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Auditory Dominance and Its Change in the Course of Development

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Young children often have a preference for auditory input, with auditory input often overshadowing visual input. The current research investigated the developmental trajectory and factors underlying these effects with 137 infants, 132 four-year-olds, and 89 adults. Auditory preference reverses with age: Infants demonstrated an auditory preference, 4-year-olds switched between auditory and visual preference, and adults demonstrated a visual preference. Furthermore, younger participants were likely to process stimuli only in the preferred modality, thus exhibiting modality dominance, whereas adults processed stimuli in both modalities. Finally, younger participants ably processed stimuli presented to the nonpreferred modality when presented in isolation, indicating that auditory and visual stimuli may be competing for attention early in development. Underlying factors and broader implications of these findings are discussed.

Words play a large role in shaping the way children and infants view the world. For example, when the same word (e.g., *dog*) refers to two appreciably different objects, young children tend to perceive these objects as more similar than when no words are introduced (Sloutsky & Fisher, 2004; Sloutsky & Lo, 1999). Similarly, when the same word refers to two entities, infants and young children tend to categorize these entities together (e.g., Balaban & Waxman, 1997; Markman & Hutchinson, 1984; Sloutsky & Fisher, 2004) and to generalize properties from one entity to the other (e.g., Gelman & Markman, 1986; Sloutsky, Lo, & Fisher, 2001; Welder & Graham, 2001).

It has been argued that the special importance of auditorily presented linguistic labels may stem in part from auditory processing dominating visual processing early in development with even nonspeech sounds often attracting more attention than corresponding visual input (Sloutsky & Napolitano, 2003). In particular, Sloutsky and Napolitano (2003) demonstrated that when 4-year-olds and adults were presented with visual stimuli accompanied by nonspeech sounds, young children, but not adults, were more likely to process auditory stimuli, even when auditory and visual stimuli were equated for discriminability and salience.

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These findings stem from two tasks. In one task, 4-year-olds and adults were trained that a particular combination of auditory and visual stimuli (AUD_1-VIS_1) indicated the location of a prize. When training was completed, the trained set was broken and the trained auditory component was paired with a new visual component (AUD_1VIS_{new}), and the trained visual component was paired with a new auditory component ($AUD_{new}VIS_1$). When asked which set indicated the location of the prize, 4-year-olds selected AUD_1VIS_{new}, whereas adults selected $AUD_{new}VIS_1$. Therefore, 4-year-olds relied mainly on auditory predictors and adults relied mainly on visual predictors. However, although revealing a differential modality preference in children and adults, this task did not reveal whether participants encoded the nonpreferred modality.

To examine this issue, Sloutsky and Napolitano (2003) used an immediate recognition task, in which participants were presented with a compound target stimulus AUD_TVIS_T. Control studies indicated that participants ably encoded both visual and auditory components of the compound target when these components were presented in isolation. The compound target was followed by a recognition item of one of four types: (a) AUD_TVIS_T, which had the same auditory and visual components as the target (old target); (b) $AUD_{new}VIS_T$, which had the same visual component as the target but changed auditory component; (c) AUD_TVIS_{new}, which had the same auditory component as the target but changed visual component; and (d) $AUD_{new}VIS_{new}$, which differed from the target in both auditory and visual components. Participants had to determine whether a recognition item was the same as the target. If

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participants encoded both auditory and visual components, they should accurately recognize old targets and reject the other items, which was the pattern exhibited by adults. However, if participants failed to encode auditory stimuli, they should fail to reject $AUD_{new}VIS_T$ while being accurate with all other items. Finally, if they failed to encode visual stimuli, they should fail to reject AUD_TVIS_{new} while being accurate with all other items. The latter pattern was found in 4-year-olds, suggesting that they failed to encode visual information, thus exhibiting auditory dominance. Furthermore, these results in conjunction with those of the control experiments indicate that auditory input overshadowed (i.e., prevented processing of) visual input: Four-year-olds failed to encode visual stimuli in the presence of auditory stimuli, whereas they had no difficulty encoding these visual stimuli in isolation.

The results from Sloutsky and Napolitano (2003) expanded earlier findings of auditory dominance in infants (Lewkowicz, 1988a, 1988b). In Lewkowicz's (1988a, 1988b) experiments, 6- and 10-month-olds were habituated to a compound stimulus consisting of a flashing checkerboard and a pulsing sound. At test, researchers manipulated temporal characteristics (i.e., rate or duration) of either visual or auditory stimuli. It was found that 6-month-olds consistently discriminated changes in the temporal characteristics of the auditory component, whereas they failed to discriminate changes in the temporal characteristics of the visual component. At the same time, 10-month-olds consistently discriminated changes in the auditory stimuli, whereas they discriminated changes in the visual component only under some conditions. That is, infants discriminated changes in the visual component when the visual and the auditory components were temporally distinct; however, they failed to discriminate changes in the visual component when the auditory and visual components were temporally identical.

However, studies reported by Lewkowicz, (1988a, 1988b) focused on infants and did not include young children, whereas studies reported by Sloutsky and Napolitano (2003) included only young children and not infants. At the same time, stimuli and procedures used by Lewkowicz with infants differed markedly from those used by Sloutsky and Napolitano with young children. Therefore, although these results present converging evidence that auditory dominance extends from infancy to early childhood, and auditory dominance may decrease in the course of development, this evidence is indirect because of important differences between tasks and stimuli used by these researchers. One of the goals of this research was to examine directly how auditory dominance changes in the course of development by using identical stimuli and similar tasks across different age groups, including infants, young children, and adults.

Another goal was to understand factors underlying auditory dominance early in development. We consider attentional and maturational factors as two (not necessarily mutually exclusive) theoretical possibilities. First, auditory dominance may stem from attentional factors. For example, certain properties of stimuli may automatically engage attention: Most (if not all) auditory stimuli are transient events that tend to disappear quickly, whereas visual stimuli (e.g., objects or visual scenes) are often present for much longer durations. Given attentional resources and processing speed limitations early in development (e.g., Kail & Salthouse, 1994), it seems adaptive to allocate automatically these limited resources to transient, dynamic stimuli before allocating them to more stable stimuli. At the same time, an increase in attentional resources or processing speed may result in adults' ability to process both auditory and visual components under the same conditions where younger children process only auditory components.

If this is the case, auditory dominance may be a special instance of automatic attending to transient, dynamic information. However, other kinds of information also automatically engage attention. In particular, there is evidence that familiar stimuli are more likely than novel stimuli to engage attention (Christie & Klein, 1995; Napolitano & Sloutsky, 2003). These findings are consistent with evidence that stimulus familiarity is established early in the course of processing, and familiar stimuli elicit a different neuronal response in the primate brain from novel stimuli (Hölscher, Rolls, & Xiang, 2003; Xiang & Brown, 1998). Therefore, if auditory dominance stems from attentional factors, under stimuli conditions that tend to engage attention automatically (e.g., highly familiar visual stimuli) auditory dominance could be reversed. Although attentional shifts between auditory and visual stimuli have never been examined directly, it is well known that young children may automatically shift attention between different properties of visual stimuli (Jones & Smith, 2002; Jones, Smith, & Landau, 1991; Smith, Jones, & Landau, 1996).

It is also possible that auditory dominance reflects maturational asynchronies: The auditory system starts functioning during the last trimester of gestation (Birnholz & Benaceraff, 1983; see also Jusczyk, 1998, for a review), whereas the visual system does not start functioning until after birth. As a result, the visual system may still lag behind the auditory system in infancy and early childhood. If auditory dominance stems only from maturational factors, reversal of auditory dominance early in development should be difficult, if not impossible, as long as stimuli have comparable discriminability and salience.

In short, previous research leaves several important questions unanswered. First, the developmental course of auditory dominance remains unclear: Stimuli and tasks used with infants and young children in previous research were too dissimilar to conclude that the auditory dominance found by Lewkowicz (1988a, 1988b) and Sloutsky and Napolitano (2003) are variants of the same phenomenon. Second, factors underlying auditory dominance remain unknown. Finally, it remains unclear whether infants and young children exhibit auditory dominance under most conditions or whether they readily switch between auditory and visual dominance.

The goals of the current research were (a) to present a more complete developmental picture of auditory dominance and its change in the course of development, and (b) to examine factors underlying auditory dominance early in development. To achieve these goals, we designed experiments in which infants, young children, and adults were presented with the same auditory–visual compound stimuli. Young children and adults represented the same age groups as those used in Sloutsky and Napolitano's (2003) studies (i.e., 4-year-olds and college undergraduates). Infant participants were selected from three age groups: Although 8-month-olds were compatible with participants of Lewkowicz's (1988a, 1988b) studies, 12- and 16-month-olds were included as a bridge between infancy and early childhood.

Experiment 1A

The primary goal of Experiment 1A was to replicate Sloutsky and Napolitano's (2003) finding using similar stimuli with a new procedure. Such a replication was necessary to ensure that the auditory preference found by Sloutsky and Napolitano is not a task-specific phenomenon. Recall that in Sloutsky and Napolitano's task, participants were presented with two different auditory–visual compound stimuli (AUD_1VIS_1 and AUD_2VIS_2) and were taught that one was a predictor of a target event, whereas the other was a distracter. In the current version of the task, participants were taught that each compound predicted a different target event. After training, the auditory and visual components switched (AUD_1VIS_2 and AUD_2VIS_1) so that the auditory input predicted one target event and the visual input predicted a different target event. If participants rely mostly on visual information in the course of learning, they should primarily make visual-based predictions, whereas the reverse should be the case if they rely mostly on auditory information. Based on Sloutsky and Napolitano's findings, we hypothesized that children would exhibit an auditory preference and adults would exhibit a visual preference.

Method

Participants. Seventeen 4-year-olds (9 boys and 8 girls, $M = 4.60$ years, $SD = 0.37$ years) and 13 adults (6 men and 7 women, $M = 19.03$ years, $SD = 1.04$ years) participated in this experiment. Young children were recruited through local day care centers located in middle- and upper-middle-class suburbs of Columbus, Ohio, and adults were undergraduate students at The Ohio State University, participating for course credit. The majority of children and adults were Caucasian. An additional 8 children were tested but did not reach the training criterion described later; therefore, their data were excluded from further analyses.

Materials. Stimuli consisted of two auditory–visual training compounds (AUD_1VIS_1 and AUD_2VIS_2), two auditory–visual test compounds where the auditory and visual information switched (AUD_1VIS_2 and AUD_2VIS_1), two black panels, and two cartoon-like animals with accompanying melody. The auditory components (AUD_1 and AUD_2) consisted of a laser sound and a static sound (white noise). In this experiment and all subsequent experiments, auditory stimuli were presented at 65 to 68 dB. The visual components consisted of 2 three-shape patterns: a circle, a pentagon, and a triangle; and a cross, an octagon, and a square. All of the geometric shapes were green and were presented in a horizontal line. Each geometric shape was 2.54 cm × 2.54 cm, and the total three-shape pattern was approximately 10 cm × 5 cm. The auditory and visual components were perfectly correlated so that the onset and offset of each component occurred at the same time. The compound stimuli appeared for 1000 ms, disappeared for 500 ms, and reappeared for an additional 1000 ms. The two black panels were approximately 5 cm × 8 cm rectangles and were presented at approximately the same height as the compound stimulus. One panel appeared to the left of the compound stimulus and the other panel appeared to the right of the compound stimulus (see Figure 1). The panels were used to mark the location where the

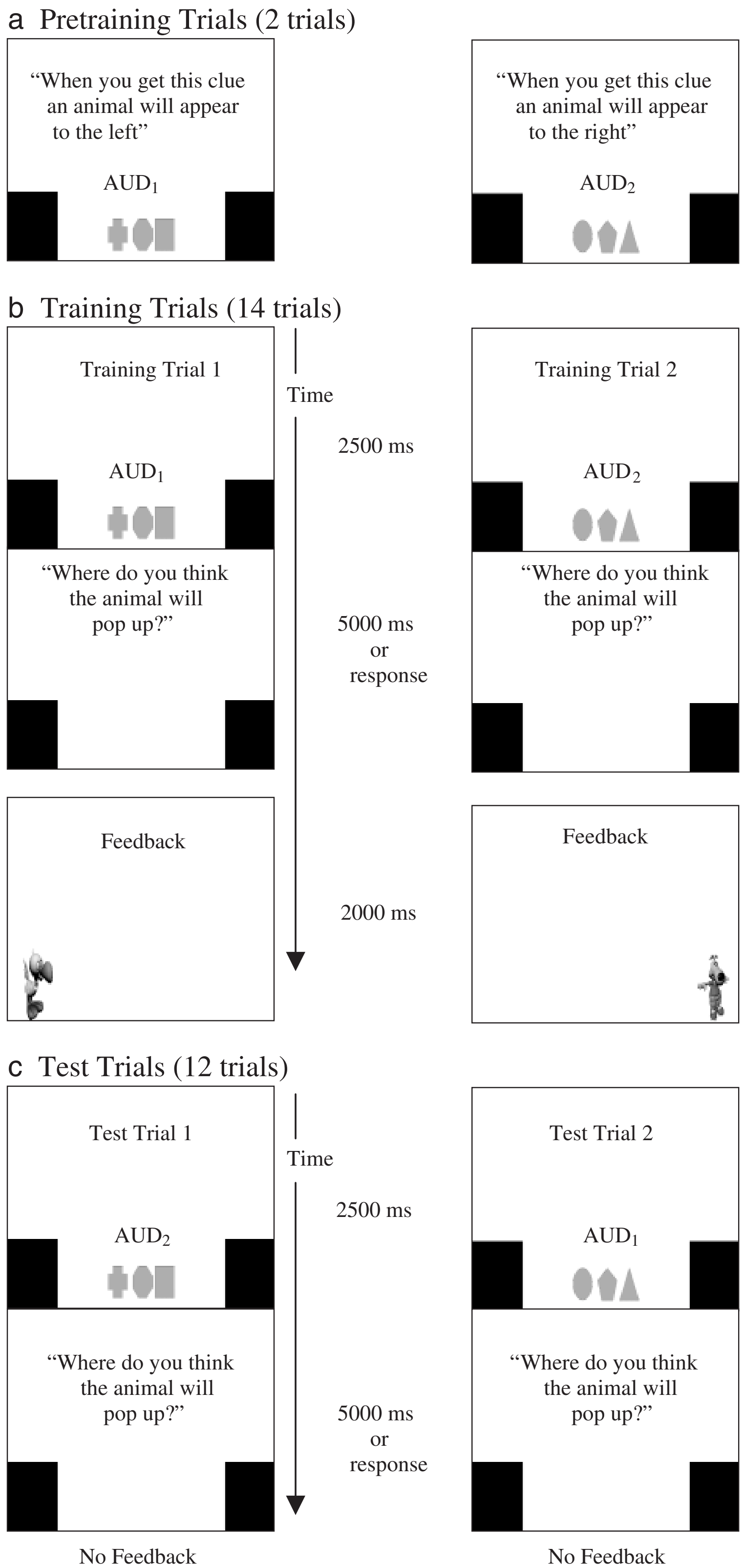

Figure 1. Stimuli and procedure for Experiments 1A and 1B. Items in quotation marks were spoken by experimenter.

animals would appear (see the Procedure section for a more detailed description of the procedure). After the participant made a prediction, a colorful cartoon-like dog or cartoon-like bird, each measuring approximately 4 cm × 7 cm, replaced one of the black panels. Both animals, which were animated using Macromedia Flash MX, appeared for 2000 ms. The animation consisted of the animal moving up for 1000 ms and moving down for 1000 ms, resembling a jumping motion. Each target animal was accompanied by a short 2000-ms melody. The left–right location of the dog and bird, and auditory–visual combinations were counterbalanced between participants.

Procedure. The procedure consisted of three phases: a pretraining phase, a training phase, and a test phase (see Figure 1 for details). During pretraining, children were presented with two trials where they were explicitly told that AUD_1VIS_1 and AUD_2VIS_2 could be used to predict where an animal would appear. Children were not told which aspect of the compound was the predictor, and the experimenter did not direct children's attention to the auditory or visual components. Thus, children could rely on auditory, visual, or both auditory and visual information when making predictions.

During training, children were presented with 14 trials where they were taught to use the auditory–visual combinations to predict where the animal would appear. After making a prediction by pointing to one of the two panels, they received feedback (i.e., a dog or bird replaced one of the panels). Children also received additional feedback: For correct predictions, the experimenter said, "Good job! You got it right. Let's try another one," and for incorrect predictions, the experimenter said, "Oops, that wasn't the right answer. Let's try another one."

Test trials were similar to training trials with two exceptions. First, auditory and visual components of the two predictors switched (AUD_1VIS_2 and AUD_2VIS_1). Second, no feedback was provided at test. If participants primarily attend to visual information during training, they should rely on VIS_1 and VIS_2. Alternatively, if they primarily attend to auditory information during training, they should rely on AUD_1 and AUD_2. There were 12 test trials, and children responded by pointing to one of the two panels.

Before training, 4-year-olds heard: "I have a fun new game where you have to guess where the animal will pop-up. One animal will pop-up here (pointing to the left panel), and another will pop-up here (pointing to the right panel). I will first give you a clue that will help you to know where the animal will pop-up. Try to use this clue to figure out if the animal will pop-up over here (pointing to left panel) or over here (pointing to right panel)." At this point, the experimenter presented AUD_1VIS_1 to the child. "When you get this clue an animal will pop-up here (pointing to left or right panel). When you get this clue (the experimenter presented AUD_2VIS_2 at this point), an animal will pop up here. Here is your first clue." After the stimulus blinked twice, the experimenter asked, "Where do you think the animal will pop-up?" If the child did not make a response, the experimenter asked, "Do you think the animal will pop up over here (pointing to left) or over here (pointing to right)? If you want to, it's OK to guess."

Children were tested in a quiet room in local day care centers using a Dell Inspiron laptop computer. Presentation software was used for stimulus presentation and to record children's responses, as indicated by their pointing. The experimenter determined the onset of each trial by pressing the space bar. The order of stimulus presentation in both training and test phases was randomized for each participant. Children received a small prize for their participation.

With a few exceptions the adult procedure was essentially the same as the procedure used with children. First, adults recorded their own predictions by pressing 1 if they thought the animal would appear to the left and 0 if they thought the animal would appear to the right. Second, adults were not provided with verbal feedback after each trial, using instead the location of the appeared animal as feedback. Third, intertrial intervals lasted 1000 ms for adults, compared with experimenter controlled for children. Finally, adults received only 12 training trials, and they were not presented with the game scenario or pretraining trials.

Results and Discussion

Training criterion. Only participants who correctly predicted where the animal appeared on four of the last six training trials or correctly predicted where the animal appeared on the last three training trials were included in the following analyses. Eight children did not reach this criterion.

Analysis of test trials. Analyses of test trials focused on percentage of responses indicating auditory- and visual-based predictions. Overall, children primarily made auditory-based predictions ($M = 68\%$), and adults primarily made visual-based predictions ($M = 78\%$), both above chance (one-sample $ts > 3.4$, $ps < .005$). A one-way analysis of variance (ANOVA) with age as a between-subject variable confirmed that the proportion of auditory-based predictions significantly differed between the two age groups, $F(1, 28) = 25.89$, $p < .001$.

Additional analyses were performed to determine individual patterns of responses. Participants who exhibited an auditory preference on at least 9 of 12 trials were identified as auditory responders (above chance, binomial test, $p = .05$), participants who exhibited a visual preference on at least 9 of 12 trials were identified as visual responders, and the rest were identified as mixed responders. Percentages of responder types are presented in Table 1, Panel A. A chi-square analysis indicated that the numbers of auditory, visual, and mixed responders differed between children and adults, $\chi^2(2, N = 30) = 17.22$, $p < .001$. In particular, (a) children were more likely to be auditory than visual responders, whereas the reverse was the case for adults (all standardized residuals > 1.96, all ps < .05), and (b) for children there were comparable percentages of auditory and mixed responders.

Control study. It could be argued, however, that auditory preference in 4-year-olds could stem from their inability to discriminate visual stimuli, whereas visual preference in adults could stem from their inability to discriminate auditory stimuli. Therefore, a control study was conducted to ascertain that children and adults could discriminate the three-shape patterns and sounds, respectively. Thirteen 4-year-olds (9 boys and 4 girls, $M = 4.70$ years, $SD = 0.52$) and 13 adults (6 men and 7 women, $M = 20.11$ years, $SD = 2.45$) participated in this study. Five children were tested but were not included in the following analysis because they failed to reach training criterion. The procedure was similar to Experiment 1A except that children and adults were presented with only one modality during training and test. That is, 4-year-olds were presented with only the three-shape patterns and adults were presented with only auditory stimuli. Both the 4-year-olds (72% correct responses at test) and the adults (90% correct responses at test) had no difficulty using the three-shape patterns (4-year-olds) or sounds (adults) when presented in isolation (both ts > 2.5, ps < .05), which suggests that modality preference could not be explained by an inability to discriminate either the auditory or visual input.

Overall, results of Experiment 1A replicate Sloutsky and Napolitano's (2003) findings indicating that although young children exhibited auditory preference, adults exhibited visual preference. The reported experiment used the same visual stimuli as those used by Sloutsky and Napolitano but used different auditory stimuli. Therefore, the reported results suggest that auditory preference is not specific to auditory stimuli used by Sloutsky and Napolitano.

The goal of Experiment 1B was to examine the possibility that auditory preference found in Experiment 1A is driven by attentional factors. Visual stimuli used in Experiment 1A were multiobject patterns that do not have an identifiable label. A separate control experiment revealed that even adults ($n = 10$) did not consistently label these

Table 1
Percentages of Responder Types

A. Percentages of responder types in Experiments 1A and 1B

Responder type	4-year-olds: Three shapes Experiment 1A	4-year-olds: Single shape Experiment 1B	Adults: Three shapes Experiment 1A	Adults: Single shape Experiment 1B
Auditory	47.06	5.88	7.69	16.67
Visual	0.00	41.17	69.23	83.33
Mixed	52.94	52.94	23.08	0.00

B. Percentages of responder types in Experiment 3

Responder type	4-year-olds: Three shapes	4-year-olds: Single shape
Auditory	27.78	28.57
Visual	44.44	66.67
Mixed	27.78	4.76

patterns as a unit: The three-shape patterns were reliably labeled only 20% of the time; however, even these labels were generic rather than pattern specific (e.g., shapes, signs). Thus, even if each shape was familiar, the patterns were not processed as easy-to-label familiar units. At the same time, it is possible that familiar and easy-to-label visual stimuli would elicit visual preference by pulling children's attention away from auditory components. Alternatively, it is possible that the auditory preference would persist under different visual stimuli conditions. Experiment 1B investigated this issue by pairing single objects that were familiar and easy to label with the same auditory stimuli used in Experiment 1A.

Experiment 1B

Method

Participants. Seventeen 4-year-olds (8 boys and 9 girls, $M = 4.46$ years, $SD = 0.49$ years) and 12 adults (7 men and 5 women, $M = 19.46$ years, $SD = 0.42$ years) participated in this experiment. Recruitment procedures and demographic characteristics of participants were the same as Experiment 1A. Six children were excluded because they did not reach the training criterion.

Materials and procedure. With one exception, the materials and procedure were the same to Experiment 1A. The three-shape patterns that were used in Experiment 1A were replaced with a single, geometric shape, either a red triangle or a green cross. Each geometric shape was 2.54 cm $\times$ 2.54 cm. Familiarity and labelablity were established in a separate calibration experiment, in which 12 young children and 10 adults (none of whom participated in the current experiment) were asked to label each visual stimulus. The visual stimuli used in the present experiment were consistently labeled 79% of the time by 4-year-olds and 95% of the time by adults. Thus, the single shapes were easy to label and highly familiar for both age groups.

Results and Discussion

The results of the current experiment differ considerably from those of Experiment 1A (see Figure 2 for the proportion of auditory-based inferences across the two experiments): In the current experiment, both young children and adults exhibited visual preference (Ms = 70% and 78%, respectively, both above chance, one-sample ts > 3, ps < .001). A one-way ANOVA with age as a between-subject variable revealed that the proportion of auditory-based inferences did not differ between the two age groups ($F < 1$). Given that children primarily made auditory-based predictions in Experiment 1A and adults had no difficulty using the sounds in isolation to make predictions (control study from Experiment 1A), it is unlikely that visual preference resulted from an inability to discriminate the auditory stimuli.

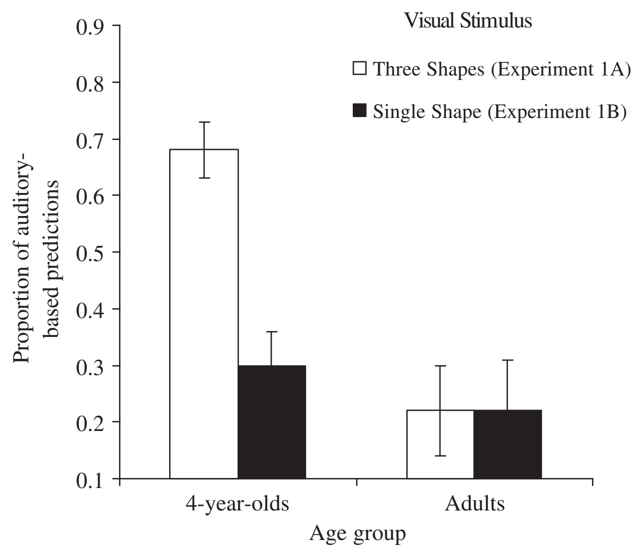

Figure 2. Proportions of auditory-based responses by age and visual stimulus conditions in Experiments 1A and 1B. Error bars represent standard errors of the mean.

Additional analyses were performed to determine individual patterns of responses. Using the same criterion as in Experiment 1A, participants were identified as an auditory, visual, or mixed responder. The percentages of responder types in Experiment 1B were paired with the percentages reported from Experiment 1A to determine whether a change in the visual stimulus affected modality preference (see Table 1, Panel A). As can be seen in Table 1, children presented with three shapes during training (Experiment 1A) were more likely to make auditory-based predictions than visual-based predictions; whereas children presented with single shapes (Experiment 1B) were more likely to make visual-based predictions than auditory-based predictions, $\chi^2(2, N = 34) = 12.44$, $p < .005$, standardized residuals for all differences > 2, ps < .05. In contrast, changing the visual stimulus had no significant effect on adults' modality preference, $\chi^2(2, N = 25) = 3.35$, $p = .19$. Thus, familiarity of the visual stimulus affected modality preference of young children.

Overall, the results of Experiments 1A and 1B indicated that across both stimulus conditions adults tended to rely on visual input, whereas 4-year-olds shifted their attention across different stimulus conditions. However, although elucidating modality preference, these results leave unanswered an important question: Do participants encode stimuli presented in the nonpreferred modality? Failure to encode the nonpreferred modality would point to modality dominance. To examine this issue, we conducted Experiment 1C, in which young children and adults were presented with the same task as in Experiments 1A and 1B, except that the preferred modality was removed at test. If participants encode the nonpreferred modality during training, they should exhibit above-chance accuracy when the preferred modality is removed at test; otherwise, they should exhibit chance responding.

Experiment 1C

Method

Participants. Thirty-four 4-year-olds (16 boys and 18 girls, $M = 4.62$ years, $SD = 0.35$ years) and 31 adults (18 men and 13 women, $M = 19.53$ years, $SD = 1.85$ years) participated in this experiment. Seventeen children and 19 adults were trained on the three-shape pattern/sounds, and 17 children and 12 adults were trained on the single shapes. Recruitment procedures and demographic characteristics of participants were identical to previous experiments. Sixteen children were excluded because they did not reach the training criterion.

Design and procedure. The stimuli and procedure were similar to Experiment 1A and 1B. However, in Experiment 1C the preferred modality was removed at test (see Table 2 for the structure of this experiment).

Results and Discussion

Each child and adult was categorized as either an above-chance or a chance/below-chance responder. Participants who made at least 9 of 12 correct responses at test were identified as above-chance responders (above chance, binomial test, $p = .05$). Two chi-square analyses were conducted comparing children with adults to determine whether children were more likely than adults to respond at or below chance across stimulus conditions. As can be seen in Table 2, children who were trained on the three shapes/sounds (control for Experiment 1A) were more likely to respond at or below chance when the preferred modality was removed, whereas adults were more likely to respond above chance, $\chi^2(1, N = 36) = 4.10$, $p < .05$. In addition, children who were trained on the single shape/sounds (control for Experiment 1B) were more likely to respond at or below chance, whereas adults were more likely to respond above chance, $\chi^2(1, N = 29) = 13.08$, $p < .001$.

Thus, Experiment 1C suggests that, unlike adults, young children are unlikely to encode the nonpreferred modality. Therefore, young children, but not adults, exhibit modality dominance by ably encoding the preferred modality and failing to encode the nonpreferred modality. These findings are remarkable given that the same auditory stimuli are ably

Table 2
Overall Structure and Results of Experiment 1C

				Results: Percentage of responder types	
Age group	Training pattern	Test pattern	Comments	Above chance accuracy at test	At and below chance accuracy at test
4-year-olds	3-shape/sound	3-shape only	Auditory component was removed at test because 4-year-olds relied on it in Experiment 1A	29.41	70.59*
Adults	3-shape/sound	Sound only	Visual component was removed at test because adults relied on it in Experiment 1A	63.16*	36.84
4-year-olds	Single shape/sound	Sound only	Visual component was removed at test because 4-year-olds relied on it in Experiment 1B	23.53	76.47*
Adults	Single shape/sound	Sound only	Visual component was removed at test because adults relied on it in Experiment 1B	91.67*	8.33

*$p < 0.05$

encoded in the three-shape condition and are not encoded in the single-shape condition. Furthermore, these findings, in conjunction with the control experiment reported in Experiment 1A, suggest that for young children the preferred modality overshadows the nonpreferred modality.

Overall, the results of Experiment 1 exhibit a partial development trajectory. First, 4-year-olds shifted between auditory and visual preference, whereas adults exhibited visual preference. Second, 4-year-olds exhibited flexible modality dominance (i.e., they processed either visual or auditory stimuli), whereas adults processed both auditory and visual stimuli. Finally, control studies eliminated the possibility that modality preference and modality dominance could stem from an inability to process stimuli in the nonpreferred modality, thus indicating that 4-year-olds exhibited overshadowing.

However, to have a fuller developmental picture, we deemed it necessary to conduct another study where participants younger than 4 years of age would be presented with the same stimuli. To achieve this goal, we conducted Experiment 2 with infants. As noted earlier, infant participants were selected from three age groups: 8-month-olds (compatible with participants of Lewkowicz's, 1988a, 1988b, studies) and 12- and 16-month-olds, who represented a bridge between infancy and early childhood.

Experiment 2

The experiment used a variant of the multimodal component variation task (see Lewkowicz, 1988a, 1988b). Infants were familiarized with a compound stimulus. At test, either the auditory, visual, or both auditory and visual components changed. If infants attend to the auditory input during familiarization, looking should increase when the auditory input changes. If infants attend to the visual input during familiarization, looking should increase when the visual input changes. Finally, if infants attend to both auditory and visual input during familiarization, looking should increase when both auditory and visual components change.

Method

Participants. Twenty-six 8-month-olds (13 boys and 13 girls, $M = 253$ days, range = 238 to 273 days), forty 12-month-olds (19 boys and 21 girls, $M = 372$ days, range = 360 to 386 days), and twenty-six 16-month-olds (8 boys and 18 girls, $M = 493$ days, range = 474 to 508 days) participated in this experiment. Fifty-one infants were familiarized to a single shape and 41 infants were familiarized to a three-shape pattern. Parents' names were collected from local birth announcements, and contact information was obtained through local directories. All children were full-term (i.e., >2500 g birth weight) with no auditory or visual deficits, as reported by parents. A majority of infants were Caucasian. Data provided by 6 children were not included because of fussiness.

Apparatus. Infants were seated on parents' laps approximately 100 cm away from a 152 cm $\times$ 127 cm projection screen, located approximately 5 cm above the infant's eye level. A Sony DCR-TRV40 camcorder was used to capture each infant's fixations and was projected to one of two Dell flat panel monitors in the observation room. A NEC GT2150 LCD projector was mounted on the ceiling approximately 30 cm behind the infant (130 cm away from the projection screen). Two Boston Acoustics 380 speakers were 76 cm apart from each other and mounted in the wall. The speakers and camcorder were located directly below the projection screen and concealed by black felt. Two small lights were located behind the infant to ensure that the room was dimly lit throughout the entire procedure. In the observation room, a Dell Dimension 8200 computer, with Presentation software, was used to present stimuli to the infants and to record the onset and offset of infant's visual fixations. Fixations were recorded online by pressing a button on an Excalibur 10-button gamepad when infants were looking at the stimulus and releasing the button when infants looked away from the stimulus. A second Sony DCR-PC120 camcorder was used to record the video stream of the infant from the monitor indicated earlier, as well as to record the image of the stimulus presentation on a second Dell flat panel monitor. This split screen recording was used to code randomly 25% of the infants offline. Offline coders were blind to the auditory and visual information presented to infants. No differences were found between looking times associated with children who were coded online and offline.

Stimuli. Each infant was familiarized to an auditory–visual compound stimulus (i.e., $AUD_{old}VIS_{old}$) and tested on four auditory–visual combinations (i.e., $AUD_{new}VIS_{old}$, $AUD_{old}VIS_{new}$, $AUD_{new}VIS_{new}$, and $AUD_{old}VIS_{old}$). $AUD_{old}VIS_{old}$ and $AUD_{new}VIS_{new}$ served as within-subject controls for familiarity or novelty preference. Infants were presented with the same auditory and visual stimuli reported in Experiments 1A and 1B. In contrast to previous experiments, each geometric shape was projected to approximately 7 cm $\times$ 7 cm, and each three-shape pattern was approximately 25 cm $\times$ 7 cm.

Procedure. The procedure consisted of 10 familiarization trials, 2 test trials, 3 retraining trials, and 2 more test trials, respectively. Each familiarization trial consisted of a compound stimulus that appeared for 1000 ms and disappeared for 500 ms. Each stimulus appeared five times during each trial with a trial duration of 7500 ms. After familiarization, infants were presented with 4 different test trials (i.e., $AUD_{new}VIS_{old}$, $AUD_{old}VIS_{new}$, $AUD_{new}VIS_{new}$, and $AUD_{old}VIS_{old}$). Test trials were 7500 ms and were randomized so that each test stimulus had an equally likely chance of appearing as the first test trial, last test trial, and so on. The retraining trials were the same as familiarization trials and were used to remind infants of the familiarization stimulus. Retraining trials always appeared between the first two and last two test trials. Fixations were recorded online by an experimenter for all training, test, and retraining trials.

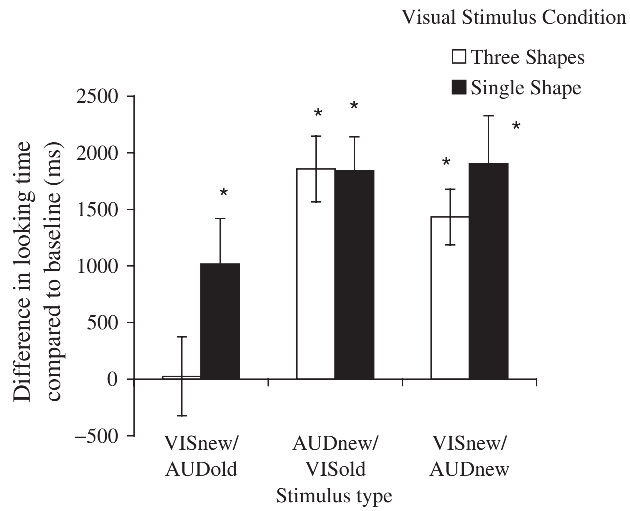

Figure 3. Differences in looking times with the baseline by stimulus condition and test item type in Experiment 2. Error bars represent standard errors of the mean. $^{*}p < .01$.

Results and Discussion

Training trials. Overall, infants' looking to the familiarization stimulus decreased across training. The average accumulated looking during the first three training trials was 6860 ms, and the average accumulated looking during the last three training trials was 4387 ms, $t(91) = 11.84$, $p < .001$. No further analyses were conducted on the training data.

Test trials. If infants encode the auditory component during familiarization, accumulated looking to $AUD_{new}VIS_{old}$ should exceed looking to baseline (i.e., $AUD_{old}VIS_{old}$). If they encode the visual component during familiarization, accumulated looking to $AUD_{old}VIS_{new}$ should exceed baseline, and if infants encode both auditory and visual components during familiarization, accumulated looking to $AUD_{new}VIS_{old}$ and $AUD_{old}VIS_{new}$ should both exceed baseline.

A difference score was calculated by taking the accumulated looking to each test stimulus and subtracting it from baseline (e.g., $DIFF_{AUDnewVISold} = AUD_{new}VIS_{old} - AUD_{old}VIS_{old}$). Thus, positive numbers indicate that looking increased as a function of changing a specific stimulus component, which suggests that infants encoded that modality during training. The difference scores across the conditions are presented in Figure 3. These scores were subjected to a 3 (age: 8, 12, and 16 months) $\times$ 2 (visual stimulus condition: single shape, three shapes) $\times$ 3 (test trial: $AUD_{new}VIS_{old}$, $AUD_{old}VIS_{new}$, $AUD_{new}VIS_{new}$) mixed ANOVA with test trial as a repeated measure. The analysis revealed a significant main effect of test trial, $F(2, 138) = 25.87$, $p < .001$. Infants looked significantly longer when the auditory component or both components changed (i.e., in the $AUD_{new}VIS_{old}$ and $AUD_{new}VIS_{new}$ trials) than when the visual component changed (i.e., in the $AUD_{old}VIS_{new}$ trial), paired-sample ts > 4.7, ps $< .001$, for all of the differences. No other effects or interactions were significant.

More detailed analyses of test trials revealed two important effects. First, collapsed across visual stimulus conditions and age groups, the effect of changing the auditory component had a larger effect than did changing the visual stimulus (i.e., $DIFF_{AUDnewVISold} = 1847$ ms $> DIFF_{AUDoldVISnew} = 566$ ms), $t(91) = 5.22$, $p < .001$, which suggests that infants were primarily attending to the auditory stimulus during familiarization. Given that $DIFF_{AUDnewVISnew} > 0$, it is unlikely that the looking time difference reported earlier stemmed from familiarity preference to the old visual stimulus. Second, changing both the auditory and visual components did not increase infants' accumulated looking over and above changing only the sound (i.e., $DIFF_{AUDnewVISold} = 1847$ ms was not statistically different from $DIFF_{AUDnewVISnew} = 1694$ ms), $p > .4$. The second finding, in combination with the first finding, suggests that infants were primarily using the auditory component when determining whether a stimulus was old or new.

Control study. However, it could be argued that results in the three-shape condition could stem from infants' inability to discriminate among the three-shape patterns. Note that this was not a concern in the single-shape condition because infants increased looking when the visual component changed. To insure that infants could discriminate the three-shape patterns, we conducted a control study with seventeen 8-month-olds (9 boys and 8 girls, $M = 249$ days, range = 238 to 267 days), fourteen 12-month-olds (8 boys and 6 girls, $M = 372$ days, range = 362 to 380 days), and fourteen 16-month-olds (9 boys and 5 girls, $M = 492$ days, range = 484 to 503 days). Data provided by 2 infants were not included because of fussiness.

Infants in the control study were familiarized to one of the three-shape patterns. In contrast to Experiment 2, the auditory component was removed during familiarization and test, and a fixation light was added to ensure infants looked at least once on each trial. At test, infants were presented with a new three-shape pattern followed by the old familiarization stimulus. Overall, infants increased looking to the new visual stimulus ($M = 5883$ ms) compared with the familiarization stimulus ($M = 4489$ ms), $t(44) = 4.68$, $p < .001$. A 3 (age: 8, 12, and 16 months) $\times$ 2 (stimulus: old, new) ANOVA with stimulus as a repeated measure confirmed that infants looked significantly longer to the new stimulus, $F(1, 42) = 22.48$, $p < .001$. No other effects or interactions were significant ($F\text{s} < 1$, $p\text{s} > .4$). Thus, infants at all three age groups had no difficulty discriminating the visual stimuli when the auditory component was removed, suggesting that, similar to young children, auditory input overshadows visual input for infants.

The results of Experiments 1 and 2 point to important developmental changes. First, auditory preference decreases with age: Infants exhibit auditory preference over a wider range of visual stimuli than do young children. Second, under the same stimuli conditions, adults are likely to attend to both modalities (although they have a preference for visual input), whereas infants and young children are more likely to attend to a single modality. Furthermore, infants and young children exhibit overshadowing—they often failed to encode the nonpreferred modality when it was paired with the preferred modality, whereas they amply encoded the nonpreferred modality when it was presented in isolation.

These results are important because the same compound stimuli are processed differently at different points of development, a pattern that is unlikely to stem solely from differences in psychophysical properties of stimuli. Rather, it is likely that the reported developmental pattern stems from (a) automatic attending to stimuli having particular properties, and (b) differential processing speeds at different points of development. We return to this issue in the General Discussion section.

Finally, results of Experiment 1 indicate that modality dominance shifts flexibly in 4-year-olds: Under some stimulus conditions they exhibit auditory dominance, whereas under other conditions they exhibit visual dominance. Therefore, auditory dominance reported by Sloutsky and Napolitano (2003) is a special case of modality dominance. This finding suggests that auditory dominance in 4-year-olds stems from attentional rather than maturational factors, with flexible shifts in modality dominance reflecting automatic pulls on attention. The goal of Experiment 3 was to examine this attentional account by examining whether young children can ignore a preferred modality when instructed to attend to the nonpreferred modality. If participants fail to ignore the preferred modality and to attend selectively to the nonpreferred modality, this finding would further indicate that automatic attention underlies modality dominance in young children.

Experiment 3

Method

Participants. Thirty-nine 4-year-olds (25 boys and 14 girls, $M = 4.55$ years, $SD = 0.33$ years) participated in this experiment, with 18 children being presented with the three-shape patterns/sounds and 21 being presented with the single shape/sounds. Recruitment procedures and demographic characteristics of participants were identical to previous experiments.

Design and procedure. The procedure was similar to Experiments 1A and 1B, except that in the current experiment participants were instructed to attend to the nonpreferred modality. For example, in the three-shape condition (where children exhibited auditory dominance), participants were instructed to look for the clues and were told that they could use the shapes to predict where the animals would appear. In the single-shape condition (where children exhibited visual dominance), participants were instructed to listen for the clues and were told that they could use the sounds to predict where the animals would appear. Nine children were excluded because they did not reach the training criterion.

Results and Discussion

Using the same criterion for establishing modality preference in Experiments 1A and 1B, each child was categorized as an auditory, visual, or mixed responder, and the proportions of responder types are presented in Table 1, Panel B. Numbers of responder types from Experiments 1A and 1B were compared with the distributions from the current experiment. The attentional manipulation had an effect on modality preference in the three-shape condition, $\chi^2(2, N = 35) = 9.82$, $p < .01$, and in the single-shape condition, $\chi^2(2, N = 38) = 12.02$, $p < .005$. More specifically, under the attentional manipulation, the percentage of children using visual input in the three-shape condition increased from 0% to 44.44%, and the percentage of children using auditory input increased from 5.88% to 28.57% in the single-shape condition (standardized residuals for differences > 2, *p*s < .05). Therefore, some 4-year-olds exhibit deliberate selective attention. At the same time, results presented in Table 1, Panel B also indicate that the majority of participants across the conditions failed to ignore the preferred modality, further suggesting that modality dominance stems from automatic attention to the preferred modality.

General Discussion

Research reported here examined processing of auditory and visual information and its changes in the course of development. The unique contribution of this research is that it provides a coherent developmental account by using the same stimuli and similar tasks with infants, young children, and adults.

Modality Preference, Dominance, and Overshadowing

Results of Experiments 1A, 1B, and 2 indicate that modality preference changes throughout development. Given the same set of auditory and visual stimuli, infants exhibit a consistent auditory preference, young children switch between auditory and visual preferences depending on the visual stimulus conditions, and adults exhibit a consistent visual preference.

Results of Experiments 1C and 2 indicate that infants and young children exhibit modality dominance: They are likely to process only one modality, whereas adults are likely to process both modalities. In addition, modality dominance shifts flexibly in 4-year-olds: Under some conditions they exhibit auditory dominance and under other conditions they exhibit visual dominance. Results of Experiment 3 indicate that the majority of 4-year-olds failed to ignore the preferred modality, although some 4-year-olds exhibited the ability to direct their attention deliberately to the nonpreferred modality when instructed to do so.

The results of the reported experiments point to several important regularities. First, these findings indicate that auditory dominance in 4-year-olds reported by Sloutsky and Napolitano (2003) may be a special case of modality dominance, thus supporting the attentional account of auditory dominance. In particular, it seems that modality dominance reflects automatic attention to the preferred modality, and this possibility received additional support in Experiment 3.

At the same time, this research does not eliminate the maturational account of auditory preference: Infants exhibited auditory preference under a wider range of stimulus conditions than did young children. Therefore, additional research is needed to examine further both accounts. For example, evidence that early in development participants process auditory stimuli faster than visual stimuli, and that this difference decreases with age, would support the maturational account. On the other hand, evidence that under some conditions even infants exhibit visual (rather than auditory) dominance would support the attentional account.

Second, modality dominance and overshadowing effects indicate that although one modality received full processing, the other modality received little or no processing. The fact that modality dominance shifts flexibly in young children further suggests that modalities may compete for attention early in development. Note that modality dominance effects reported here are consistent with earlier findings indicating that in reasoning tasks children often focus on a single, most salient predictor, while ignoring the less salient predictor, even when no conflict between predictors is introduced (e.g., Siegler, 1978; see Piaget & Inhelder, 1969, for a review). However, the finding that children fail to encode a nonpreferred modality when it is paired with the preferred modality, but ably encode the nonpreferred modality when it is presented in isolation, is novel.

The reported modality dominance and overshadowing effects also advance our understanding of cross-modal processing: Under some conditions, modalities compete for attention. These findings differ from previous research on cross-modal processing that indicates young infants can ably process bimodal stimuli (e.g., Bahrick, 2002; Lewkowicz, 2000b; Slater, Quinn, Brown, & Hayes, 1999; see also Lewkowicz, 2000a; Lickliter & Bahrick, 2000, for reviews).

However, there are several important differences between previous research and the current experiments. First, much of the empirical work concerning cross-modal processing in the auditory and visual domains included amodal relations, such as temporal synchrony, rhythm, tempo, or rate of presentation, with the same relation expressed in both modalities. Second, many of these studies included either dynamic stimuli (i.e., moving objects) or highly familiar stimuli (i.e., human faces). At the same time, it is known that these kinds of visual stimuli attract attention (Morton & Johnson, 1991; Nelson & Horowitz, 1987). Finally, many studies examining cross-modal processing (e.g., Bahrick, 1992, 1994) presented stimuli for a longer duration than in the reported experiments.

The latter difference is especially important because it can further elucidate factors underlying modality dominance. Although our account remains speculative at this point, it is possible there are temporal differences in processing and habituation rates in the preferred and nonpreferred modalities. In particular, stimuli presented in the modality that automatically engages attention could be processed faster, and this modality could habituate faster than the nonpreferred modality. If this is the case, presentation time may play an important role in modality dominance: Modality dominance would be more likely under shorter presentation times than under substantially longer presentation times.

Processing Across Modalities: What Develops?

The reported results point to several developmental changes taking place between infancy and adulthood. First, the importance of visual information increases in the course of development. Second, older participants are more likely to process information coming from both modalities, whereas modalities are likely to compete for attention early in development. Why do these changes take place in the course of development? Current results, in conjunction with previous research on cross-modal processing, point to an important developmental change capable of accounting for these developments. However, the account presented next remains speculative at this point, and more research is needed to examine the discussed possibilities.

The increasing importance of visual information may stem from the different processing speeds of auditory and visual stimuli at different points of development: Auditory stimuli are processed faster than visual stimuli in adults (Green & von Gierke, 1984), and it is possible that these differences are even more pronounced early in development. If this is the case, then given the same presentation time, younger participants should be more likely to exhibit auditory dominance than should older participants. Alternatively, it is possible that the importance of visual information increases as a result of learning (Posner, Nissen, & Klein, 1976). Posner, Nissen, and Klein (1976) argued that visual stimuli are less likely automatically to engage attention than auditory stimuli, and people have to learn to direct their attention to visual information.

The greater likelihood of modalities competing for attention early in development may stem from an increase in processing speed or attentional resources, or both, in the course of development. If adults have greater resource capacity and they process stimuli faster than 4-year-olds (e.g., Kail & Salthouse, 1994), then given the same amount of processing time, they should be able to process stimuli in both modalities. Furthermore, if processing time is a factor in modality dominance effects, under shortened processing time conditions adults may also exhibit modality dominance. In fact, we have preliminary evidence that when compound stimuli are presented for a shortened time (thus increasing task demands), adults also exhibit modality dominance effects. The fact that under increased task demands adults also exhibit resource switching (i.e., accurate processing of a single modality) rather than resource sharing (i.e., attenuated or full processing of both modalities) suggests that across points of development cross-modal stimuli may be processed in a competitive ''horse-race'' manner.

Note that in this research, visual, and auditory stimuli were presented in a synchronous manner, and it could be argued that modality dominance stems from such synchronous presentation. However, based on preliminary evidence, we believe that modality dominance (and horse-race processing) may reflect more general aspects of processing of multimodal stimuli. In particular, even when the three-shape patterns appeared for 500 ms before unfamiliar sounds, 4-year-olds continued to exhibit auditory dominance. However, more research is needed to examine whether the asynchrony of stimuli onset or offset affects modality dominance.

Broader Implications

Research reported here may have implications for our understanding of the role of auditorily presented linguistic information in a variety of semantic tasks. Recall that although labels affect the way infants and young children perform semantic tasks such as categorization and induction (Gelman & Markman, 1986; Markman & Hutchinson, 1984; Sloutsky et al., 2001), little is understood about the underlying processes. It has been argued that labels are important because they mark semantic categories (Gelman & Coley, 1991) or because they contain prosody of human speech (Balaban & Waxman, 1997).

Although no labels were introduced in the current experiments, results demonstrate that infants are more likely to attend to nonspeech sounds over visual information, and under certain stimulus conditions, 4-year-olds also demonstrate a preference for nonspeech sounds. The pattern of findings reported here and the patterns reported by Sloutsky and Napolitano (2003) are consistent with findings reported by Thompson and Massaro (1994) in a word comprehension task. Thompson and Massaro found that when labels (i.e., auditory cues) and gestures (i.e., visual cues) gave conflicting information about the meaning of the word, (a) children were more likely to rely on the auditory cues and (b) the influence of visual cues increased with age. Taken together, Sloutsky and Napolitano's (2003) and Thompson and Massaro's (1994) findings suggest that both speech and nonspeech sounds may play an important role in processing: Younger participants are more likely to rely on auditory information than visual information. Although the current findings do not eliminate the importance of linguistic factors, these results suggest that for 4-year-olds and infants, effects of labels may stem from a higher likelihood of attending to auditory information.

Conclusions

In sum, when auditory and visual stimuli are presented simultaneously, (a) infants and young children are more likely to exhibit auditory dominance, which decreases with age; (b) infants and young children are likely to process stimuli only in the preferred modality, whereas adults are likely to process both modalities; and (c) early in development, auditory and visual information may compete for attention.

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