisted of two phases. In the first phase, children’s discrimination of the auditory and visual stimuli was assessed when the stimuli were presented bimodally (bimodal presentation). In the second phase, children’s discrimination of the auditory and visual stimuli was assessed when the stimuli were presented in isolation (unimodal presentation).

Prior to the experiment, children were told that they were going to play a matching game where they would be given a picture and a sound and then another picture and sound. If both the pictures and sounds were exactly the same, they were instructed to say “same”. If the sound changed, the picture changed or both the sound and picture changed, they were instructed to say “different”.

Six different auditory-visual targets were constructed, and each target had four different test trials, which resulted in 24 trials (see Figure 1 for trial types). On each trial, an AUD-VIS target stimulus was presented for 1 s, followed by a 1 s inter-stimulus interval. An AUD-VIS test stimulus was then presented for 1 s. Some of the test items had the same auditory-visual components as the target (i.e., same trials). A correct response on these trials was “same” because the auditory and visual stimuli were in agreement. The remaining test trials had a change in either the auditory component (i.e., different auditory/same visual), the visual component (i.e., different visual/same auditory) or in both components (i.e., both different). A correct response on these trials was “different”. Six trials were presented from each of the four trial types, and the 24 trials were randomized for each subject.

After completing the 24 bimodal trials, children moved to the next phase where discrimination of the unimodal stimuli was assessed. Prior to the unimodal phase, children were told that they were going to play a similar game, however, this time they would only see pictures or only hear sounds. The unimodal phase also consisted of 24 trials (12 auditory trials and 12

visual trials), which were randomized for each child. Half of the trials within each modality were same trials and half were different trials. The auditory and visual stimuli were identical to those presented in the bimodal phase, thus, making performance in this phase a measure of baseline discrimination.

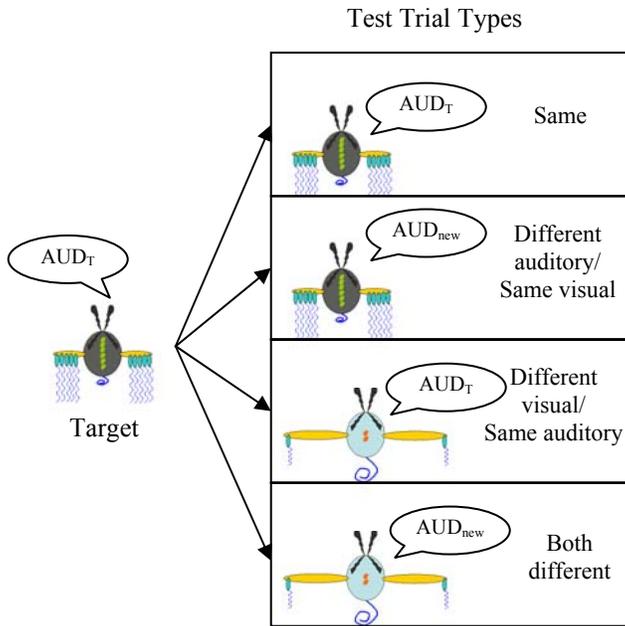


Figure 1: Overview of trial types in Experiment 1.

Results and Discussion

Discrimination accuracy was calculated separately for the unimodal trials and for the bimodal trials. For example, discrimination of visual stimuli in the unimodal condition was calculated by subtracting the proportion of false alarms on different trials from the proportion of hits on same trials. Accuracy in the auditory and visual unimodal conditions are reported in the black bars of Figure 2. As can be seen in the figure, unimodal accuracy in both modalities approached ceiling.

Discrimination accuracy in the bimodal conditions was also calculated by subtracting the proportion of false alarms on different trials from the proportion of hits on same trials. Discrimination of the visual stimuli was calculated by subtracting the proportion of false alarms on different visual/same auditory trials from the proportion of hits on same trials. Discrimination of the auditory stimuli was calculated by subtracting the proportion of false alarms on different auditory/same visual trials from the proportion of hits on same trials. These values are reported in the gray bars in Figure 2. Note that participants had no difficulty rejecting both different trials, correct rejections > .94.

Discrimination of auditory and visual stimuli when presented bimodally was compared to discrimination of

the same stimuli in the unimodal phase by submitting accuracy scores to a 2 (Modality: Auditory vs. Visual) x 2 (Presentation: Bimodal vs. Unimodal) x 2 (Stimulus Condition: Familiar Sound vs. Nonsense Label) ANOVA with Modality and Presentation manipulated within subjects (see Figure 2 for Means and Standard Errors).

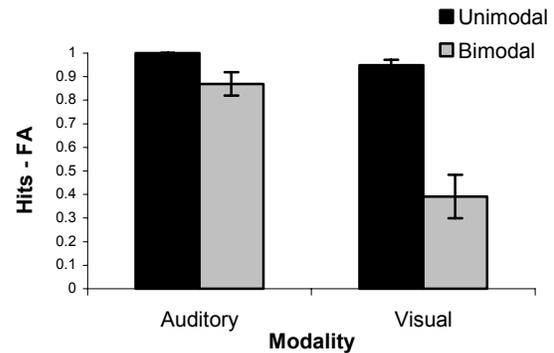


Figure 2: Children's discrimination of auditory and visual input in Experiment 1. Means and standard errors are collapsed across stimulus condition.

The analysis revealed a Presentation x Modality interaction, $F(1, 21) = 15.28, p < .001$, which suggests that the auditory stimulus hindered visual discrimination more than the visual stimulus hindered auditory discrimination. As can be seen above, the analysis also revealed effects of Presentation and Modality, $F_s > 21.44, p_s > .001$. It is also important to note that there was no significant effect of Stimulus Condition nor did Stimulus Condition significantly interact with the other factors, $F_s < 1.14, p_s > .30$. This suggests that nonsense labels and familiar sounds had comparable effects on attenuating visual discrimination.

In summary, Experiment 1 is consistent with previous research examining processing of arbitrary, auditory-visual pairings in young children: Familiar auditory stimuli such as familiar sounds and human speech both had comparable effects on visual discrimination (Napolitano & Sloutsky, 2004; Robinson & Sloutsky, in press-a).

Experiment 2

The goal of Experiment 2 was to further examine the auditory dominance effects found in Experiment 1. As in Experiment 1, children were presented with an auditory-visual compound target stimulus. However, in contrast to the previous experiment, children were only presented with one modality at test (e.g., AUD-VIS → VIS). Because the auditory stimulus was not present at test to interfere with a response, any attenuated discrimination in Experiment 2 could be

directly attributed to the auditory stimulus attenuating the encoding of the target visual stimulus. On the other hand, if auditory dominance effects disappear, this would suggest that children did encode the target visual stimulus, however, the auditory stimulus interfered with their decision or response.

Method

Participants Eighteen four-year olds (12 girls and 6 boys, $M = 4.4$ years, $SD = .30$ years) participated in this experiment. Nine children heard familiar sounds paired with the visual stimuli and nine children heard nonsense labels paired with the same visual stimuli. Demographics and subject recruitment were identical to Experiment 1.

Stimuli and Procedure The auditory and visual stimuli were identical to Experiment 1. Children were first presented with 24 bimodal trials and then 24 unimodal trials. The unimodal trials were identical to Experiment 1. As mentioned above, the bimodal trials differed from the previous experiment in one important way: While the target stimulus was presented bimodally, only one modality was presented at test (see Figure 3 for an overview of trial types). Half of the trials were auditory trials and half of the trials were visual trials, and trials were randomized for each child. Thus, children had no way of knowing whether they were going to be asked about the auditory or visual stimulus while the target stimulus was presented. On visual test trials children were asked “were those two pictures the same or different?” and on auditory test trials they were asked “were those two sounds (or words) the same or different?”.

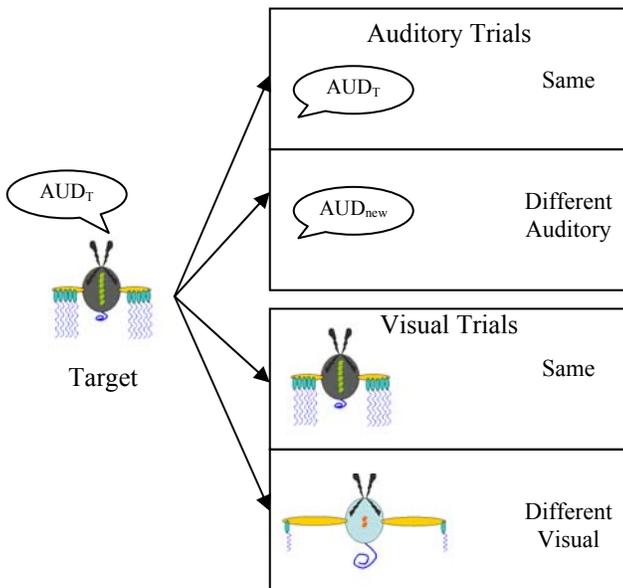


Figure 3: Overview of trial types in Experiment 2.

Results and Discussion

As in Experiment 1, discrimination accuracy scores were submitted to a 2 (Modality: Auditory vs. Visual) x 2 (Presentation: Bimodal vs. Unimodal) x 2 (Stimulus Condition: Familiar Sound vs. Nonsense Label) ANOVA with Modality and Presentation manipulated within subjects. As can be seen in Figure 4, the analysis revealed no significant effects or interactions, all $F_s < 1.91$, $p_s > .19$. Thus, while familiar sounds and nonsense labels markedly attenuated visual discrimination in Experiment 1, these same stimuli had no significant effect when they were removed from the testing stimulus.

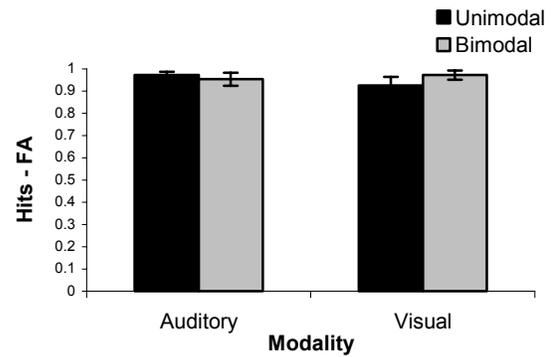


Figure 4: Children’s discrimination of auditory and visual input in Experiment 2. Means and standard errors are collapsed across stimulus condition.

General Discussion

The current study reveals several important findings. First, when auditory and visual stimuli are paired together, the presence of an auditory stimulus often corresponds with a decrease in visual discrimination (Experiment 1). Second, this effect is not restricted to linguistic input: Both familiar sounds and linguistic labels had comparable effects on visual discrimination. Finally, the attenuated discrimination found in Experiment 1 is likely to stem from auditory input interfering with visual processing during the decision or response phase (Experiment 2).

The current findings are important for understanding how children process auditory and visual pairings more generally, however, it will also be important to integrate these findings with children’s performance on more sophisticated tasks. For example, in categorization and induction tasks (e.g., Gelman & Markman, 1986; Sloutsky & Fisher, 2004), an experimenter labels a target picture and then labels two test pictures. Children’s task is to generalize a non-obvious property or category membership, and they can rely on appearance (visual) or on the label (auditory) to make their

generalizations. It is often found that young children are more likely to rely on the label when making a generalization than on appearance. Several different explanations can account for this effect, and these explanations are not mutually exclusive. The first possibility is that children understand the conceptual importance of labels, with labels serving as proxies to category membership (Gelman & Coley, 1991). A second possibility is that auditory input (including words) overshadows or attenuates the processing of visual input (Sloutsky & Napolitano, 2003), and children rely more on the label because they did not fully encode the visual stimulus. The current study offers a third possibility: Even under situations where there is no evidence of overshadowing, it is possible that the auditory stimulus interferes with a child's response.

The current study may also resolve a discrepancy surrounding the role of familiarity in modality dominance. In some conditions, increasing the familiarity of the auditory stimulus corresponds with stronger auditory dominance effects (Napolitano & Sloutsky, 2004). However, in other conditions, increasing the familiarity of the auditory stimulus attenuates auditory dominance effects (Robinson & Sloutsky, in press-a; in press-b). One possible explanation that may resolve this discrepancy is by positing that stimulus familiarity has different effects during the encoding phase than during the decision/response phase. During encoding, unfamiliar auditory stimuli are likely to require more attentional resources than familiar auditory stimuli, and therefore making unfamiliar auditory stimuli more likely to interfere with the encoding of a visual stimulus. However, when the task is to make a response or to make comparisons in memory, familiar auditory stimuli may be retrieved faster and more efficiently than unfamiliar auditory stimuli. This in turn could make familiar auditory stimuli more likely to dominate a decision or response.

If these considerations are correct, then the differential familiarity effects should fluctuate under different experimental conditions. In tasks such as Experiment 1 (see also Napolitano & Sloutsky, 2004; Sloutsky & Napolitano, 2003) where the auditory stimulus is presented when the child needs to make a response, more familiar auditory stimuli elicit stronger auditory dominance effects than unfamiliar auditory stimuli. In contrast, when the auditory stimulus is only presented during the encoding phase, it is often found that unfamiliar auditory stimuli are more likely to interfere with visual processing than familiar auditory stimuli (Robinson & Sloutsky, in press-b). For example, in Robinson and Sloutsky's (in press-b) study, infants were familiarized to different exemplars from within a category. Category members were either associated with unfamiliar sounds (laser sound) or words (e.g., "a cat"). After familiarization, infants were shown two stimuli: a

novel exemplar from the *familiar* category and a novel exemplar from a *novel* category. Even though no auditory input was provided at test, recognition and categorization performance was often worse in the auditory conditions compared to a silent baseline. Furthermore, unfamiliar sounds were more likely to attenuate categorization and recognition than familiar auditory stimuli ("a cat"). These findings provide strong evidence that overshadowing can also drive auditory dominance effects. These findings also suggest that familiarity may have different effects during the encoding phase and during the decision or response phase.

In summary, there are many tasks that require infants and children to process simultaneously presented auditory and visual information, and it is likely that both overshadowing and response competition affect the way children respond to these stimuli. Understanding these processes may not only shed light on how attention is allocated to cross-modal stimuli, but it is likely that many of these low-level effects also permeate children's responses in a variety of cognitive tasks.

Acknowledgments

This research has been supported by grants from the NSF (REC 0208103) and from the Institute of Education Sciences, U.S. Department of Education (R305H050125) to Vladimir M. Sloutsky.

References

- Balaban, M. T., & Waxman, S. R. (1997). Do words facilitate object categorization in 9-month-old infants? *Journal of Experimental Child Psychology*, *64*, 3-26.
- Gelman, S. A., & Coley J. (1991). Language and categorization: The acquisition of natural kind terms. In S.A. Gelman, & J.P. Byrnes (Eds.). *Perspectives on language and thought: Interrelations in development* (146-196). New York: Cambridge University Press.
- Gelman, S. A., & Markman, E. (1986). Categories and induction in young children. *Cognition*, *23*, 183-209.
- Napolitano, A. C., & Sloutsky, V. M. (2004). Is a Picture Worth a Thousand Words? The Flexible Nature of Modality Dominance in Young Children. *Child Development*, *75*, 1850-1870.
- Robinson, C. W., & Sloutsky, V. M. (2004). Auditory dominance and its change in the course of development. *Child Development*, *75*, 1387-1401.
- Robinson, C. W., & Sloutsky, V. M. (in press-a). Visual processing speed: Effects of auditory input on visual processing. *Developmental Science*.

- Robinson, C. W., & Sloutsky, V. M. (in press-b). Linguistic labels and categorization in infancy: Do labels facilitate or hinder?. *Infancy*.
- Sloutsky, V. M., & Fisher, A. V. (2004). Induction and categorization in young children: A similarity-based model. *Journal of Experimental Psychology: General*, *133*, 166-188.
- Sloutsky, V. M., Lo, Y., & Fisher, A. V. (2001). How much does a shared name make things similar? Linguistic labels, similarity, and the development of inductive inference. *Child Development*, *72*, 1695-1709.
- Sloutsky, V. M., & Napolitano, A. (2003). Is a picture worth a thousand words? Preference for auditory modality in young children. *Child Development*, *74*, 822-833.
- Sloutsky, V. M., & Robinson, C. W. (in press). The role of words and sounds in visual processing: From overshadowing to attentional tuning. *Cognitive Science*.
- Welder, A. N., & Graham, S. A. (2001). The influences of shape similarity and shared labels on infants' inductive inferences about nonobvious object properties. *Child Development*, *72*, 1653-1673.
- Xu, F. (2002). The role of language in acquiring object kind concepts in infancy. *Cognition*, *85*, 223-250.