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Suppression of multisensory integration by modality-specific attention in aging

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Abstract

Previous research demonstrates that modality-specific selective attention attenuates multisensory integration in healthy young adults. Additionally, older adults evidence enhanced multisensory integration compared to younger adults. We hypothesized that these increases were due to changes in top-down suppression, and therefore older adults would demonstrate multisensory integration while selectively attending. Performance of older and younger adults was compared on a cued discrimination task. Older adults had greater multisensory integration than younger adults in all conditions, yet were still able to reduce integration using selective attention. This suggests that attentional processes are intact in older adults, but are unable to compensate for an overall increase in the amount of sensory processing during divided attention.

Keywords

aging; attention; cross-modal; elderly; multisensory integration; selective attention

Introduction

The brain interfaces with the environment through multiple sensory channels carrying information about different forms of environmental energy. Some of these inputs are processed separately, but others are combined to form a unified percept of the world. Such multisensory interactions are governed by a combination of stimulus characteristics such as intensity, timing, and spatial coincidence [1-3], and higher-order cognitive functions such as semantic congruence [4] and attention [5-8]. Interestingly, older adults show increased multisensory integration [9,10]. One potential explanation for this increase is age-related changes in top-down regulation of multisensory interactions, specifically attention.

Previous research has observed that attention modulates interactions between the senses [5-8]. Of particular relevance are two studies demonstrating significant reductions in multisensory integration when attention is focused on one sense compared to when attention is directed to visual and auditory modalities simultaneously [6,7]. Although research on the effects of aging on modality-specific or cross-modal attention is limited [11], there is evidence that it may be altered in some circumstances. Poliakoff and colleagues (2006) noted that older adults were more slowed than younger adults by visual distractors when they were completing a tactile task, but not by tactile distractors in the visual task. In addition, aging research suggests

more broadly that inhibitory processes (including voluntary attention) may be impaired with increasing age (see [12] for review). If older adults do not successfully engage selective attention, this might reduce regulation of multisensory interactions and increase integration relative to their younger counterparts. Therefore, the purpose of this study was to investigate the effects of aging on the ability to restrict multisensory integration with modality-specific attention. It was hypothesized that older adults would integrate more under conditions of selective attention than younger adults.

Methods

Subjects

Twenty-one young (mean age = 26.6, 9 women) and 20 older (mean age = 73.3, 11 women) adults completed this study. Participants were required to be in good health and have normal sensory and cognitive function. Potential participants were excluded if their mini-mental state examination (MMSE) score was greater than 2.5 standard deviations from the mean for their age and education [13]. Volunteers were also excluded for self-reported diagnoses or medications consistent with psychiatric disorders, neurological problems, head injuries, stroke, or diabetes, or evidence of alcoholism measured with the Alcohol Use Disorders Identification Test [14]. Volunteers who reported a diagnosis of depression were included if they had been receiving treatment for at least 3 months and were currently non-symptomatic when assessed using the Center for Epidemiological Studies Depression Scale (CES-D) [15]. Subjects were required to have corrected visual acuity of 20/40 or better in both eyes measured with a modified Snell visual acuity exam and no more than moderate hearing loss, defined as 50dB measured with a digital audiometer (Digital Recordings, Halifax, Nova Scotia). Participants provided informed consent. All study procedures were approved by the Wake Forest University School of Medicine Institutional Review Board for the protection of human subjects in research and performed in accordance with the Declaration of Helsinki.

Study design

Participants completed a cued, multisensory discrimination task that required a choice between the colors red and blue [7]. Participants were seated in a sound and light attenuated booth (Whisper Room, Morristown, TN, USA) with their head positioned 60 cm from a computer monitor in a comfortably adjusted chin rest. Stimuli were presented and accuracy and response time were collected using E-prime software (PST, Pittsburg, PA, USA). Each trial began with a 750 ms cue that directed participants to pay attention to the visual modality, the auditory modality, or to divide their attention across both the auditory and visual modalities. The attentional cue was visual and consisted of two white pictures on a black background, one located to the left of fixation and one to the right. The visual attention cue was two eyes, the auditory cue was two ears, and one ear and one eye directed subjects to divide their attention between the visual and auditory modalities.

After a 250 ms delay, a target was displayed for 150 ms. The target could be unisensory (e.g. a visual presentation of a red circle or an auditory presentation of the word “red”) or multisensory (e.g. participants simultaneously saw the red circle and heard the word “red”). The target was followed by a response interval of up to 3,000 ms, during which participants were to make a quick and accurate choice between red and blue response buttons. Participants were instructed that auditory cues could be followed by auditory or multisensory targets, but they should pay attention to the auditory modality. Similarly, visual cues could be followed by visual or multisensory targets, but attention was to be focused on the visual modality. Divided attention cues could be followed by any target type. Cues were always correct, i.e. an auditory attention cue always contained an auditory component. The 7 cue-target trial types

are listed in Table 1. Participants completed 24 of each cue-target trial type, presented in a pseudorandom order over 3 trial blocks.

To compare accuracy on unisensory and multisensory trials during selective and divided attention, separate $2_{\text{Age}} \times 2_{\text{Attention Cue}} \times 2_{\text{Target}}$ mixed model ANOVAs were conducted for auditory and visual trial types. To analyze response time (RT), error trials and outliers (± 3 standard deviations) were removed, and similar ANOVAs were performed on mean RT data. Error trials were considered to be trials with an inaccurate response, e.g., pressing the blue response button on a red trial.

Although ANOVA analyses can identify group differences in mean performance on unisensory and multisensory trials, these tests can not account for enhancements due to the presence of two stimuli in the multisensory conditions (i.e. multisensory trials contain both an auditory and a visual component, while unisensory trials contain only one of these components). The independent race model is used to determine if responses on multisensory trials are faster than would be predicted based on responses to both unisensory trial types [16]. If observed responses to multisensory trials are faster than those predicted by the race model, multisensory integration is said to have occurred.

In order to complete race model analyses, participants' RTs in each attention condition were converted to cumulative distribution functions (CDFs) using 4 ms time bins. Each participant's race model curve (calculated from their unisensory CDFs) was then subtracted from their multisensory CDFs for divided and selective attention conditions. The 3 resulting difference curves (divided attention, selective auditory attention, and selective visual attention) were averaged across individuals in each age group, yielding mean curves where positive numbers represented intervals where responses to multisensory targets were faster than predicted by race model. One-sample t-tests were performed across these distributions to determine whether these multisensory enhancements were significantly above zero.

Because each subject has a different time course of responses, averaging difference curves across individuals may not give a complete indication of group differences. To obtain a measure of integration that is not affected by timing differences across individuals, we calculated the area under each of the subjects' 3 difference curves. Area under the curve was determined by calculating the integral for the positive region under each curve. These area values were then averaged across participants in each age group, and group differences in integration were assessed using a $2_{\text{Age}} \times 3_{\text{Attention Cue}}$ mixed model ANOVA.

Results

Accuracy

Accuracy was very high in all conditions (Table 1). A $2_{\text{Age}} \times 2_{\text{Attention Cue}} \times 2_{\text{Target}}$ ANOVA comparing accuracy between auditory and multisensory trials revealed no significant main effects or interactions. When visual and multisensory trials were compared, a main effect of Target was observed ($F(1, 39) = 5.16, p < 0.03$), reflecting the fact that older and younger adults showed slightly improved accuracy to multisensory targets.

Reaction time

Average reaction times are reported in Table 1. A $2_{\text{Age}} \times 2_{\text{Attention Cue}} \times 2_{\text{Target}}$ ANOVA analyzing reaction times to auditory and multisensory trials showed main effects of Age ($F(1, 39) = 28.62, p < 0.01$), Attention Cue ($F(1, 39) = 11.37, p < 0.01$) and Target ($F(1, 39) = 188.56, p < 0.01$). These results indicate that reaction times were significantly different between the two age groups (older responded more slowly), selective and divided attention (responses to selective attention were faster overall), and target type (responses to multisensory targets

were faster). A significant Target $\times$ Group interaction was also observed ($F(1, 39) = 6.10$, $p < 0.02$) that resulted from older adults being more speeded on multisensory trials than younger adults. A corresponding ANOVA performed on visual and multisensory trials demonstrated similar results. Main effects of Age ($F(1, 39) = 27.01$, $p < 0.01$), Attention Cue ($F(1, 39) = 32.96$, $p < 0.01$), and Target ($F(1, 39) = 46.64$, $p < 0.01$) were observed. In addition, a Target $\times$ Group ($F(1, 39) = 5.21$, $p < 0.03$) interaction was again observed because older adults were more speeded by multisensory trials than younger adults, and an Attention $\times$ Target ($F(1, 39) = 4.42$, $p < 0.05$) interaction reflected that both younger and older adults were more speeded by selective attention on visual trials than multisensory trials.

Race model comparisons

Positive deflections in the difference curves shown in Figure 1 A and B reflect time bins where observed responses to multisensory stimuli are faster than those predicted by the race model. Replicating previous results [7], younger adults showed evidence of multisensory integration during divided attention, with a peak of approximately 5%. However, during selective attention to both vision and hearing, multisensory integration was almost completely suppressed. In contrast, older adults showed more integration than younger adults in all conditions. While integration was reduced by selective attention, the peak of integration under visual selective attention is still as high as the peak of younger adults who were dividing their attention. Significant differences were noted between younger and older adults in the divided attention condition, but not during the selective attention conditions. The clear differences between age groups under selective attention conditions likely do not reach significance because of the way they are compared in this analysis. Due to variability between subjects and groups, areas of integration occur in different time bins. Therefore, the area under the difference curves was also compared.

Significant differences were observed between age groups for all three attention conditions when area under the race model difference curve was analyzed (Figure 1C). A $2_{\text{Age}} \times 3_{\text{Attention Cue}}$ ANOVA comparing divided and selective auditory attention showed significant main effects of Age ($F(1, 39) = 8.50$, $p < 0.01$) and Attention Cue ($F(1, 39) = 3.84$, $p < 0.05$), arising from the fact that older adults had significantly greater area under the curve in all conditions, and selective attention significantly reduced the area under the curve for both age groups. A similar result was observed for visual selective attention where significant effects were seen for Age ($F(1, 39) = 5.71$, $p < 0.05$) and Attention Cue ($F(1, 39) = 9.64$, $p < 0.01$). Area under the curve was doubled for older adults relative to younger adults during divided attention and selective attention to hearing, and the difference between age groups was even larger during selective attention to vision. Interestingly, no Attention Cue $\times$ Group interaction was observed for either the auditory ($F(1, 39) = 0.57$, $p = 0.45$) or visual ($F(1, 39) = 0.74$, $p = 0.40$) selective attention comparisons, suggesting that there was no difference between the two age groups in the reduction of multisensory integration by selective attention.

Discussion

In this study, multisensory integration was virtually abolished in younger adults when they directed attention selectively to vision or hearing, replicating previous findings [7]. As hypothesized, older adults exhibited increased multisensory integration relative to younger adults in all attentional conditions. However, contrary to our hypothesis, older adults evidenced successful instantiation of modality-specific attention. Integration was reduced under conditions of selective attention to vision or hearing relative to divided attention, and no Attention Cue $\times$ Group interactions were observed, suggesting that while older adults integrated more than younger adults, they showed a proportional reduction in integration due to modality-specific attention.

These results reinforce the idea that multisensory integration is increased with age. When attention was directed to both vision and hearing, older adults showed approximately double the integration of younger adults, both in area under the race model difference curve and in the peak of their difference curves. The same tendency was observed during selective attention, where the area under the curve was approximately doubled in older adults.

However, this difference in integration does not appear to be due to changes in top-down modulation of integration by modality-specific attention. The race model difference curves illustrate that while older adults integrate more than younger adults, integration is substantially reduced by attention. When area under the curve was compared, both Attention Cue and Age Group showed significant effects, but no interaction between Attention Cue $\times$ Age Group was observed. These findings reflect that integration was greater when participants divided their attention than when they selectively attended and older adults integrated more than younger adults, but that the reduction in integration by attention was comparable for both age groups.

Research on the effects of aging on modality-specific attention is limited. It has been consistently observed that older adults process more distracting information than younger adults both in cross-modal [11,17] and unimodal [18,19] tasks, and this has often been interpreted as evidence that older adults do not effectively engage attention. However, studies of other forms of voluntary attention show more mixed results; older adults do not differ from younger adults in their ability to attend in many situations [20,21]. Results from this study suggest that modality-specific attention can be effectively used by older adults and that increased processing of distractors may be due to some other mechanism, such as changes in the baseline processing of sensory information.

Conclusions

Together, these data indicate that there is a baseline increase in multisensory integration with increased age, such that older adults integrate more under all conditions than younger adults. Top-down regulation of multisensory integration by attention is still effective, suggesting that fundamental alterations in baseline state or sensory functioning may underlie this overall shift in integration in older adults.

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Reference list

1. Stein BE, Huneycutt WS, Meredith MA. Neurons and behavior: the same rules of multisensory integration apply. *Brain Res* 1988;448(2):355–358. [PubMed: 3378157]
2. Stein, BE.; Meredith, MA. *The merging of the senses*. MIT Press; Cambridge, Massachusetts: 1993.
3. Stein BE, Stanford TR. Multisensory integration: current issues from the perspective of the single neuron. *Nat Rev Neurosci* 2008;9(4):255–266. [PubMed: 18354398]
4. Laurienti PJ, Kraft RA, Maldjian JA, Burdette JH, Wallace MT. Semantic congruence is a critical factor in multisensory behavioral performance. *Exp Brain Res* 2004;158(4):405–414. [PubMed: 15221173]
5. Talsma D, Woldorff MG. Selective attention and multisensory integration: multiple phases of effects on the evoked brain activity. *J Cogn Neurosci* 2005;17(7):1098–1114. [PubMed: 16102239]

6. Talsma D, Doty TJ, Woldorff MG. Selective attention and audiovisual integration: is attending to both modalities a prerequisite for early integration? *Cereb Cortex* 2007;17(3):679–690. [PubMed: 16707740]
7. Mozolic JL, Hugenschmidt CE, Peiffer AM, Laurienti PJ. Modality-specific selective attention attenuates multisensory integration. *Exp Brain Res* 2008;184(1):39–52. [PubMed: 17684735]
8. Alsius A, Navarra J, Campbell R, Soto-Faraco S. Audiovisual integration of speech falters under high attention demands. *Curr Biol* 2005;15(9):839–843. [PubMed: 15886102]
9. Laurienti PJ, Burdette JH, Maldjian JA, Wallace MT. Enhanced multisensory integration in older adults. *Neurobiology of Aging* 2006;27(8):1155–1163. [PubMed: 16039016]
10. Peiffer AM, Mozolic JL, Hugenschmidt CE, Laurienti PJ. Age-related multisensory enhancement in a simple audiovisual detection task. *Neuroreport* 2007;18(10):1077–1081. [PubMed: 17558300]
11. Poliakoff E, Ashworth S, Lowe C, Spence C. Vision and touch in ageing: crossmodal selective attention and visuotactile spatial interactions. *Neuropsychologia* 2006;44(4):507–517. [PubMed: 16098997]
12. Healey MK, Campbell KL, Hasher L. Cognitive aging and increased distractibility: costs and potential benefits. *Prog Brain Res* 2008;169:353–363. [PubMed: 18394486]
13. Bravo G, Herbert R. Age- and education-specific reference values for the Mini-Mental and Modified Mini-Mental State Examinations derived from a non-demented elderly population. *International Journal of Geriatric Psychiatry* 1997;12:1008–1018. [PubMed: 9395933]
14. Bohn MJ, Babor TF, Kranzler HR. The alcohol use disorders identification test (audit): validation of a screening instrument for use in medical settings. *Journal of Studies on Alcohol* 1995;56:423. [PubMed: 7674678]
15. Haringsma R, Engels GI, Beekman AT, Spinhoven P. The criterion validity of the Center for Epidemiological Studies Depression Scale (CES-D) in a sample of self-referred elders with depressive symptomatology. *Int J Geriatr Psychiatry* 2004;19(6):558–563. [PubMed: 15211536]
16. Miller J. Timecourse of coactivation in bimodal divided attention. *Percept Psychophys* 1986;40(5):331–343. [PubMed: 3786102]
17. Alain C, Woods DL. Age-related changes in processing auditory stimuli during visual attention: evidence for deficits in inhibitory control and sensory memory. *Psychol Aging* 1999;14(3):507–519. [PubMed: 10509703]
18. Andres P, Parmentier FB, Escera C. The effect of age on involuntary capture of attention by irrelevant sounds: a test of the frontal hypothesis of aging. *Neuropsychologia* 2006;44(12):2564–2568. [PubMed: 16797613]
19. Yang L, Hasher L. The enhanced effects of pictorial distraction in older adults. *J Gerontol B Psychol Sci Soc Sci* 2007;62(4):P230–233. [PubMed: 17673533]
20. Madden DJ, Whiting WL, Cabeza R, Huettel SA. Age-related preservation of top-down attentional guidance during visual search. *Psychol Aging* 2004;19(2):304–309. [PubMed: 15222823]
21. Groth KE, Allen PA. Visual attention and aging. *Front Biosci* 2000;5:D284–297. [PubMed: 10704152]

Figure 1.

Positive deflections in the race model difference curves for younger (A) and older (B) participants show time bins where multisensory integration has occurred. Divided attention curves are higher and broader than selective attention curves for both age groups, and curves for older adults are both wider and higher than those for younger adults in all conditions. These differences are shown clearly by comparing area under the curve (C) for each age group and attention condition. The * indicates significant differences between older and younger adults. Area under the curve is reported in arbitrary units (AU).

Table 1
Mean accuracy and reaction time data for each attentional condition

Cue / Target	Accuracy (% correct)		RT (ms)	
	<i>Young</i>	<i>Older</i>	<i>Young</i>	<i>Older</i>
Auditory Attention				
auditory target	98.8 (0.6)	97.5 (1.5)	574.7 (23.5)	763.7 (24.7)
multisensory target	99.6 (0.3)	98.3 (1.5)	473.7 (20.2)	620.1 (23.0)
Visual Attention				
visual target	98.8 (0.6)	95.8 (1.9)	494.5 (18.5)	653.4 (22.3)
multisensory target	99.0 (0.4)	97.3 (1.5)	470.6 (18.3)	606.6 (24.4)
Divided Attention				
auditory target	98.4 (0.7)	98.3 (1.1)	601.6 (23.8)	784.9 (28.2)
visual target	99.0 (0.5)	94.2 (2.0)	528.7 (19.9)	700.6 (28.1)
multisensory target	99.4 (0.3)	97.9 (1.1)	491.1 (17.4)	624.2 (22.6)

Mean responses are reported with standard deviation in parentheses.