

Aging in Multisensory Integration

Undergraduate Research Thesis

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by

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Abstract

Multisensory integration is the simultaneous processing of multiple sensory inputs into a single percept. The current study aims to further the understanding of multisensory integration across development and the individual contributions of visual and auditory information. Integration was observed using the Sound-Induced Flash Illusion task. In the first experiment, young children, young adults, and older adults participated in a variant of the Sound-Induced Flash Illusion, and found that auditory input had a stronger effect on visual processing than vice versa, and this effect increased with age. Experiment 2 used a similar version of the Sound-Induced Flash Illusion task on young adults, but half of the stimuli were lowered to just above threshold to test if weakened auditory and visual stimuli could account for increased multisensory integration in older adults. It was observed that lowering intensity to above threshold resulted in decreased integration effects. The findings of the current study support auditory dominance literature and the modality appropriateness hypothesis and have implications for many tasks that require the processing of multisensory information.

Key Terms: multisensory integration, sound-induced flash illusion, auditory dominance, development, inverse effectiveness

Inverse Effectiveness and Aging in Multisensory Integration

A majority of our daily experiences require people to process multisensory information. As a person walks down the street, for example, they may see a car, hear the engine as it approaches, smell the exhaust and feel the breeze as the car passes by. Thus, it is important to know how our brain processes the signals from different modalities simultaneously. How information from the different sensory modalities is integrated and combined into a unitary percept is considered multisensory integration. For example, when a person sees, hears and smells a car, these things are perceived as one stimulus instead of three independent experiences. Given the evident impact of multisensory integration, it is important to understand the underlying process and how it changes across development.

Support for Multisensory Integration

Many studies have looked at multisensory integration. Shams, Kamitani, and Shimojo (2000) developed a new test of multisensory integration that created the illusion of multiple flashes when shown in conjunction with multiple beeps, also known as the Sound-Induced Flash Illusion (SIFI). In their study, they presented one, two or three flashes, and these flashes were paired with one, two or three beeps which were presented through headphones. Participants were then asked to report how many flashes they saw, regardless of how many beeps they heard. Shams et al. (2000) found that the number of beeps heard influenced the perceived number of flashes when beeps and flashes are simultaneously presented. This shows that the auditory information is being integrated with the visual information.

Another study, using a different procedure and stimuli, tested perception of beeps to see

if they could create a Flash-Induced Sound Illusion (Andersen, 2004). When auditory stimuli were presented at full intensity, there was little evidence that visual input affected beep perception; however, when the auditory stimulus was lowered to near threshold (level of intensity which a stimulus is only perceived about half of the time), a flash-induced sound illusion was observed in the count-beep condition. This finding, in conjunction with Shams et al., may suggest that auditory information has a stronger effect on visual processing than vice versa; however, there were also numerous differences across studies; thus, making it difficult to make strong conclusions.

Theoretical Developments

Why do auditory beeps affect participants' perception of the number of visual flashes? One possible explanation underlying this illusion is auditory dominance (Robinson & Sloutsky, 2010). According to this account, auditory and visual stimuli compete for attentional resources; thus, increased attention to one modality might come with a cost-delayed or attenuated processing in the other modality. Moreover, because auditory stimuli are dynamic and transient, it may be adaptive to first allocate attention to the auditory modality before the information disappears. Most of the supporting research for auditory dominance comes from the developmental literature, where multisensory presentation attenuates visual processing more than auditory processing (Lewkowicz, 1988a; 1988b; Robinson & Sloutsky, 2004; 2010b; Sloutsky & Napolitano, 2003; Sloutsky & Robinson, 2008). Thus, according to the auditory dominance account, the beeps in SIFI may interfere with processing of the visual flashes; whereas, the visual input may have little effect on processing of the beeps (because sounds are processed automatically).

Another possible reason why beeps may affect flash perception is modality appropriateness hypothesis, which states that the modality that is more appropriate for the task is the one that dominates (Welch & Warren, 1980). Welch and Warren (1980) describe that with information processing, vision is dominant in spatial situations and audition is dominant for temporal judgements. When these two modalities are simultaneously presented and the task has a temporal aspect, audition is the dominant modality and can influence vision (Wada, Kitagawa, & Noguchi, 2003). The SIFI task is a temporal task, by nature, which would make the auditory modality the more fitting modality for the task. Thus, both auditory dominance and modality appropriateness predict that auditory input should have a greater effect on visual perception than vice versa.

Predicting that auditory information will have a greater effect on visual processing conflicts with much of the past research with adults that showed visual dominance, where the simultaneous presentation of auditory and visual information seems to inhibit auditory processing (see Sinnott, Spence, & Soto-Faraco, 2007, and Spence, Parise, & Chen, 2012, for reviews). For example, in most of the studies supporting visual dominance, adults were required to press one button when they detected a visual stimulus, a different button when they detected an auditory stimulus, and a third button (or both buttons) when both stimuli were presented at the same time. Participants often made errors on cross-modal trials by only pressing the visual button (Colavita, 1974). Thus, visual dominance tends to occur when adults are required to make speeded, modality-specific responses to auditory and visual stimuli (Colavita, 1974; see Sinnott, Spence, & Soto-Faraco, 2007 for a review). One possible explanation for visual dominance is that adults may have a visual response bias to compensate for the fact that visual input is less alerting than auditory (Posner et al., 1974). It is important to note that the current study testing

the SIFI is different from some of the modality dominance studies because it requires quantity judgements (how many beeps or flashes), rather than requiring speeded, modality-specific responses to auditory and visual input. Thus, if visual dominance is a result of a visual response bias, it shouldn't be seen in this task.

Multisensory Integration and Development

Since the introduction of the SIFI, several studies have examined the development of multisensory integration. Nava and Pavani (2013) used the SIFI task to test multisensory integration in young children and adults. They found that auditory stimuli had a larger effect on multisensory integration, especially for the children's sample (see Robinson & Sloutsky, 2004; Sloutsky & Napotlitano, 2003 for similar developmental shifts using different methodologies).

While Nava and Pavani (2013) examined developmental changes in multisensory integration in kids and adults, other studies have examined effects of aging on multisensory integration. DeLoss, Pierce, and Andersen (2013) demonstrated that multisensory integration is stronger in older adults than in young adults. In the DeLoss et al. (2013) study, the authors examined multisensory integration and unimodal accuracy in older adults compared to younger adults. They presented 1, 2 or 3 flashes and 1, 2 or 3 beeps to participants (only one of the modalities for unimodal blocks), and asked young and older adults to report how many flashes they saw regardless of how many beeps they heard. They quantified multisensory integration by observing the number of errors made in incongruent trials (different numbers of beeps and flashes). Older adults made more errors on incongruent trials than young adults, and the errors were based on auditory information. Additional support for stronger multisensory integration in older adults comes from responses on congruent trials (same number of beeps and flashes), with

older participants benefiting more from congruent multisensory information compared to younger adults (see also Laurienti, Burdette, Maljian, & Wallace, 2006 for a similar finding using a simple detection task).

DeLoss et al. mentioned different possibilities for the age-related differences between young adults and older adults in integration. Initially it was thought that differences in integration may be due to older adults having a more difficult time ignoring irrelevant information (Poliakoff, Ashworth, Lowe, & Spence, 2006). The DeLoss et al. study then tested attention as a possibility for the difference in age with multisensory integration. SIFI did vary under attentional manipulations, but changes in attention could not account for the increased multisensory integration with age (DeLoss et al., 2013). DeLoss et al. also found that older individuals did better with congruent multisensory information than younger individuals, which is in line with past research that reveals that older individuals perform better with redundant multisensory information (Hugenschmidt, Peiffer, McCoy, Hayasaka, & Laurienti, 2009). In another study, Laurienti, Burdette, Maldjian and Wallace (2006), provided further support by presenting bimodal and unimodal information to younger and older adults in a simple detection task, which resulted in greater reaction time gains (difference between bimodal reaction time and fastest unimodal reaction time) for older adults than for young adults in the bimodal trials.

Poorer processing within individual sensory systems (audition or vision) may also account for increased multisensory integration. For example, He, Dubno and Mills (1998) demonstrated the age-related difference to discriminate between high and low frequencies are greater at low frequencies in older adults versus younger adults. He, et al. also found that older adults have a more difficult time distinguishing differences in frequency and intensity as

demonstrated by increased variability compared to young participants. Studies have also shown a decline in vision in aging adults. Some examples include a decrease in visual acuity (Weale, 1975), depth perception (Norman, Clayton, Norman, & Crabtree, 2008) and discriminating luminance of the stimuli (Crassini, Brown, & Bowman, 1988).

The current study is built on the hypothesis offered by DeLoss et al. (2013), stating that the stronger multisensory integration may be a compensating response to weakened unimodal senses. This idea is related to inverse effectiveness, which claims that responses to a stimulus near threshold is stronger than a response to a stimulus presented at a higher intensity level (Meredith & Stein, 1983). If older adults have stronger multisensory integration as a result of weaker stimulus perception, it may support the idea of Inverse Effectiveness (Meredith & Stein, 1983).

Overview of Current Study

The current study used a modified SIFI task to test both auditory and visual processing and expands previous research in two ways. First, the study expands SIFI research by examining the relative contributions of the auditory and visual modalities in multisensory integration, as opposed to only examining the effects of auditory input on multisensory integration or visual input on multisensory integration. Based on auditory dominance (Robinson & Sloutsky, 2010) and modality appropriateness hypothesis (Welch & Warren, 1980), it is expected that auditory input should have a stronger effect on multisensory integration. Additionally, the study aims to measure the developmental trajectory of multisensory integration across young children, young adults, and older adults in Experiment 1. Previous research only examined developmental changes in children and young adults (Nava & Pavani, 2013) or in young adults and older adults

(DeLoss et al., 2013). Based on DeLoss et al. (2013), it is expected that the older adults will show stronger integration than the young adults in Experiment 1. The older adults are also expected to be less accurate in the unimodal conditions, due to poor unimodal processing. Based on Nava and Pavani (2013), children are expected to have stronger multisensory integration than young adults. No past study has used the same stimuli and procedure across the lifespan, which makes the current study novel.

In the second experiment, we manipulated the intensity of flashes and beeps to near threshold as to possibly facilitate increased multisensory integration in younger adults as seen in older adults in the DeLoss et al. study (2013). As in Experiment 1, participants were asked to report either the flashes seen or the beeps heard during each trial and report the results. If inverse effectiveness is the cause of differing multisensory integration between younger and older adults (stronger multisensory integration because unimodal senses are weakened), then similar results as in the DeLoss et al. paper for older individuals should be observed with our manipulation of the flashes and beeps to close to threshold. If this manipulation proves otherwise, then it is possible that the cause is instead related to other changes, for example, increased connections between sensory cortices across age.

Experiment 1

Method

Participants. Participants for Experiment 1 included 19 children (7 Females, $M= 8.89$ years, $SE = .52$), 24 young adults (16 Females, $M= 18.35$ years, $SE = .19$) and 10 older adults (5 Females, $M= 71.06$ years, $SE = 2.05$). Most of the participants were tested in a quiet room in the

psychology laboratory at The Ohio State University at Newark. Young adults were recruited from the Ohio State University Newark, and received class credit for the Introductory Psychology course in return for their participation. An additional fourteen participants (cumulatively across all three groups) were tested, but not included, due to uncorrected hearing or vision, as reported by parents or self-reported, or accuracies lower than 75% on the catch trials in the crossmodal auditory-response block.

Apparatus. The experiment was conducted on a 22" Dell PXL 2230 MW monitor with 1920x1080 resolution and Dell Optiplex 7040 systems with Intel Core i5 processors. Bose QuietComfort 25 Noise Canceling headphones were used for auditory stimulus presentation. Stimulus timing and presentation and reaction time/accuracy data was collected using Direct RT software. Additionally, five participants were tested in a quiet room on a Dell Latitude E6430 laptop computer.

Stimuli. The stimuli and timing was modeled after the original sound-induced flash illusion study (Shams, Kamitani & Shimojo, 2000). The visual stimulus was a white circle 2° in visual angle in the center of the screen with a black background. Each flash had a 20ms duration with a 50 ms Inter-Stimulus Interval (ISI) between consecutive flashes. The auditory stimulus was a sine wave presented at 3.5 kHz. Each beep lasted for 20ms, and there was a 50ms ISI in between consecutive beeps. In the crossmodal condition, there were two experiments which were counterbalanced across subjects. In one condition the auditory stimulus came first in crossmodal trials, while the visual stimulus came first in the other. Figure 1 shows the timing of an auditory first cross-modal stimulus.

Design. The experiment consisted of four blocks: visual unimodal, auditory unimodal,

visual-response crossmodal, and auditory-response crossmodal, see Table 1 for trial types and frequencies. There were five trials for each stimulus (2 flashes, 3 flashes, 4 flashes) in the unimodal visual condition. There were five trials for each possible stimulus (2 beep, 3 beeps, 4 beeps) in the unimodal auditory condition. There were also five trials of each possible stimulus in the crossmodal conditions (2 flashes/2 beeps, 2 flashes/3 beeps, 2 flashes/4 beeps, etc.). There were 45 trials for auditory-response block, and 45 for visual-response block. Altogether, there were 30 unimodal trials (15 visual and 15 auditory) and 90 cross-modal trials. Of the crossmodal trials, 30 trials were congruent (15 in auditory-response and 15 in visual-response). Congruent trials had the same number of flashes and beeps. The remaining 60 trials were incongruent (different number of flashes and beeps), which will provide conflicting information. Trials were randomized within each block, and the order of the blocks was also randomized. The entire experiment lasted about ten minutes.

Procedure. In the unimodal auditory condition, participants heard 2, 3, or 4 beeps, and they were asked to report how many beeps they heard by pressing 2, 3, or 4 on the keyboard. In the unimodal visual condition, they saw 2, 3, or 4 flashes and were asked to report how many they saw. In the crossmodal auditory-response condition, participants were presented with 2, 3, or 4 flashes and 2, 3, or 4 beeps and they were asked to report only how many beeps they heard. To ensure that they were paying attention to the visual stimuli in the auditory-response condition, a green square replaced the white circle on 9 trials and young adults and older adults were asked to hit the spacebar instead of 2, 3, or 4 when they saw the green stimulus. Participants had to detect 7 out of 9 of these catch trials to be included in the final analysis. In the crossmodal visual-response condition, participants were presented with 2, 3, or 4 beeps and 2, 3, or 4 flashes,

and they were asked to report only how many flashes they saw. In both visual-response and auditory-response crossmodal blocks, some trials had an equal number of flashes and beeps (congruent) and some had an unequal number of flashes and beeps (incongruent).

Each condition had a set of instructions before the trials and a conclusion to let the participant know when that condition was over, and the order of blocks were randomized among the participants. The block did not start until the spacebar is pressed after reading the instructions. Within the block, each trial started as soon as the participant answered to the previous trial. At the end of the experiment, participants were debriefed.

Children participated in the same experiment as described above, with the following exceptions. First, the experimenter started the trial for the young children to make sure that they are paying attention. Thus, there was no need for the green square catch trials because the experimenter made sure the child was looking at the visual stimuli before starting the trial. Also, children said their responses and the experimenter typed their responses into the computer.

Results and Discussion. All of the results in Experiment 1 can be seen in *Figure 2*, which are broken down by age, the number of stimuli that were presented, accuracy of responses in congruent trials (same number of beeps and flashes), unimodal trials (only auditory or only visual), and incongruent trials (different number of beeps and flashes). The dependent variable is accuracy. Each participant was asked to report either how many beeps they heard or flashes that they saw. For example, if they saw 3 flashes, a correct response would be 3, and an incorrect response could be 2 or 4. Then their average accuracy was calculated in the figures below for auditory-response (participants were asked to report how many beeps they heard) and visual-response (participants were asked to report how many flashes that they saw).

Auditory and Visual Processing across Development. Does auditory and visual processing change with age? The change in processing across the different age groups was assessed using a 2 (auditory, visual) x 3 (children, young adults, older adults) mixed factors ANOVA, with accuracy on unimodal trials being the dependent variable. A significant effect of modality was found, $F(1,50)=7.08$, $p=.010$, $\eta_p^2=.124$, with auditory accuracy ($M=.58$, $SE=.03$) being significantly higher than the visual accuracy ($M=.52$, $SE=.02$). This implies that auditory and visual processing did not change with age. Moreover, the findings are consistent with the modality appropriateness hypothesis (better accuracy in auditory responding than in visual responding) (Welch & Warren, 1980).

Visual Response Block. A majority of the past research using the SIFI has examined the effect of auditory input on visual responding; thus, initial analyses focused on effects of beeps on visual accuracy. The accuracies from the visual-response block were analyzed in a 3 (children, young adults, older adults) x 3 (congruent, incongruent, unimodal) mixed-factors ANOVA with age manipulated between subjects. The analysis revealed a significant effect of congruency, $F(2,100)=50.39$, $p<.001$, $\eta_p^2=.502$, with the incongruent accuracy ($M=.31$, $SE=.02$) being significantly less than congruent accuracy ($M=.63$, $SE=.03$) and unimodal accuracy ($M=.52$, $SE=.02$), pairwise comparisons, p 's $< .001$. Additionally, congruent accuracy was significantly higher than unimodal accuracy, $p < .001$.

A significant Congruency x Age interaction was also found, $F(4,100)=5.08$, $p=.001$, $\eta_p^2=.169$, suggesting that effects of beeps on perception of flashes changed with age. See left side of *Figure 3* for a visual representation of the effects. Congruent ($M=.54$, $SE=.05$) and unimodal trials ($M=.51$, $SE=.03$) did not differ significantly in children, pairwise comparisons, p 's $>.05$,

but congruent trials was marginally above incongruent trials ($M=.38, SE=.05$), $p = .059$. The effects increased with age. For young adults, the incongruent trial accuracy ($M=.21, SE=.02$) was significantly lower than the accuracy in the congruent trials ($M=.66, SE=.03$), $p<.001$, and the unimodal trials ($M=.53, SE=.03$), $p<.001$. Additionally, the congruent accuracy was significantly higher than the unimodal accuracy, $p=.004$. For older adults, the incongruent trial accuracy ($M=.35, SE=.06$) was also significantly lower than accuracy in the congruent trials ($M=.69, SE=.05$), $p=.001$. In addition, congruent accuracy was significantly higher than unimodal accuracy ($M=.51, SE=.05$), $p=.035$. This implies that the presence of auditory information had both facilitative and inhibiting effects on visual responding, and these effects increased with age. See Figure 3 for effect sizes.

Auditory Response Block. The results from the auditory-response block, or the effects of visual input on beep perception, were analyzed using a 3 (children, young adults, older adults) x 3 (congruent, incongruent, unimodal) mixed-factors ANOVA, which found a significant effect of congruency, $F(2,100)=9.06, p<.001, \eta_p^2=.153$, with accuracy being significantly higher in congruent trials ($M=.65, SE=.03$) than incongruent trials ($M=.51, SE=.03$), $p=.001$, and unimodal trials ($M=.58, SE=.03$), $p=.006$. Incongruent trials and unimodal trials did not differ significantly. This suggests that visual input had an effect on the number of reported beeps; however, the effect size was smaller than the effect of auditory input on visual accuracy ($\eta_p^2=.502$). There was also a main effect of age, $F(2,50) = 4.17, p = .021, \eta_p^2=.143$. Overall, children ($M=.52, SE=.03$) were significantly less accurate than the young adults ($M=.65, SE=.03$), $p=.018$. Accuracy in the older adult group ($M=.58, SE=.05$) did not differ significantly from the young adult population or the children's group, $p>.05$. A significant Congruency x Age interaction was also observed,

$F(4,100)=2.68, p=.036, \eta_p^2=.097$, showing that the congruent ($M=.65, SE=.03$) and incongruent ($M=.51, SE=.03$) accuracies differ significantly for children, $p=.001$, and do not differ for young adults or older adults. Refer to right side of *Figure 3* for a visual representation of the effects.

It was expected that auditory would have stronger effects on visual processing than vice versa, and this was supported. The prediction that unimodal processing would decrease with age was not supported. Multisensory integration did change across development, as hypothesized, but not exactly as it was expected to. Older adults did not show stronger effects of integration than young adults in the visual-response block. Although older adults and young adults did not differ much in the strength of integration in the visual-response condition, stronger integration might be implied by the fact that processing was affected by both modalities instead of just the auditory modality. Recall that visual input had no effect on auditory processing in young adults; whereas, visual input did affect older adults' auditory accuracies.

Experiment 2

Experiment 1 offers novel insight about the development of multisensory integration across the lifespan. Experiment 2 aims to further examine the fact that auditory input affected visual responding and visual input affected auditory responding in the older adult population. It was speculated by DeLoss et al. (2013) that older adults may compensate for weaker unimodal senses by utilizing stronger multisensory integration. Experiment 2 addresses this by weakening half of the stimuli to above threshold in young adults to see if we can replicate older adult data in young adult populations.

Method

Participants. Participants for Experiment 2 include 14 young adults (7 Females, *Mean* =

19.21 years, $SE = .54$). All participants were tested in a quiet room in the psychology laboratory at The Ohio State University at Newark. Young adults were recruited from the Ohio State University Newark, and received class credit for the Introductory Psychology course in return for their participation. An additional 6 participants were excluded from data analyses for either self-reported uncorrected hearing or vision or for missing more than 25 percent of the catch trials that show whether or not they were looking at the visual stimuli during the auditory report crossmodal condition.

Apparatus, Stimuli, and Design. Experiment 2 used the same equipment and stimuli as Experiment 1, but half of the stimuli were weakened in intensity to a level right above threshold. In visual stimuli, the weaker stimuli were dimmer, and in the auditory stimuli, the volume was lowered using Audacity software. Experiment 2 was a two-part experiment. The first part was a simple detection task to find each participant's threshold for visual and auditory stimuli. Once the threshold was established, the value just above threshold was used as the weak stimulus in part 2. Part 2 was identical to Experiment 1 in design and procedure, with the exception of having more stimuli, with each stimulus having a weak version. See *Table 2* below for the layout of the stimuli for part 2 of Experiment 2.

Procedure. In the detection task, 4 auditory and 6 visual stimuli were created and stimuli varied in intensity. Stimuli were randomly presented one at a time in an auditory block and a visual block separately, and participants had to hit the spacebar whenever they detected a stimulus. For each participant, the intensity level just above threshold was assessed (intensity level where detection was consistently greater than 75%) and then these stimuli were used in part 2. The procedure for part 2 was identical to experiment 1. Participants were asked to respond to

the stimuli by reporting whether 2, 3, or 4 were presented by hitting the spacebar. They were informed that some of the stimuli would be quieter than others and some dimmer than others, but that this is a part of the experiment and they should respond to these as they do to the others.

Results and Discussion. The data from Experiment 2 are shown in *Figure 4*, which displays the accuracy for congruent trials and incongruent trials in the strong condition and in the weak condition in the second part of the experiment.

Visual Response Block. Data from the visual-response condition was analyzed using a 2 (Intensity: strong, weak) x 3 (Congruency: congruent, incongruent, unimodal) repeated measures ANOVA (see left side of *Figure 5* for means, standard errors, and effect sizes). A significant effect of intensity was observed $F(1,13)=6.22, p=.027, \eta_p^2=.324$, showing that responding to the strong trials ($M=.47, SE=.02$) was significantly more accurate than responding to the weak trials ($M=.41, SE=.01$). A significant effect of congruency was also found, $F(2,26)=24.76, p<.001, \eta_p^2=.656$, with accuracy in the congruent trials ($M=.55, SE=.03$) being significantly higher than accuracy in the incongruent trials ($M=.30, SE=.02$), $p<.001$, and with accuracy on incongruent trials being significantly lower than accuracy in the unimodal trials ($M=.47, SE=.02$), $p<.001$. There was also a significant Intensity x Congruency interaction, $F(2,26)=7.86, p=.002, \eta_p^2=.377$, showing that auditory input had a greater effect on multisensory integration when both stimuli were presented at full intensity, see *Figure 5* for effect sizes. In the strong condition, congruent trials ($M=.62, SE=.04$) were significantly higher in accuracy than incongruent trials ($M=.26, SE=.03$), $p<.001$. Additionally, the incongruent accuracy was significantly lower than the unimodal accuracy ($M=.51, SE=.04$), $p<.001$. Congruent and unimodal accuracies did not differ significantly. In the weak condition, accuracy in the congruent trials ($M=.47, SE=.04$) was

significantly higher than in the incongruent trials ($M=.34$, $SE=.02$), $p=.037$. The incongruent trials also had a significantly lower accuracy than the unimodal trials ($M=.43$, $SE=.02$), $p=.014$. The congruent and unimodal trials did not differ significantly in accuracy.

Auditory Response Block. Data from the auditory-response condition was also analyzed in a 2 (strong, weak) x 3 (congruent, incongruent, unimodal) repeated measures ANOVA (see right side of Figure 5 for means, standard errors, and effect sizes). A significant effect of intensity was found, $F(1,13)=36.38$, $p<.001$, $\eta_p^2=.737$, with the strong condition ($M=.64$, $SE=.03$) having a higher accuracy than the weak condition ($M=.42$, $SE=.03$). There is no significant interaction, meaning that weakening intensity did not increase multisensory integration. Additionally, the decreased effect of congruency implies that multisensory integration was weaker.

General Discussion

The current study used a variation of the Sound-Induced Flash Illusion to test the contributions of auditory and visual modalities on multisensory integration and the effect of aging on integration. Auditory and visual contributions were measured by having both a visual-response and an auditory-response block in the experiment. The effects of aging were observed by measuring the accuracy of young children, young adults, and older adults in this task. Experiment 2 examined the principle of inverse effectiveness in young adults by lowering the intensity of half of the stimuli to just above threshold.

In Experiment 1, results showed that auditory input had a stronger effect on visual processing than visual input had on auditory processing. There was also no evidence that unimodal processing in either modality decreased with age. The only finding was better processing of the unimodal auditory trials. The effects of auditory input on visual processing

increased in magnitude with age (young and older adults' visual processing was more affected by auditory input than children's). In the auditory-response condition, the effects were not strong (see right side of Figure 3). There was no evidence that visual input affected auditory processing in the young adult group.

There was not strong support for the claim that multisensory integration increases as we age. The effect size was actually larger for the young adults in the visual-response block. However, it also appeared that older adults were affected by visual information, and based on the effect size would have been significant with a few more participants. This may offer weak support for increased multisensory integration, in that young adults were only affected by auditory input, but older adults were affected by both.

Experiment 2 replicated Experiment 1 by finding that auditory input had a stronger effect on visual processing than visual input had on auditory processing. Across both modalities, multisensory integration was more pronounced for strong stimuli than for weak stimuli, see Figure 5 for effect sizes.

The findings from the current study support the auditory dominance literature (Robinson & Sloutsky, 2010) and the modality appropriateness hypothesis (Welch & Warren, 1980), because the auditory input had a stronger effect on visual processing than vice versa. The findings on the development of multisensory integration were interesting. They were different than Nava and Pavani (2013) and auditory dominance literature (Robinson & Sloutsky, 2010) in that the children did not have as strong of effects of auditory input on visual processing. Additionally, they also differed from DeLoss et al. (2013) in that older adults did not have stronger effects of multisensory integration in the visual-response block, although they were

affected by both modalities, whereas young adults were only affected by the auditory modality.

Past research has shown that there is a stronger neural response to weaker stimuli than to stronger stimuli, which is an idea called inverse effectiveness (Meredith & Stein, 1983), and it is possible that stronger multisensory integration in older adults (Deloss et al., 2013) is driven by poor unimodal processing. This idea was not supported by our research. Recall that multisensory integration in Experiment 2 was actually weaker when the stimulus intensity was decreased to near threshold. This suggests that any increased integration may be a result of maturation of the brain or more intersensory connections, instead.

The current study had a number of limitations that may be worth addressing. One limitation is the sample sizes of each group. It would have been favorable to have larger sample sizes, despite the fact that rather large effects were still observed. Another limitation was that there were a few errors made in the children's data collection, based on a response bias. For example, if a child consistently answered "2", it could cause the researcher to mistakenly hit 2 when a different answer was given. This is also in part due to the fact that children's data had to be ran rather quickly to avoid them getting restless and impatient. In the detection task, it would also help to have more levels of volume.

An interesting direction to take this study in would be to test a larger range of children in separate groups to find where the significant effects of visual input on auditory responding diminishes. The children in the current study were older than children in typical auditory dominance research (typically 4 years old). It will be important to test younger kids, as auditory dominance effects should be more robust (Robinson & Sloutsky, 2004; Sloutsky & Napolitano, 2003). Additionally, it would be interesting to present a similarly designed study with the

Colavita Task instead of the Sound-Induced Flash Illusion, as the Colavita task robustly shows visual dominance in adults (Colavita, 1974).

In concluding, it is important to study multisensory integration, as it is utilized in a majority of our experiences in our daily life. The current study was novel in the sense that it measured multisensory integration across the lifespan, rather than only comparing two groups.

Additionally, the auditory and visual contributions to multisensory integration were observed, and the effects of stimulus intensity on multisensory integration were also analyzed. Across both studies, effects of auditory input had a stronger effect on multisensory integration and these effects appeared to change across development.

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Table 1

Experiment 1 trial types and (frequencies). Note “” Denotes congruent trials.*

Unimodal Trials	
<u>Auditory Response</u>	<u>Visual Response</u>
2 Beeps (5)	2 Flashes (5)
3 Beeps (5)	3 Flashes (5)
4 Beeps (5)	4 Flashes (5)
Crossmodal Trials	
<u>Auditory Response</u>	<u>Visual Response</u>
*2 Beeps/2 Flashes (5)	*2 Beeps/2 Flashes (5)
*3 Beeps/3 Flashes (5)	*3 Beeps/3 Flashes (5)
*4 Beeps/4 Flashes (5)	*4 Beeps/4 Flashes (5)
2 Beeps/2 Flashes (5)	2 Beeps/2 Flashes (5)
2 Beeps/4 Flashes (5)	2 Beeps/4 Flashes (5)
3 Beeps/2 Flashes (5)	3 Beeps/2 Flashes (5)
3 Beeps/4 Flashes (5)	3 Beeps/4 Flashes (5)
4 Beeps/2 Flashes (5)	4 Beeps/2 Flashes (5)
4 Beeps/3 Flashes (5)	4 Beeps/3 Flashes (5)

Table 2

Experiment 2 trial types and (frequencies). Note “” Denotes congruent trial*

Unimodal Trials			
<u>Strong</u>	<u>Weak</u>	<u>Strong</u>	<u>Weak</u>
2 Beeps (5)	2 Beeps (5)	2 Flashes (5)	2 Flashes (5)
3 Beeps (5)	3 Beeps (5)	3 Flashes (5)	3 Flashes (5)
4 Beeps (5)	4 Beeps (5)	4 Flashes (5)	4 Flashes (5)
Crossmodal Trials			
<u>Auditory Response</u>		<u>Visual Response</u>	
<u>Strong</u>	<u>Weak</u>	<u>Strong</u>	<u>Weak</u>
*2 Beeps/2 Flashes (5)	*2 Beeps/2 Flashes (5)	*2 Beeps/2 Flashes (5)	*2 Beeps/2 Flashes (5)
*3 Beeps/3 Flashes (5)	*3 Beeps/3 Flashes (5)	*3 Beeps/3 Flashes (5)	*3 Beeps/3 Flashes (5)
*4 Beeps/4 Flashes (5)	*4 Beeps/4 Flashes (5)	*4 Beeps/4 Flashes (5)	*4 Beeps/4 Flashes (5)
2 Beeps/2 Flashes (5)	2 Beeps/2 Flashes (5)	2 Beeps/2 Flashes (5)	2 Beeps/2 Flashes (5)
2 Beeps/4 Flashes (5)	2 Beeps/4 Flashes (5)	2 Beeps/4 Flashes (5)	2 Beeps/4 Flashes (5)
3 Beeps/2 Flashes (5)	3 Beeps/2 Flashes (5)	3 Beeps/2 Flashes (5)	3 Beeps/2 Flashes (5)
3 Beeps/4 Flashes (5)	3 Beeps/4 Flashes (5)	3 Beeps/4 Flashes (5)	3 Beeps/4 Flashes (5)
4 Beeps/2 Flashes (5)	4 Beeps/2 Flashes (5)	4 Beeps/2 Flashes (5)	4 Beeps/2 Flashes (5)
4 Beeps/3 Flashes (5)	4 Beeps/3 Flashes (5)	4 Beeps/3 Flashes (5)	4 Beeps/3 Flashes (5)



Figure 1. The figure represents the timeline of a 2 flash/2 beep stimulus. The dark blocks represent presentation of the stimuli. The numbers above represent the time in ms from the beginning of the stimulus. Participants were counterbalanced so that some saw the visual stimulus first and some heard the auditory stimulus first.

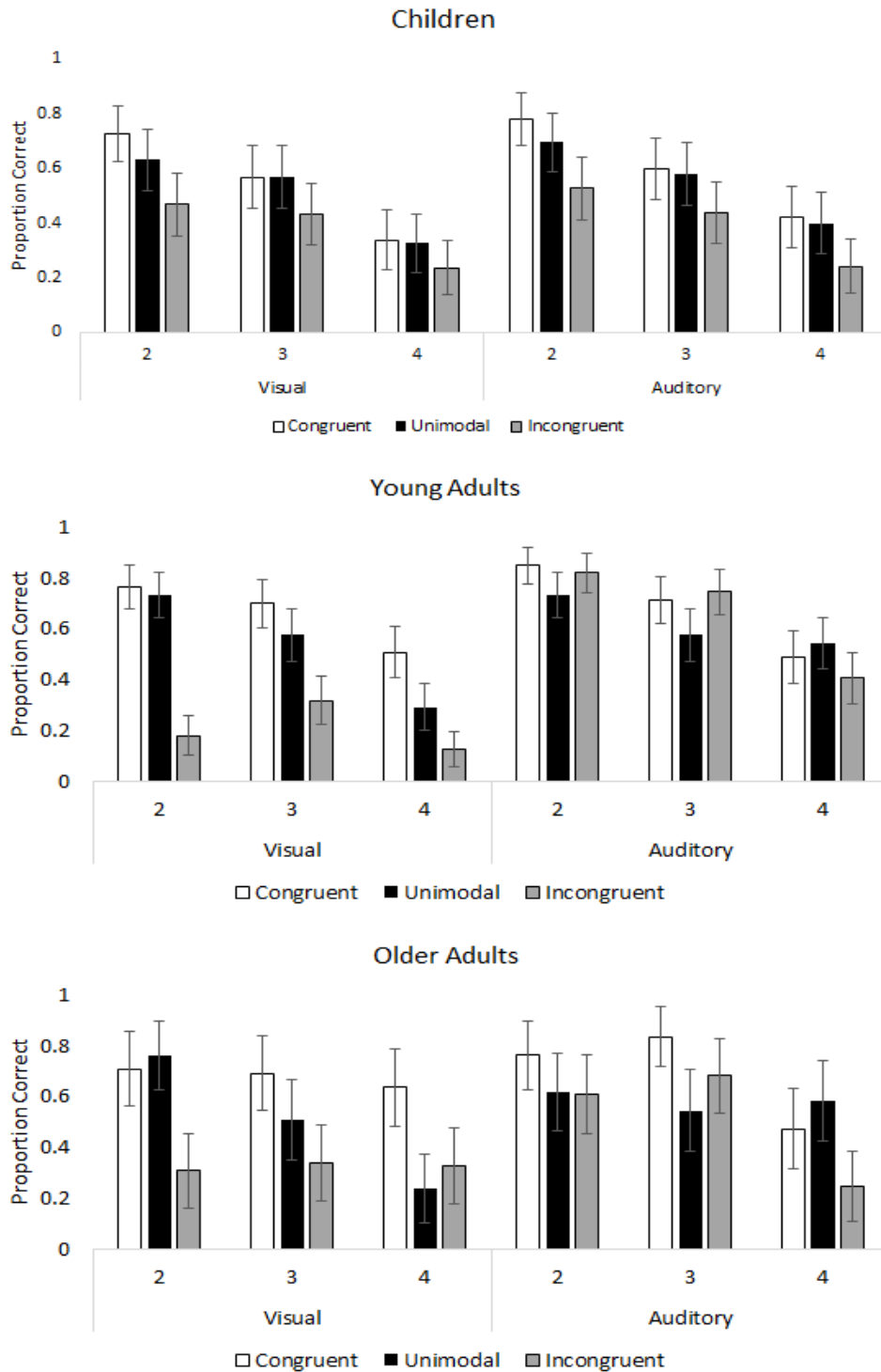


Figure 2. Accuracy data in responding to 2, 3, or 4 stimuli in auditory-response and visual-response across children, young adults, and older adults.

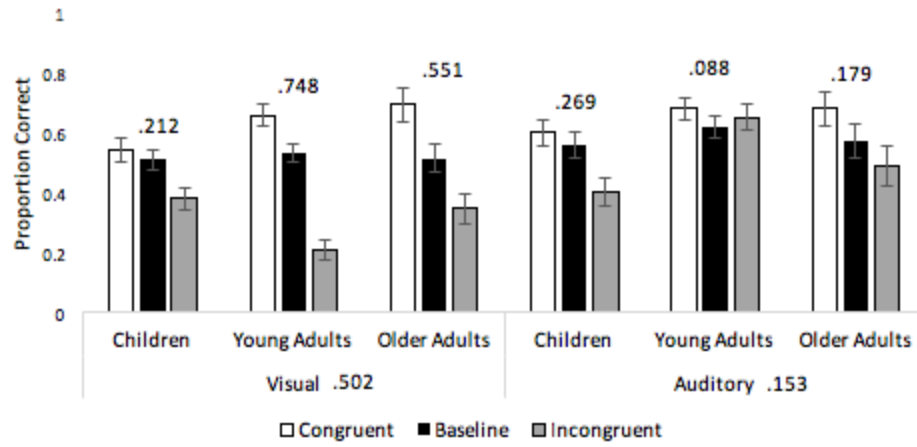


Figure 3. Accuracy data for congruent, unimodal baseline, and incongruent trials in the auditory and visual-response conditions across children, young adults, and older adults. Values denote effect sizes (Partial Eta Squares).

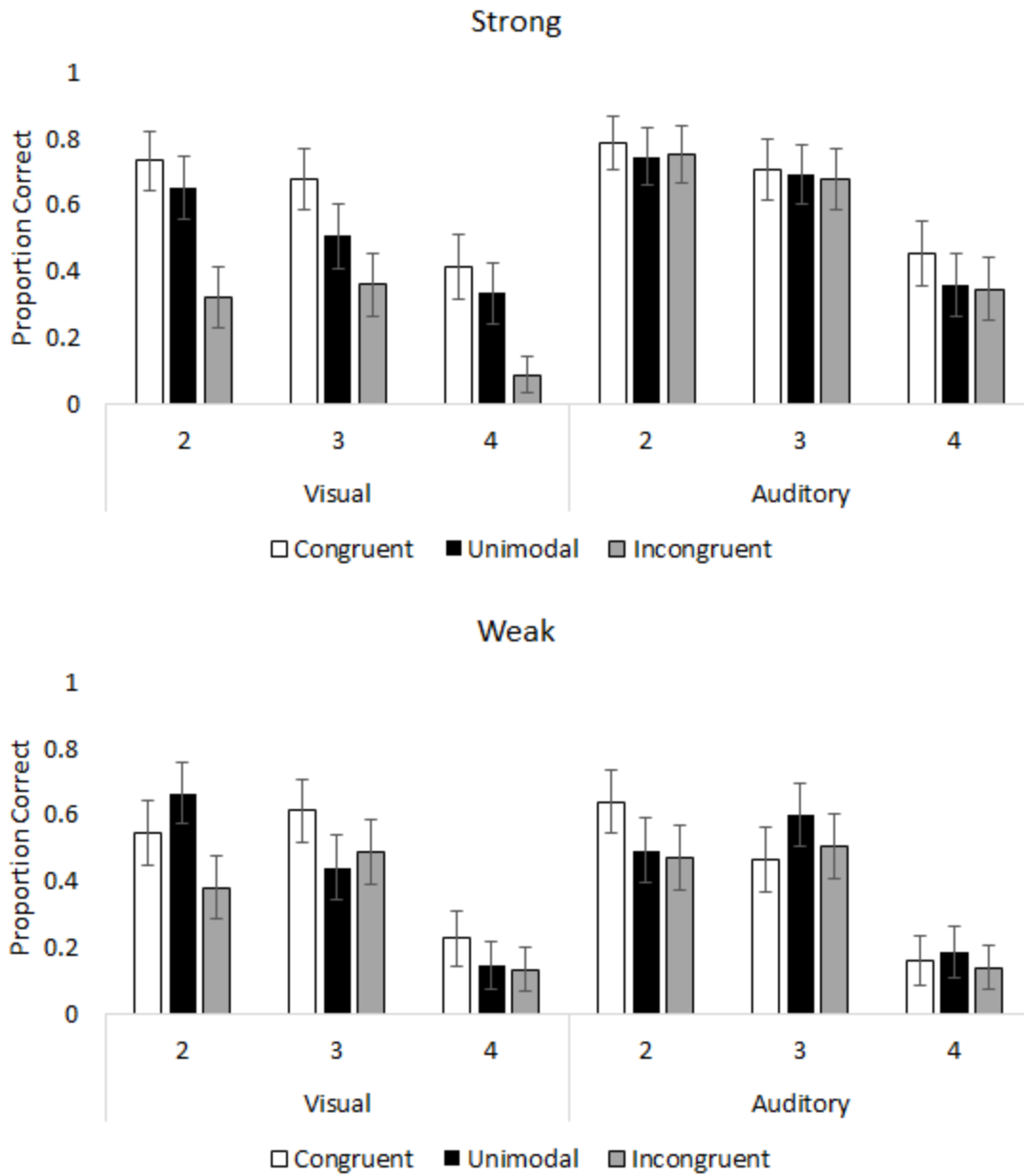


Figure 4. Accuracy data in responding to 2, 3, or 4 stimuli in auditory-response and visual-response across weak and strong stimulus condition

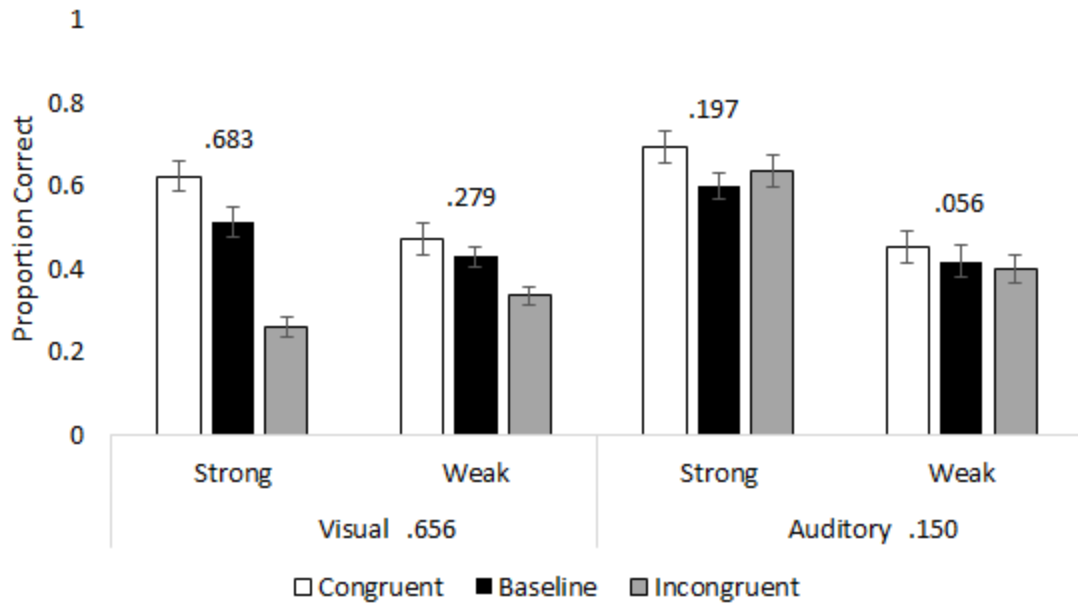


Figure 5. Accuracy data for congruent and incongruent trials in the auditory and visual-response conditions across strong and weak intensities. Values denote effect sizes (Partial Eta Squares).