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Visual–Somatosensory Integration is Linked to Physical Activity Level in Older Adults

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Abstract

Studies examining multisensory integration (MSI) in aging consistently demonstrate greater reaction time (RT) facilitation in old compared to young adults, but often fail to determine the utility of MSI. The aim of the current experiment was to further elucidate the utility of MSI in aging by determining its relationship to physical activity level. 147 non-demented older adults (mean age 77 years; 57% female) participated. Participants were instructed to make speeded responses to visual, somatosensory, and visual–somatosensory (VS) stimuli. Depending on the magnitude of the individuals' RT facilitation, participants were classified into a MSI or NO MSI group. Physical activity was assessed using a validated physical activity scale. As predicted, RTs to VS stimuli were significantly shorter than those elicited to constituent unisensory conditions. Multisensory RT facilitation was a significant predictor of total number of physical activity days per month, with individuals in the NO MSI group reporting greater engagement in physical activities compared to those requiring greater RT facilitation.

Keywords

Multisensory integration; sensory processing; aging; physical activity

1. Introduction

Every moment of our lives, we are bombarded by a variety of physical stimuli across different sensory modalities that are transduced and processed by our nervous systems, making the perception of our world necessarily multisensory. In our society, simultaneous sensory information is constantly transduced across equipment that is practically attached to our bodies (e.g., smart phones, laptops, tablets, etc.). For years, researchers have been investigating how the brain integrates multisensory signals like those of a lit-up mobile phone that is simultaneously ringing and vibrating. Much of the work in the field of multisensory integration (MSI) has demonstrated early multisensory integrative effects on both psychophysical and electrophysiological levels (e.g., Fort *et al*., 2002; Foxe *et al*., 2000, 2002; Giard and Peronnet, 1999; Mahoney *et al*., 2011; Molholm *et al*., 2002, 2004; Murray

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et al., 2005; Schroger and Widmann, 1998; Schurmann *et al.*, 2002). In terms of the psychophysical findings, researchers consistently demonstrate reaction time (RT) facilitation to multi-sensory conditions compared to unisensory conditions. Yet, very little effort has been dedicated to determining the consequences, or rather value of the magnitude of RT facilitation — a major knowledge gap in the field recognized in several recent influential editorials (Meyer and Noppeney, 2011; Wallace, 2012).

One specific population where MSI research could prove most valuable is for the elderly, given: the inevitable sensory processing decline associated with normal aging (Freiherr *et al.*, 2013); the fact that unisensory impairments have been linked to various adverse health behaviors including slower gait speed (Kaye *et al.*, 1994), functional decline (LaForge *et al.*, 1992), increased risks of falls (Lord *et al.*, 1999), worse quality of life (Carabellese *et al.*, 1993); and the notion that a common underlying neural mechanism is responsible for age-related declines in sensory, cognition, and motor functioning (Baltes and Lindenberger, 1997; Lindenberger and Baltes, 1994). There is growing evidence for differential multisensory integrative processing in old *versus* young adults, but this research is still in its early stages. While the majority of these MSI studies demonstrate increased RT facilitation for older compared to younger adults using auditory–visual (Laurienti *et al.*, 2006; Mahoney *et al.*, 2011; Mozolic *et al.*, 2012; Peiffer *et al.*, 2007) and visual–somatosensory (Mahoney *et al.*, 2011) stimuli, most fail to report the behavioral or clinical implications associated with such increased MSI effects.

At present, it is unclear whether increased RT facilitation effects to multi-sensory stimuli are actually beneficial for elders. In a recent visual–somatosensory integration experiment highlighting the utility of MSI in aging, the existence of differential patterns of multisensory processing based on the individual's most resilient unisensory system were reported and our results indicated that older adults requiring less MSI RT facilitation actually maintained better balance and reported less falls (Mahoney *et al.*, 2014a). While these results were in line with previous findings linking increased susceptibility to a multisensory AV illusion with increased falls (Setti *et al.*, 2011) and poorer balance (Stapleton *et al.*, 2013), we argued that successful integration between visual and somatosensory systems is likely more important for balance maintenance, as supported by evidence from early multisensory training studies of balance in older adults (Hu and Woollacott, 1994a, b). Nevertheless, our findings revealed that older adults may require increased RT facilitation to maintain adequate sensory–motor functioning, suggesting that MSI could play a compensatory role in overcoming age-related declines in unisensory processing (Mahoney *et al.*, 2014a).

There is good reason to believe that there is an inherent association between physical activity level and multisensory integrative processes in the elderly. As the adult ages, alterations in visual, somatosensory, proprioceptive, and vestibular systems are increasingly common. These alterations limit sensory integration capabilities in the central nervous system, resulting in reduced sensory and motor resources essential to maintain adequate postural control (Shumway-Cook and Woollacott, 2012), which in turn are ultimately necessary for more complex motor activities like physical activity (Barela *et al.*, 2003). Results from Prioli *et al.* (2004), who investigated the link between sensory integration, postural control, and physical activity in older adults, reported that sedentary seniors have more difficulty integrating sensory information compared to active seniors and younger adults, and further suggested that physical activity may improve sensory integration. Similarly, other researchers have reported the beneficial effects of engaging in physical activities (Perrin *et al.*, 1999) and more specifically dancing (Kattenstroth *et al.*, 2011, 2013) on both posture and balance, stating that regular engagement in such activities can potentially counteract various age-related balance disorders. Surprisingly, however, there have been no studies linking physical activity levels to quantitative measures of multisensory integration.

In an effort to further elucidate the utility of MSI and its relationship with sensory–motor functioning in aging, the aim of the current experiment was to determine whether magnitude of visual–somatosensory RT facilitation is linked to level of physical activity in a large group of community-dwelling older adults. Here, we used visual and somatosensory stimulation that individuals likely encounter on a day-to-day basis (e.g., light-emitting-diodes (LEDs) and pager vibrators found in mobile phones). We hypothesized that differential integrative processes would be linked to varying levels of physical activity, where elders requiring increased RT facilitation would report low engagement in total physical activity days per month.

2. Material and Methods

2.1. Participants

A total of 208 participants recruited from the Central Control of Mobility in Aging (CCMA) study at the Albert Einstein College of Medicine (AECOM) in Bronx, NY participated in the current study. However, 13 participants were unsuccessful at providing any RT responses using the foot pedal; 38 participants were excluded due to accuracy of less than 70% on any one of the three sensory conditions; and 10 participants were not included because responses to the physical activity questionnaire were not available. Thus, a total of 147 older adults (age range 66–92 years) were included in the current study. CCMA study procedures have been previously described (see Holtzer *et al.*, 2014a, 2014b; Mahoney *et al.*, 2014a). All participants provided written informed consent to the experimental procedures, which were approved by AECOM's institutional review board.

Participants were deemed non-demented using reliable cut scores from the AD8 Dementia Screening Interview (cutoff score ≥ 2; Galvin *et al.*, 2005) and the Memory Impairment Screen (MIS; cutoff score < 5; Buschke *et al.*, 1999) and diagnosis was confirmed using consensus clinical case conference procedures (see Holtzer *et al.*, 2008). Global cognitive status was assessed with the Repeatable Battery for Assessment of Neuropsychological Status (RBANS; Duff *et al.*, 2008). Global disease summary scores (range 0–10) were obtained from dichotomous rating (presence or absence) of physician diagnosed diabetes, chronic heart failure, arthritis, hypertension, depression, stroke, Parkinson's disease, chronic obstructive pulmonary disease, angina, and myocardial infarction (Mahoney *et al.*, 2011, 2014a).

All participants were required to successfully complete a sensory screening exam. For the purposes of this study, visual acuity was reported as the highest (i.e., best) monocular value on the Snellen eye chart. A computerized tone-emitting otoscope that delivered lateral and bilateral 20, 25, and 40 dB tones at 500, 1000, 2000, and 4000 Hz using E-prime 2.0 software (Psychology Software Tools, Inc. (PST), Pittsburgh, PA, USA) was employed to assess hearing loss; where individuals that were unable to hear a 2000 Hz tone at 25 dB in both ears were not included in the study. Presence of neuropathy in hands was based on the study neurologist's clinical evaluation. Participants were excluded if the neurologist confirmed significant neuropathy in the hands that would preclude accurate detection of the experimental stimulation.

2.2. Stimuli and Task Procedures

Participants responded to three different sensory conditions [visual (**V**), somatosensory (**S**) and multisensory (**VS**)]. Stimuli were produced from a custom built stimulus generator (Zenometrics, LLC; Peekskill, NY) that contained two control boxes, each consisting of 0.6″ diameter blue light emitting diodes (LEDs) and a 1.2″ × 0.8″ × 0.5″ plastic housing containing a vibrator motor with 0.8 G vibration amplitude (see Fig. 1A). The devices were cycled on and off at precise intervals either alone (unisensory conditions) or in combination (multisensory VS condition) through the computer's parallel port. A TTL (transistor–transistor-logic, 5 V, duration 100 ms) pulse was used to trigger each stimulus and the inter-stimulus interval (ISI) varied randomly from 1.0 to 3.0 s to avoid anticipatory effects. Participants rested their fingers around the somatosensory vibrators with their thumb placed on the front of box and four fingers behind the box against the actual vibration elements that are similar to vibrators used in toys, pagers, and cell phones (see Fig. 1). Stimuli were presented in random order with equal frequency using E-prime 2.0 software; in total, there were three blocks of 45 trials (15 trials per condition per block; see Fig. 1B).

Participants were seated comfortably in a well-lit room with their arms rested on the custom built apparatus and were required to look at a fixation point (a bull's eye target with a center circle diameter of 0.4 cm) visible on a central 'dummy' control box (see Fig. 1A). The viewing distance was set at 57 cm and the fixation circle subtended a visual angle of 0.4°. The active control boxes were located 18° from the left and right of the central control box. RT and accuracy data were collected as participants performed a simple RT task by pressing a foot pedal located under their right foot as quickly as possible in response to all stimuli.

2.3. Physical Activity Level

The World Health Organization (WHO, 2010) defines physical activity "as any bodily movement produced by skeletal muscles that requires energy expenditure — including activities undertaken while working, playing, carrying out household chores, traveling, and engaging in recreational pursuits". We implemented a modified version of Verghese and colleagues' validated physical activity scale (Verghese *et al.*, 2003) to determine each participant's current level of physical activity. Individuals were first asked to report the number of days in the last month that they engaged in physical activity or sport. Next, they were asked to report whether or not they engaged in one of the following physical activities (tennis, golf, bowling, swimming, cycling, calisthenics, dancing, walking, jogging, hiking, yoga, meditating). For the purposes of this study, participation in household related tasks was not included as we were interested in assessing participation of physical activities outside of the home.

2.4. Statistical Approach

Mean RTs to unisensory visual, somatosensory, and multisensory VS conditions were group averaged. Individual RTs were recorded for each trial and only trials with correct responses were analyzed. As in our previous studies, trials with RT responses < 100 ms and trials that exceeded ±2 standard deviations from the individual mean ($<5\%$ per condition) were excluded (Mahoney *et al.*, 2011, 2012, 2014a, b).

A 3 × 2 repeated-measures ANOVA tested for the overall MSI RT facilitation effect, as well as the main effect of MSI classification, and the interaction between the two variables. The within-subject factor was RT to sensory condition (unisensory **V**, unisensory **S**, and multisensory **VS**) and the between-subjects variable was MSI classification (MSI *vs.* NO MSI group). Huynh–Feldt corrections were used when appropriate. Simple contrast analyses were used to determine the differential effects of multisensory stimulus processing by comparing the RT of the multisensory condition to the RTs of the two constituent unisensory conditions.

Results from our very recent study confirm the existence of differential MSI processes across older adults (Mahoney *et al.*, 2014a). Here, using a similar approach, we examined the mean MSI RT facilitation effects (or ‘MSI effects’) on an individual basis by subtracting RTs to the VS condition from the RTs to the shortest (i.e., most efficient) unisensory condition. Each of the 147 participants was classified into one of two groups; those that demonstrated RT facilitations to multisensory stimulation (MSI group) and those who demonstrated no to negligible RT facilitations (NO MSI group). Specifically, we compared RT facilitation effects of individuals in the lowest quartile to RT facilitation effects from the rest of the sample; the cutoff for the lowest quartile was equal to 16.1 ms. Of the 36 individuals in the NO MSI group, 14 individuals’ demonstrated negative RT facilitation effects where RTs to S stimuli were marginally faster than RTs to VS stimuli. The other 22 individuals had positive RT facilitation effects where RTs to VS stimuli were not materially shorter from RTs to unisensory stimuli (range 1–16 ms). If however, the participant demonstrated a RT facilitation greater than 16 ms, the person was said to exhibit a MSI effect, where RTs to VS stimuli were materially different from RTs to unisensory stimuli (range 16.5–96 ms shorter). Actual and predicted cumulative probability (CP) distribution waveforms were subsequently plotted by MSI classification to further corroborate existence of differential MSI patterns in this elderly sample.

2.4.1. Test of the Race Model

RTs were sorted in ascending order by stimulus condition and then averaged on an individual basis. For each participant, the RT range within the valid RTs was calculated across the three stimulus conditions and quantized into twenty bins from the fastest RT (or zero percentile) to the slowest RT (hundredth percentile) in 5% increments (0%, 5%, . . ., 95%, 100%). Differences between *actual* CP distributions [$P(\mathrm{RT}_{XY} \leq t)$] and *predicted* CP distributions {$\min[P(\mathrm{RT}_X \leq t) + P(\mathrm{RT}_Y \leq t)]$} were calculated across each time bin across all participants (see Mahoney *et al.*, 2014a for specifics); where values greater than zero are indicative of race model violation, providing support for multisensory integrative processes.

2.4.2. MSI and Physical Activity Level—Hierarchical regression analyses were performed with physical activity level as the dependent variable, and RT facilitation effect (actual RT difference in ms) as the predictor in Step 1 (unadjusted model). Additional covariates, such as age, gender, and ethnicity, were entered into Step 2. In Step 3, presence of neuropathy, visual acuity, and global health status were added as covariates. A chi-square analysis was conducted to determine whether older individuals within MSI classifications reported differential engagement in the highest endorsed physical activity. All data analyses were run using IBM's Statistical Package for the Social Sciences (SPSS), Version 20.0 (IBM Corp., released, 2011).

3. Results

3.1. Demographics

One hundred and forty-seven older adults (mean age 77.20 ± 6.39 years; 57% female) participated in the current experiment. None of the participants met criteria for dementia using established clinical consensus case-conference procedures (Holtzer *et al.*, 2008). All participants were deemed relatively healthy as determined by their global health status. Of the 147 participants, 124 were right-handed as assessed by the Edinburgh handedness inventory (Oldfield, 1971). Table 1 delineates additional demographic information including but not limited to mean education level (in years), RBANS total score, Geriatric Depression Scale (GDS; Yesavage *et al.*, 1982) score, visual acuity, overall RT in milliseconds (ms), and total physical activity days per month. The highest endorsed physical activity in this sample was walking, which included brisk-walking.

3.2. MSI Results by Classification

Overall, participants maintained 92% accuracy for the somatosensory trials, 93% accuracy for the visual trials, and 92% accuracy for the VS trials. Individuals in the NO MSI group ($n = 36$) maintained 90% accuracy for the somatosensory trials, 92% accuracy for the visual trials, and 90% accuracy for the VS trials, while individuals in the MSI group ($n = 111$) maintained 92% accuracy for the somatosensory trials, 94% accuracy for the visual trials, and 92% accuracy for the VS trials. Only correct trials were included in the current analyses. Performance accuracy for individuals in the NO MSI *vs.* MSI group was not materially different for the somatosensory ($p = 0.03$), visual ($p = 0.09$), or VS ($p = 0.19$) conditions when examined using simple t-tests with Bonferroni corrections ($p \leq 0.02$). In terms of reaction time, mean RT values (with SEM bars) to the multisensory VS condition are displayed next to the constituent unisensory conditions in Fig. 2.

Results from the 3 × 2 repeated-measures ANOVA indicated a main effect of sensory condition ($F(2, 144) = 190.34$, $p < 0.001$). Simple contrast analyses revealed that mean RTs to multisensory VS stimuli were significantly shorter than mean RTs to visual ($F(1, 145) = 121.47$, $p < 0.001$) and somatosensory [($F(1, 145) = 375.47$, $p < 0.001$) stimuli; also see Fig. 2 —first set of bars]. Results also revealed a significant interaction of sensory condition ×

MSI classification ($F(2, 290) = 10.37$, $p < 0.001$) indicating that the effect of RT facilitation varied based on MSI classification. That is, participants in the MSI group had significantly shorter mean RTs to VS stimuli than to visual ($F(1, 110) = 534.32$, $p < 0.001$) and somatosensory ($F(1, 110) = 614.15$, $p < 0.001$) stimuli, whereas participants in the NO MSI group demonstrated mean RTs to visual stimuli that were not materially different than the mean RTs to the multisensory VS stimuli ($F(1, 35) = 2.60$, $p = 0.12$; see Fig. 2). The reaction time profile of the individuals in the NO MSI *vs.* MSI group differed predominately based on RTs to the unisensory visual condition, however these group differences were not significant ($p = 0.26$; see also overlapping SEM bars in Fig. 2).

3.3. Race Model Results

Difference waveforms between actual and predicted CP distributions for the overall group (solid black trace), as well as the two MSI classifications and are depicted in Fig. 3. Again, positive values represent a violation in the race model (i.e., support for multisensory integrative processing) and were significant over the fastest quartile of RTs (shaded box) for the overall sample. The difference waveforms by MSI classification corroborate the existence of differential MSI patterns in this elderly sample, where individuals in the NO MSI group (dot-dashed grey trace) never violate the race model, compared to individuals in the MSI group (dashed grey trace) who demonstrate significant race model violations over the fastest quartile of RTs.

In order to determine the reliability of each violation, one-way ANOVAs were conducted over the first 25% of all RTs and Bonferroni corrections were applied to adjust for multiple comparisons. Significant race model violation was obtained for the overall group as well as for the MSI group ($p \leq 0.01$).

3.4. Physical Activity and MSI Classification

Total number of physical activity days per month is listed in Table 1 by group. Results from the hierarchical regression are presented in Table 2. The total number of physical activity days was 16 (± 12 days per month) for individuals in the NO MSI group and 10 (± 10 days per month) for individuals in the MSI group. In the unadjusted model (1), *the RT facilitation effect* was a significant predictor of total number of physical activity days ($\beta = -0.18$, $p \leq 0.05$). *RT facilitation effect* remained a significant predictor of total number of physical activity days even after controlling for age, gender, ethnicity, presence of neuropathy, visual acuity, and global health score in models 2 and 3 ($\beta = -0.20$, $p \leq 0.05$).

Table 3 delineates the percent of elders that reported engaging in various physical activities in rank order by MSI classification. Here, the highest endorsed physical activity was walking, which included brisk walking. A chi-square analysis revealed that significantly more individuals in the NO MSI group (70%) reported walking for physical activity compared to individuals in the MSI group (49%; $\chi^2 = 4.73$; $p \leq 0.05$).

4. Discussion

Results from the current experiment confirm that overall older adults demonstrate significant VS multisensory RT facilitation effects that are consistent with previous MSI discoveries in aging (Laurienti *et al.*, 2006; Mahoney *et al.*, 2011, 2014a, b; Peiffer *et al.*, 2007). Our findings further indicate the presence of differential patterns of multisensory processing in aging based on the individual's most resilient unisensory system; where individuals in the NO MSI group, those with RT facilitation effects in the lowest quartile, demonstrated no statistical difference in RTs to VS compared to RTs to the fastest unisensory condition. The robustness of the differential MSI patterns was further exemplified by race model acceptance for the NO MSI group which demonstrated that RTs to VS stimuli were merely triggered by the visual input, and that the somatosensory input was of little to no help in facilitating the multisensory response.

In terms of the value of MSI, older adults in the NO MSI group reported significantly greater engagement in physical activities compared to elders in the MSI group, even after controlling for many important covariates. The current findings are directly in line with our previous findings where older adults with no to very little RT facilitation demonstrated significantly better balance and reported less history of falls (Mahoney *et al.*, 2014a) compared to older adults requiring increased levels of RT facilitation. In the current study, walking (which also included brisk walking) was the highest endorsed activity for this older sample. Furthermore, elders requiring no to very little RT facilitation to multisensory stimulation were significantly more likely to engage in this activity compared to those elders requiring greater levels of RT facilitation.

As the adult ages, alterations in sensory systems limit sensory integration capabilities in the brain, resulting in reduced sensory and motor resources essential to maintain adequate balance/postural control (Shumway-Cook and Woollacott, 2012), which are in turn necessary for more complex motor activities like physical activity (Barela *et al.*, 2003). The current experiment was designed to determine if RT facilitation effects to multisensory stimuli could predict participation in physically demanding tasks. Our present findings are in line with previous research reporting the beneficial effects of older adults engaging in physically demanding activities (Kattenstroth *et al.*, 2010, 2011, 2013; Perrin *et al.*, 1999) on not only postural control/balance, but also on efficiency of sensory function.

In the limited number of MSI and aging experiments, the finding that older adults' manifest larger RT facilitation effects compared to younger adults has been attributed to age-related degenerative changes in neuronal architecture. The neuroanatomical correlates, including neural connectivities of VS integration are not well-established in older adults. The basic circuitry of the sensory systems involves a series of interactive neuronal loops (both feedback and feedforward) between the thalamus — which plays a critical role in cortico-cortical communication and integration of sensory information (Sherman, 2005; Sherman and Guillery, 1996) — primary sensory regions, and multisensory cortical areas (e.g., STS) in order to effectively process sensory and higher-order information (Schroeder and Foxe, 2004). Research suggests that these loops are compromised with age, resulting in impaired information processing in the aging brain that has been attributed to various theoretical models such as dedifferentiation (Dustman and Snyder, 1981); compensatory reallocation (Cabeza, 2002; Cabeza *et al.*, 2002); or neural compensation (Stern *et al.*, 2005). Compensatory models of aging seem most appropriate here as they suggest that alternate brain networks are recruited to help older adults compensate for age-related differences

(Stern *et al.*, 2005). Thus, it is reasonable to contend that multisensory RT facilitation is a compensatory process used to overcome age-related physiological declines in unisensory functioning.

Future neuroimaging studies are clearly necessary to corroborate and further develop this concept. While speculative, it could be the case that increased RT facilitation in aging brains might be associated with (1) reduced brain volume in known multisensory (e.g., thalamus or STS) and motor/balance (e.g., primary motor cortex, prefrontal regions, and cerebellar) areas; and/or (2) sensory re-weighting defined as a decrease in overall connectivity between multisensory brain regions and these motor/balance areas. Unfortunately, direct support for these suppositions is not readily available given the limited number of studies investigating the neuroanatomical utility of MSI in aging. Nevertheless, and in keeping with the current findings, studies examining the effect of physical and motor activity on neural plasticity in the elderly report changes in specific neuronal networks and connectivities between various known multisensory and motor regions including: thalamus, prefrontal cortex, premotor areas, parietal cortex, superior temporal gyrus, and the superior parietal lobule (e.g., Colcombe, 2004; Voelcker-Rehage *et al.*, 2010, 2011, and Voss *et al.*, 2010; but also see Hötting and Röder, 2013 and Voelcker-Rehage and Niemann, 2013 for a detailed review). Alterations in these brain regions, specifically in white matter tract connectivity and/or overall activity of direct pathways in both uni- and multi-sensory regions, could lead to more efficient unisensory processing, which in turn could ultimately enhance not only processing speed, but also the efficiency of integrative processes. Clearly future research is required to validate the accuracy of this assumption.

It is not surprising that the use of different physical stimuli in the current experiment resulted in a different RT profile, where RTs to visual LEDs were faster on average than RTs to small vibrations. This finding is in stark contrast to our previous experiments where RTs to electrical pulses were faster on average than RTs to visual asterisks displayed on a computer monitor (Mahoney *et al.*, 2014a). As stated earlier, the objective of the current experiment was to investigate multisensory RT facilitation effects using more naturalistic visual and somatosensory stimuli that people are likely to encounter on a daily basis. While we are cognizant of the fact that different physical sensory stimulation affords different psychophysical responses — depending on many variables including sensory modality, intensity, age, physical health, response pads, etc. (Woodworth and Schlosberg, 1954) — what is most compelling is that regardless of the actual unisensory stimulators, the association of RT facilitation with important sensory–motor outcomes, like balance, falls, and physical activity level remains significant. These findings stress the impact of unisensory processing on the likelihood of multisensory integration and suggest that unisensory processing might be a mediator between RT facilitation and important motor outcomes like balance, falls, and physical activity. However, future studies will be required to test this very important hypothesis.

This study is not without its limitations as the association between physical activity level and RT facilitation is not causal; thus it remains unclear at present whether increased RT facilitation causes one to participate in less physical activities or whether individuals that engage in less physical activities have a need for increased (i.e., compensatory) multisensory processing —clearly, the latter seems more appropriate given the inherent lack of exposure to multisensory stimulation (excluding television watching) in more sedentary lifestyles. It seems plausible that the link between physical activity and MSI could be due to the notion that increased exposure to physical activity can ameliorate declines in age-related performance (see Kattenstroth *et al.*, 2013). Here, increased engagement in physical activity could potentially lead to a decreased need for compensatory MSI processing to fulfill this task, or for that matter everyday tasks, given the known positive effect of physical activity on posture, balance, and sensory function (Kattenstroth *et al.*, 2010, 2011, 2013). Additionally, studies from Voelcker-Rehage and colleagues (2010, 2011) examining the relationship between physical (cardiovascular and motor coordinative) fitness and cognition in aging report that increased exposure to physical activities, particularly those demanding visual–spatial integration, improved perceptual speed; further supporting the idea that increased engagement in physical activities could diminish the need for compensatory multisensory processing. Alternatively, it could be that people with better sensory functioning and health might be more likely to engage in physical activities and require less RT facilitation without a direct link between the two. Further, it could even be the case that this association is due to extraneous variables like subtle declines in overall sensory functioning and health. Nevertheless, this is the first study to report an association between level of physical activity and MSI; future studies are clearly warranted to further investigate this association. In conclusion, this study confirms the existence of differential patterns of VS integration, while detailing the utility of MSI in predicting physical activity level in older adults.

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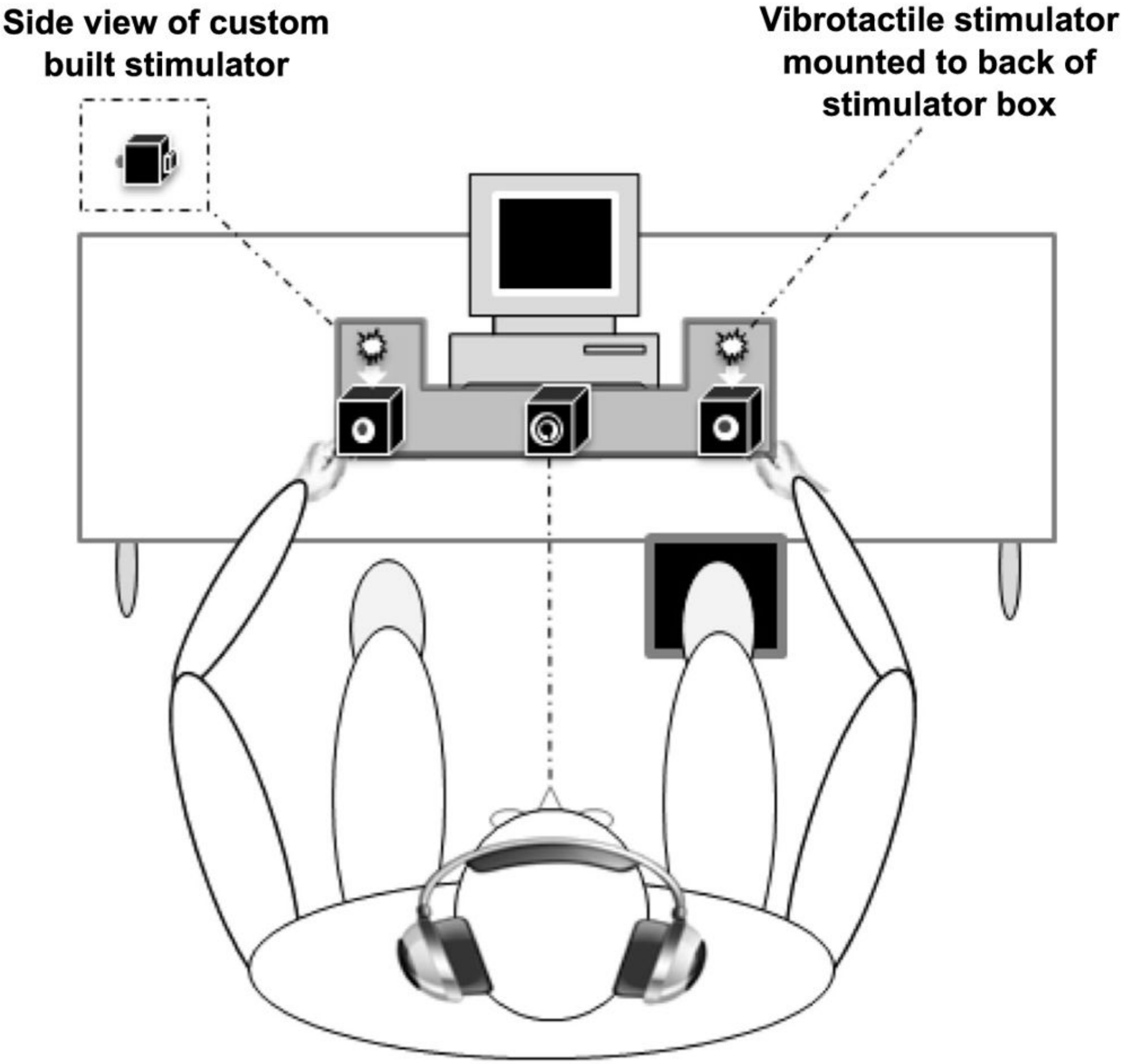
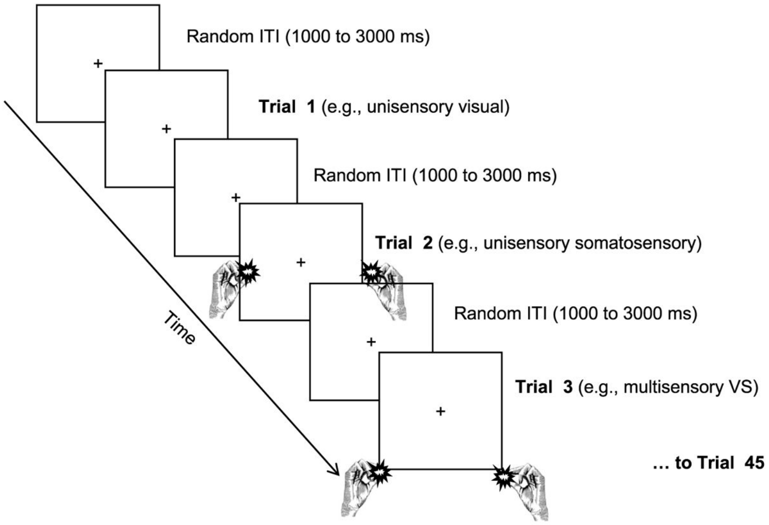

Side view of custom built stimulator
Vibrotactile stimulator mounted to back of stimulator box

(A)



(B)

Figure 1.

Experimental procedures. (A) Apparatus: Participants rested hands comfortably on a custom-built apparatus while maintaining fixation on a target, and were required to make speeded responses to all stimuli, regardless of sensory modality, by pressing a foot pedal located under their right foot. (B) Sequence of events: Three blocks of V, S, and multisensory VS stimuli (45 trials per block) were randomly presented with random inter-trial-intervals (ITIs) of 1–3 s.

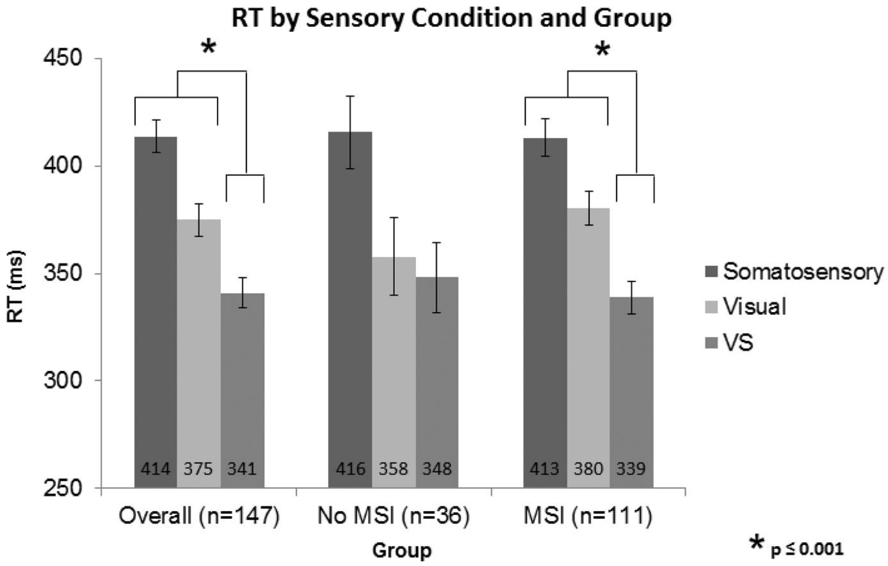


Figure 2.

Averaged RT data by modality. Mean RT values (with SEM bars) for VS, V, and S for the overall group and the two MSI classifications.

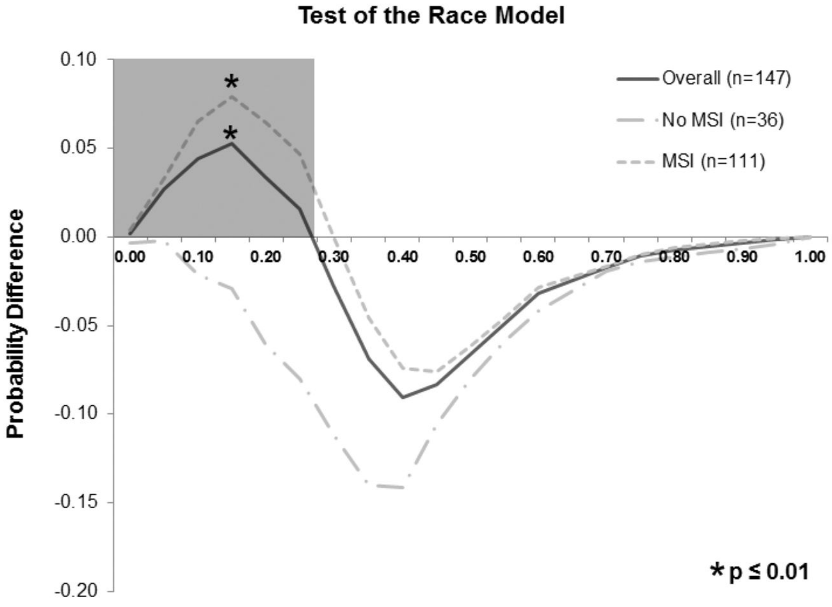


Figure 3.

Results of Miller's test of the race model. The cumulative probability difference waves (actual minus predicted) over the trajectory of averaged responses for the overall group and the two MSI classifications. The shaded grey box represents the fastest quartile of RTs (i.e., 25th percentile). Values greater than zero indicate violations of the race model.

Table 1

Participant demographics

	Overall	**NO MSI**	**MSI**
Sample size	147	36	111
Age (years)	77.20 (6.39)	77.28 (6.75)	77.18 (6.30)
Education (years)	14.61 (2.80)	14.17 (2.78)	14.75 (2.80)
Global health scale score (0–10)	1.17 (1.00)	1.44 (1.11)	1.08 (0.95)
% Female	57	56	57
% Caucasian	80	72	82
% With neuropathy	6	3	7
% Right handed	86	86	85
% Walkers	54	70	49
RBANS total score standard score (55–145)	94.98 (13.28)	94.53 (12.85)	95.13 (13.47)
Geriatric Depression Scale (0–30)	4.65 (3.70)	4.58 (3.59)	4.68 (3.75)
Visual acuity (0.2–1.00)	0.53 (1.53)	0.53 (1.44)	0.53 (1.56)
Overall RT (ms)	376.22 (86.74)	373.42 (96.32)	377.13 (83.85)
RT facilitation effect (ms)	29.65 (25.04)	−1.59 (19.99)	39.78 (16.79)
Total physical activity days per month (0–30)	11.19 (10.60)	15.81 (11.80)	9.66 (9.76)

Mean values (± SD) unless otherwise noted.

Table 2

Summary of linear regression model for predicting physical activity level (physical activity days per month)

Model		Coefficients						
		Unstandardized coefficients		**Standardized coefficients**	***t***	**Sig.**	**95.0% Confidence interval for *B***	
		B	**Std. error**	**β**			**Lower bound**	**Upper bound**
1	RT facilitation effect	−0.08	0.03	−0.18	−2.22	0.03	−0.15	−0.01
2	RT facilitation effect	−0.08	0.03	−0.19	−2.31	0.02	−0.15	−0.01
	Age	0.03	0.14	0.02	0.24	0.81	−0.24	0.31
	Gender	0.35	1.83	0.02	0.19	0.85	−3.26	3.96
	Ethnicity	−2.23	1.73	−0.11	−1.29	0.20	−5.64	1.19
3	RT facilitation effect	−0.08	0.03	−0.20	−2.43	0.02	−0.15	−0.02
	Age	0.00	0.14	0.00	−0.03	0.98	−0.28	0.27
	Gender	0.63	1.79	0.03	0.35	0.73	−2.91	4.17
	Ethnicity	−2.59	1.72	−0.13	−1.51	0.13	−5.99	0.81
	Neuropathy	−10.31	3.88	−0.22	−2.65	0.01	−17.99	−2.63
	Visual acuity	0.03	0.07	0.03	0.39	0.69	−0.11	0.16
	GHS score	−1.01	0.88	−0.10	−1.15	0.25	−2.74	0.73

Table 3

Percent of elders engaged in individual physical activities by MSI classification

Activity	NO MSI group	MSI group
Walking/jogging	70	49
Meditation	39	23
Yoga	36	23
Babysitting	22	19
Weight training	17	19
Aerobics	11	15
Calisthenics	14	11
Swimming	8	10
Dancing	8	8
Cycling	8	5
Golf	3	7
Tennis	3	4
Bowling	3	3
Hiking	3	2