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Inhibitory processes relate differently to balance/reaction time dual tasks in young and older adults

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Abstract

Inhibitory processes have been suggested to be involved in maintaining balance in older adults, specifically in the integration of sensory information. This study investigated the association between inhibition and the ability to shift attention between auditory and visual modalities during a balance challenge. Young (21–35 yrs; $n=24$) and older (70–85 yrs; $n=22$) healthy subjects completed tasks assessing perceptual inhibition and motor inhibition. Subjects then performed dual-task paradigms pairing auditory and visual choice reaction time tasks with different postural conditions. Sensory channel switch cost was quantified as the difference between visual and auditory reaction times. Results showed that better perceptual and motor inhibition capabilities were associated with less sensory switch cost in the old (perceptual inhibition: $r=0.51$; motor inhibition: $r=0.48$). In the young, neither perceptual nor motor inhibition was associated with sensory switch cost. Inhibitory skills appear particularly important in the elderly for processing events from multiple sensory channels while maintaining balance.

Keywords

balance; inhibition; dual-task; posturography; aging

Introduction

In recent years, it has become clear that cognition plays a role in balance, especially in older adults (Brauer, Woollacott, & Shumway-Cook, 2001; Horak, 2006). The amount of cognitive processing necessary to maintain balance is dependent both on the complexity of

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any concurrent tasks and on the individual's postural control system capabilities (Horak, 2006). The relationship between cognition and balance has been explored using dual-task paradigms, in which participants must maintain balance while performing information processing tasks (Redfern, Muller, Jennings, & Furman, 2002; Shumway-Cook & Woollacott, 2000). Of particular interest is how elements of executive function relate to balance differentially between young and older adults.

Executive function is a construct that encompasses many cognitive processes such as initiating and inhibiting actions, planning, working memory, and aspects of cognitive flexibility and judgment (Salthouse, Atkinson, & Berish, 2003). Inhibition can be thought of broadly as the ability to control or prevent automatic tendencies not appropriate to the current task or environmental context. Recently, two separable components of inhibition have been defined that act at different points during information processing (Nassauer & Halperin, 2003). Perceptual inhibition acts early in sensory processing to screen out stimulus information that, while highly salient, is irrelevant to the demands of the task. Motor inhibition is also required later to prevent execution of automatic or prepotent motor responses inappropriate to the present situation (Hasher, Zacks, & May, 1999). Perceptual inhibition and motor inhibition appear to involve distinct cognitive networks which can be separately assessed by different tasks (Nassauer & Halperin, 2003).

Inhibitory function appears to decline as people age although both the degree of empirical support for this and the mechanisms continue to be discussed (Hasher, Zacks, & May, 1999; Hasher, Lustig, & Zacks, 2007; McDowd, 1997; Grant & Dagenbach, 2000). A portion of this discussion focuses on whether a generalized slowing with aging can account for findings that appear to be implicated in more complicated processes, such as inhibitory function (Bugg, Zook, DeLosh, Davalos, & Davis, 2006; Schretlen et al., 2000). A decline in inhibitory function has been suggested as one mechanism for reduced postural control in some older adults (Redfern, Jennings, Martin, & Furman, 2001). Redfern et al. (2001) utilized a go/no-go (inhibitory) reaction time task concurrent with various standing postural tasks and found the 'go' reaction time increased during high sensory conflict postural conditions (i.e. when vision and proprioception give conflicting information). They suggested that sensory integration for postural control may require inhibitory processes that were then unavailable to process potential inhibitory signals in the go/no-go task. However, research into the relation between inhibitory function and balance paradigms has been limited. Neuropsychological measures of other aspects of executive function, such as working memory and planning, have been associated with general dual-task performance in older adults and in traumatic brain injury (Holtzer, Stern, & Rakitin, 2005; McDowell, Whyte, & D'Esposito, 1997); however, inhibitory function has not been specifically examined in relation to dual-task balance measures. Since superior dual-task performance may be achieved by timely decision making under adaptive executive control (Schumacher et al., 2001), inhibitory function should be related to dual-task measures.

Our recent balance dual-task work has suggested that the sensory modality of the information processing task impacts attentional streams used to maintain balance when participants are standing (Redfern & Musolino, 2007; Redfern, Muller, & Jennings, 2008). Attention to the visual stream for maintaining balance appeared to facilitate or, at least, not

interfere with a concurrent visual information processing task. By contrast, the non-visual task, the auditory task, was negatively affected during this same standing condition. Based upon this finding, we hypothesized that adaptability in switching attention between different sensory streams would impact the degree to which interference between postural control and information processing would occur in the visual and auditory tasks. For example, performing an auditory information processing task concurrent with a postural task when visual processing for balance is high would require increased ability to switch between visual and auditory channels to perform both tasks. Clearly, perceptual inhibitory function could be involved in this adaptability, but motor inhibitory function may be involved as well. We define “sensory switch cost” during our tasks as the cost (greater time required) of switching between sensory modalities of the information processing task while maintaining postural control. Lower sensory switch cost would result in minimal impact of the sensory channel on the dual-task results (i.e., a person with low sensory switch cost will not take significantly longer to complete auditory tasks as compared to visual tasks during a dual-task paradigm). Thus, in this study we use the difference between the auditory and visual reaction times when performed during the standing postural challenge, termed the dual-task difference (DTD), as a measure of sensory switch cost during standing postural control. We hypothesized that DTD would be correlated with motor and perceptual inhibition solely when the sources of information necessary for balance maintenance conflicted. Such conflicts occur only in the standing conditions and only when visual input is present, i.e. light conditions. The correlations should be higher when visual information is processed within the conflicting condition produced by sway referencing the visual score or sway referencing the support platform, i.e. by making the platform or the visual scene move with the balance adjustments made by the participants. Perceptual inhibition was anticipated to correlate well with all conditions with the possible added correlation of motor inhibition when the platform was sway referenced.

The original auditory and visual reaction times used to determine the DTDs were reported in a recent publication (Redfern, Muller, & Jennings, 2008). Briefly, reaction times were longer during conditions where sensory integration requirements were high (i.e. when sensory information for balance was in conflict) compared to conditions where vision and proprioception were veridical. The changes in RTs due to postural conditions also varied depending upon the information processing task (auditory versus visual). Changes in auditory RTs were affected by the postural conditions of sensory conflict more than visual dRTs, suggesting that sensory compatibility between balance and the information processing tasks (i.e. the requirements for vision for balance) facilitates performance of the task. Interestingly, there were no effects of aging on the impact of postural condition on RTs, suggesting that once sensorimotor slowing is accounted for by subtracting the seated baseline RTs, the healthy older adults had similar dual-task effects for the more challenging postural conditions.

The primary aim of this study was to investigate the relationship between measures of inhibition and sensory switch cost during postural dual-task paradigms in young and older adults. Specific performance-based measures of perceptual and motor inhibition were based upon the procedures of Nassauer and Halperin (Nassauer & Halperin, 2003). Our dual-task balance paradigms included two information processing tasks and both auditory and visual

choice reaction times, obtained during different standing balance conditions. We then computed the DTD as a measure of sensory switch cost during the dual-task paradigms. Mechanistically, subjects who perform equally well on the auditory and visual tasks (i.e., have good sensory switch cost and small DTD scores) during posturally challenging conditions are skilled at both deemphasizing the visual modality necessary for postural control when an auditory task is presented and deemphasizing the auditory modality to focus on the visual modality to maintain balance between auditory tasks. We theorize that perceptual inhibitory functioning is involved in this process and that motor inhibitory function may be related to subsequent regulation of balance adjustment. Thus, we hypothesized that participants who demonstrate superior ability to switch attentional focus between modalities during posturally challenging conditions would demonstrate better perceptual and/or motor inhibition. This relationship may not differ based on age, but older adults may have less inhibitory capability. Thus, we hypothesized that inhibitory function would be correlated with sensory switch cost, and aging effects on both performance speed and inhibition might accentuate the relationships in older adults.

Methods

Participants

Twenty four young, healthy adults (mean age 25.8 years, s.d. 3.9 years, range 21–34 yrs; 12 female, 12 male) and twenty two healthy older adults (mean age 74.3 years, s.d. 4.5 years, range 70–82 yrs; 12 female, 10 male) with no history of vestibular or neurological disorders participated in this study. Informed consent was obtained prior to any participation.

All subjects were screened for sensory, cognitive and musculoskeletal health. Normal vestibular function was confirmed with caloric and rotational vestibular testing (Furman & Cass, 1996), as well as clinical dynamic posturography (Equitest, Inc). Sensory function was normal, including: 1) a binocular visual acuity (with corrective lenses) of better than 20/40, 2) normal audiogram, and 3) proprioceptive and cutaneous sensation as determined using ankle angle proprioception tests and Semmes-Weinstein monofilaments, with an exclusionary cut-off of 5.07.

Perceptual and Motor Inhibition Tests

Inhibitory functioning was evaluated using a cognitive test paradigm adapted from Nassauer and Halperin (Nassauer & Halperin, 2003). This test measures two separable components of inhibitory function: Perceptual Inhibition (PI) and Motor Inhibition (MI). The test is based upon reaction times to specific stimuli on a computer screen. The stimulus consisted of an arrow 3.7 cm long pointing either to the right or left. Subjects held the index fingers of their right and left hands on two response keys. The stimuli were presented until the subject responded. A visual fixation point, indicated by a central cross, disappeared with onset of the stimulus.

For the PI task, a right- or left-pointing arrow appeared 8.5 cm to the right or left of the central fixation and the subject was to press the button on the side toward which the arrow pointed. There were two conditions: Congruous and Incongruous. In the Congruous

condition, the spatial location of the arrow (i.e., the side of the screen on which it appeared) was the same as the direction the arrow pointed (e.g., a left-pointing arrow appeared to the left of fixation). In the Incongruous condition, the location of the arrow conflicted with the direction it pointed (e.g., a right-pointing arrow appeared to the left of fixation). In this condition, the subject had to inhibit processing the arrow's location, focusing only on the direction it pointed. There were 40 congruous and 40 incongruous trials randomly intermixed. Note that in this condition the subject always responded on the key congruent with the direction in which the arrow pointed. The subject's median reaction time (RT) and accuracy were determined for each condition.

The MI task consisted of two conditions presented in separate blocks of trials. In the first condition (Congruous) an arrow appeared in the center of the computer screen; on 40 trials it pointed right while on the other 40 it pointed left, with right- and left-pointing arrows being randomly intermixed. Subjects were to press the key on the side toward which the arrow pointed. In the second condition (Incongruous) there again were an equal number of right- and left-pointing arrows, but now subjects had to press the button on the side *opposite* the direction the arrow pointed (e.g., if the arrow pointed right they were to press the left button). Thus, in this condition the subject must inhibit an over-learned spatially compatible response in order to make a response that is spatially incompatible with the presented stimulus.

As a control for sensorimotor speed, a simple reaction time task was also administered in which the subject pressed a button held in the dominant hand as soon as a 1 cm dot appeared in the center of the computer screen. The inter-stimulus interval was preset and varied randomly between 1.5 and 3 seconds so that the subject could not anticipate stimulus onset.

The measures of PI and MI were calculated from the RTs of the various conditions. Median RTs for each participant for each condition were calculated as the subject's response. Individual medians were used instead of means to summarize participant scores to minimize the influence of large outlier RTs in some participants. RT scores were excluded from analysis if accuracy was less than 75% for any task, resulting in the exclusion of the scores of 4 older adults in the MI task. Thus, a MI score could not be calculated for these participants. The MI and PI scores were derived as follows:

$$PI = \text{Perceptual Incongruous condition RT} - \text{Perceptual Congruous condition RT} \quad (1)$$

$$MI = \text{Motor Incongruous condition RT} - \text{Motor Congruous condition RT} \quad (2)$$

Postural Dual-task Paradigms

Instrumentation—Postural challenge during standing was provided in the dual-task experiments using a dynamic posturography platform (Equitest; Neurocom, Inc.). The dynamic posturography platform allows rotations of the support surface and/or rotation of the visual scene about an axis coincident with the ankles (Nashner, Black, & Wall, 1982).

The platform is capable of ‘sway referencing’, where specific rotations of the platform are performed in direct proportion to the individual’s sway in the antero-posterior direction. The result of sway referencing is an attempt to keep the ankle angle constant, which results in unreliable proprioceptive information from the ankles. The same principle is used for sway referencing the visual scene, in an attempt to move the scene with the individual during sway. Visual sway referencing is performed to provide erroneously stable vision even though the person is swaying. Thus, sway referencing creates conditions of sensory conflict stressing the sensory integration capabilities of the individual (i.e. sway referencing the platform reduces reliable proprioceptive information from the ankles, requiring increased reliance on vision and vestibular channels). Six possible postural conditions result from dynamic posturography: 1) fixed visual scene/fixed floor, 2) no visual information (eyes open in the dark)/fixed floor, 3) sway referenced visual scene/fixed floor, 4) fixed visual scene/sway referenced floor, 5) no visual information (eyes open in the dark)/sway referenced floor, and 6) visual sway referenced/sway referenced floor. Each condition produces different sensory integration requirements. For example, in condition 1 all sensory information (vision, proprioception and vestibular) is available. In condition 4, only vision and vestibular are available. In condition 6, only vestibular is reliable, with proprioception and vision giving erroneously stable information. The experimental apparatus also contained equipment to perform the information processing tasks. Two types of information processing tasks were performed: 1) auditory choice reaction time (ACRT) and 2) visual choice reaction time (VCRT). The equipment for the ACRT task consisted of insert earphones connected to a computer that delivered the stimulus. For the VCRT task, the stimulus was a red LED located at eye level on the visual surround. The responses were performed using a handheld microswitch in each hand. The ACRT stimuli consisted of two tones at 980 Hz with loudness amplitudes of 71 dB and 81 dB. The VCRT stimulus was an LED lit for 500 ms at one of two brightness levels of 104 cd/m² and 25 cd/m². The levels of the stimuli were determined in pilot studies in an attempt to control task difficulty (i.e., ACRT and VCRT tasks were designed so that reaction times would be comparable between auditory and visual tasks at baseline).

Protocol—Six postural conditions were included by providing changes in the platform and visual scene. The three visual conditions were: 1) eyes open in the light with a fixed visual environment (LIGHT), 2) eyes open in the dark (DARK), and 3) visual-sway referenced (VSR). The platform conditions were: 1) fixed floor or 2) sway referenced floor. Thus, all six posture conditions possible with the dynamic posturography platform were conducted by combining the 3 visual conditions and 2 platform conditions. The two information processing tasks were performed under all six postural conditions. Each information processing task was presented on a separate day. Stimuli (both visual and auditory) were presented for 1 second randomly in 2 to 4 second intervals for all trials. Each trial consisted of 45 stimuli over a duration of 3 minutes for a particular postural condition. For the auditory tasks, the target tone (i.e. the high or low loudness) and the order of postural conditions were randomized for each subject. During the ACRT task, subjects were asked to respond as quickly as possible to the louder tone with a button push from one hand and the softer tone with the other hand. The tones were each presented randomly 30 times during every trial. The VCRT task required discrimination of the brightness of the LED stimulus

and a button push in response, with one button for the brighter stimulus and the other button for the dimmer stimulus.

Seated RTs were employed initially to provide practice in responding for participants and subsequently during each testing session to provide a baseline reaction speed, which could be subtracted from the remaining RTs to correct for differences between age groups and between lighting conditions. A practice session was given to the subjects for one day before any data collection began. All practice was performed seated. During each testing session, control reaction time trials were included with the subject seated in the light and in the dark. For the VCRT task performed in the dark (DARK), the room was totally dark. These tests resulted in baseline seated RTs for each subject for the two information processing tasks for both LIGHT and DARK conditions. These seated RTs (within the LIGHT condition or with the DARK condition) were then subtracted from the corresponding RTs during the postural conditions in the analysis to form the dual-task effect scores.

Data Analysis Methods—Reaction times to the VCRT and ACRT tasks were recorded as participants completed the tasks on the posturography platform. Postural sway also was recorded as the change in the center of pressure under the feet in the anteroposterior direction and is described elsewhere (Redfern & Muller, 2008). The median RTs for each subject during each of the postural conditions were found. For each subject, the baseline RT (i.e., the RT during the seated condition) was subtracted from the auditory RT and the visual RT. This gave us an auditory dual-task RT (dRT) score and a visual dual-task RT (dRT) score, as is shown below:

$$\text{Auditory dRT} = \text{Standing auditory RT} - \text{Seated auditory RT} \quad (3)$$

$$\text{Visual dRT} = \text{Standing visual RT} - \text{Seated visual RT} \quad (4)$$

Specifically, the seated RTs taken in the light were subtracted from the LIGHT condition trials, while the seated RTs taken in the dark were subtracted from the DARK condition trials. This normalization was performed to eliminate the difference of performing the RT tasks in the light and in the dark. The DTD, the measure of sensory switch cost used in the analysis, was calculated from the dRT scores. The DTD is simply the difference between the auditory dRT and the visual dRT:

$$\text{DTD} = \text{auditory dRT} - \text{visual dRT} \quad (5)$$

The DTD is a measure of the differential dual-task effect between auditory and visual information processing tasks. Since the baseline seated RTs are subtracted from the dual-task RTs, the DTD measures the differential dual-task interference for an auditory task compared to a visual task during the balance challenges. Data were analyzed using repeated measures ANOVA and linear correlation analysis with a significance level of $\alpha=0.05$.

Outliers were defined as values more than 1.5 times the inter-quartile range below the first quartile or above the third quartile. While all 46 subjects completed the inhibition tests (top of Table 1), one young subject was identified as an outlier in the MI task and was excluded from the analyses. Four additional subjects had to be excluded from analyses related to the DTD: 2 older adults and 1 young adult experienced technical problems during the visual choice task, invalidating their scores, and 1 young subject was defined as an outlier in the DTD task (bottom of Table 1). Thus, 21 young adults and 20 older adults remained for the DTD analyses and the associated figures.

Results

Perceptual and Motor Inhibition RTs

The RT results from the inhibition testing showed the expected influence of congruency and age: incongruent tasks were performed more slowly than congruent tasks and older adults were slower than young adults (Table 1). PI and MI scores were greater for the older adults compared to the young adults, reflecting decreased inhibitory function in the older adults. PI and MI scores were positively correlated in the older group ($r=0.54$, $p=.01$) but were not correlated in the younger group ($r=0.21$, $p=.36$).

Dual-task RTs

The dRTs were calculated by subtracting the seated baseline RTs from the RTs captured during the standing conditions. The bottom portion of Table 1 presents the mean seated and standing auditory and visual choice RTs for the two age groups. The standing and seated choice RTs were differenced yielding the dRTs (Equations 3, 4). The DTD (also presented in Table 1) was derived as the difference between the auditory dRT and the visual dRT (Equation 5). The details of the dRT results are published elsewhere (See Redfern, Muller & Jennings 2009).

The DTD scores computed in this study as a measure of sensory switch cost showed no direct impact of aging. Using a repeated measures ANOVA, we compared the DTD scores with main effects of Group (young, older), Floor (fixed or sway referenced) and Scene (LIGHT, DARK, VSR), along with all interaction effects. There were no significant effects of the independent variables (Group, Floor, Scene) on DTDs. There were no significant interaction effects either (e.g. group $\times$ floor, group $\times$ scene); that is, despite the increasing challenge of the balance task, the DTD scores remained stable. Thus, neither age nor postural condition affected the DTD scores.

Inhibition vs. Sensory switch cost

The inhibition scores (PI and MI) were correlated with sensory switch cost (DTD) in *light* conditions (LIGHT or VSR in either floor condition), in which visual input is available for postural control (Table 2). Underlying this association are the component auditory and visual dRTs, which were not significantly associated with either of the inhibition scores. PI was positively correlated with sensory switch cost in older adults ($r=0.51$, $p=.02$), but no significant relationship existed in young adults ($r=-0.02$, $p=.95$) (Figure 1). The difference between these two correlations is not significant, however ($p=.08$). MI was positively

correlated with sensory switch cost in older adults ($r=0.48$, $p=.03$), but no correlation was observed in young adults ($r=-0.38$, $p=.09$) (Figure 2). The difference between these correlations was significant ($p=.01$). For the *dark* conditions (DARK visual condition in either floor condition) no significant correlations were observed between inhibition and the overall DTD measures in either age group.

Since significant correlations were observed in the *light* conditions, each of the four postural conditions making up the total scores was examined separately for the sake of completeness (Table 2). In older adults, PI measures were positively correlated with DTD during the *light* conditions when the floor was fixed or sway referenced but not when the visual scene was sway referenced. MI was positively correlated with DTD only during the sway referenced floor-eyes open condition ($r=0.56$, $p=.01$). In young subjects, there was inadequate power to establish whether there were significant correlations between PI and DTD or MI and DTD.

Finally, the primary analyses were rerun using two techniques to explore the degree to which inhibitory measures shared variance with general slowing of processing speed in the older group. Two different techniques were used to examine this relationship, though none of the techniques have been universally adopted (Salthouse, 2000). First, a proportion score expressed each incongruent condition RT as a proportion of their congruent RT. This calculation has been suggested in order to take into account any differences between the age groups in basic processing speed more fully than the difference score approach. Correlations between the adjusted PI and DTD changed only slightly, with the correlation in the old becoming $r=0.43$ with $p=.06$, and the correlation in the young becoming $r=0.12$ with $p=.58$. The correlations between the adjusted MI and DTD also changed somewhat, with the correlation in the old $r=0.35$ with $p=.13$ and the correlation in the young $r=-0.47$ with $p=.03$. The second technique used partial correlation to predict the DTD score using the unadjusted PI or MI score while partialing out covariance due to median simple RT obtained in a separate block of trials. The simple RT score was used as a measure of basic processing speed. The older participants showed a trend between DTD and PI (partial $r=.44$, $p=.06$) and MI (partial $r=.40$, $p=.13$). Similarly, the relationships did not change substantially from earlier analyses for younger participants: PI (partial $r=.16$, $p=.49$) and MI (partial $r=-.46$, $p=.03$). These analyses suggested that the greatest portion of the shared variance between DTD and inhibition scores could not be attributed to basic processing speed.

Discussion

This study investigated the relationship between inhibitory function and the ability of younger and older adults to shift attention between sensory modalities while maintaining balance. The primary finding was that both PI and MI were correlated with sensory switch cost during a balance challenge in older adults. In contrast, there were no correlations between measures of inhibition (MI or PI) and sensory switch cost in young adults. Furthermore, there were no underlying associations between inhibitory function and either auditory or visual performance in either group. We had hypothesized that balance challenges involving conflicting inputs (sway referencing in lighted conditions) would lead to correlations between our measure of sensory switch cost. This was largely upheld, but only

in the elderly participants. It is interesting that only the relative switching with auditory or visual input for a participant relates to inhibition measures.

The observed results in older adults supported our original hypothesis of an accentuated relationship in the elderly. These differential effects between inhibitory function and sensory switch cost in the two groups have several possible explanations. One possibility consistent with the current literature is a corollary of the decreased overall inhibitory function seen in older adults (Butler & Zacks, 2006; Miyake et al., 2000; Treitz, Heyder, & Daum, 2007). Older adults appear to be more dependent on higher cognitive function compared to young adults (Woolacott & Shumway-Cook, 2002), which may also include inhibitory function. Accordingly, deficits in inhibitory processes require older adults to devote more cognitive resources to maintain postural control. Thus, these relationships between measures of inhibition and dual-task interference begin to appear. Both PI and MI are diminished in older adults and may be linked to significant reduction in postural control in individuals suffering from aging-related disorders. Mechanistically, this may be due to insufficient cognitive resources, impaired coordination or allocation of the cognitive resources, or both (Brauer et al., 2001; Hauer et al., 2003). As is often the case, the differences in range and variability of scores between younger and older participants should be considered. Although these changes themselves are likely due to aging, statistically the increase in range of scores amplifies the ability to detect relationships in the old relative to the young. Our belief in the inhibitory loss with aging is somewhat tempered by this consideration.

The measure of sensory switch cost related differently to performance of the dual tasks among young and older adults. The visual task allows participants to use visual input to complete the task and maintain balance, whereas the auditory task forces participants to divert their attention back and forth from the visual stream to the auditory stream every few seconds. Since the auditory task challenges participants to inhibit irrelevant input and prevent inappropriate responses, it is more difficult for older adults with deficient inhibition. Perceptual and motor inhibitory function were significantly better in young adults and unrelated to sensory switch cost. Among the younger subjects, two individuals had exceptionally large motor inhibition scores and were excluded as outliers—interestingly, inclusion of these individuals lead to a weak paradoxical inverse relationship, opposite to that seen in the older group, i.e. an association of better motor inhibition with greater switch cost. This finding was also evident when the relationships were analyzed with an adjustment for basic processing speed. The inverse relationship between motor inhibitory function and attentional flexibility seen in young adults may stem from differences in the strategies of healthy adults in dual-task situations. Bloem et al. (Bloem, Valkenburg, Slabbekoorn, & Willemsen, 2001) had subjects perform the Multiple Tasks Test, in which a battery of increasingly complex dual-tasks is designed to closely mimic everyday situations, such as undisturbed walking, walking while holding a tray, and walking with a tray in reduced illumination. Ironically, young healthy subjects were more likely to favor the maintenance of balance over optimizing performance on the information processing task, i.e., young subjects employed a posture first strategy. If young healthy individuals with good postural control are more inclined to employ a safe strategy, prioritizing balance over concurrent tasks, their attentional flexibility capabilities would not necessarily associate with inhibition in the predicted way.

The differing relationships between young and older adults may be explained by general changes that occur with normal aging. Although the older subjects went through extensive screening, subclinical deficits in visual (Lord, Clark, & Webster, 1991), vestibular (Rosenhall, 1973), and/or sensory reception (Skinner, Barrack, & Cook, 1984) each alter postural control and would influence the relationship between inhibition and sensory switch cost. Furthermore, age-related changes in structures critical to balance such as the vestibular nuclei (Lopez, Honrubia, & Baloh, 1997), cerebellum (Furman & Redfern, 2001) and ventricles (Tell, Lefkowitz, Diehr, & Elster, 1998) also affect central processing and balance even if they are not regarded as pathological. Thus, structural and functional changes that modify balance in healthy aging may be responsible for the differing relationships between sensory switch cost and inhibition in the two age groups.

In some studies, researchers have found that age-related decreases in inhibitory function are largely due to the generalized slowing that occurs with increasing age (Rossit & Harvey, 2008; Salthouse, 1996, 2000). To address this possibility, we examined how two additional models compared in determining how the relationship between inhibition and sensory switch cost was attributable to differences in overall processing speed. This was accomplished by normalizing the inhibition scores by dividing each participant's incongruent RT by his/her congruent RT (rather than differencing these values) and separately by partialling out of the correlation covariance due to processing speed as assessed by simple RT. These analyses suggested that sensorimotor speed only accounted for a small fraction of the variation (at most 8%) in how well inhibition scores explained sensory switch cost indices. Thus, sensorimotor slowing due to age alone (as assessed by simple RT) only explains a minor portion of the covariation seen between sensory switch cost and the inhibition variables.

Our interpretation implies that inhibition is required when attention is focused on a single sensory channel such that switching between channels delays or interferes with processing. This may not be uniformly true, however. Recent research in modality switching shows mixed results. On the one hand, numerous studies support the view of mostly independent resources for visual and auditory attentional resources (Alais, Morrone, & Burr, 2006; Schumacher et al., 2001). However, other studies support our perspective, a shared system where modality switching leads to delays in processing speed (Bonnell & Hafter, 1998; Turatto, Benso, Galfano, & Umiltà, 2002). To complicate matters, these studies use a wide array of information processing tasks and subject inclusion/exclusion criteria, making conclusions difficult to generalize. To evaluate the validity of our results and the extent to which inhibition actually predicts sensory switch cost, experiments with similar methodology would be needed. An examination of both aging and balance disorders within such experiments would also be illuminating. In the absence of these studies, we tentatively conclude that there is a definite positive correlation between both PI and MI and sensory switch cost in older adults.

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Figure 1. Perceptual Inhibition versus Dual Task Difference by Age Group. A significant positive correlation is observed in older adults (left panel: $r=0.51$, $n=20$), but not in young adults (right panel: $r=-0.02$, $n=21$).

Figure 2.

Motor Inhibition versus Dual Task Difference by Age Group. A significant positive correlation is observed in older adults (left panel: $r=0.48$, $n=20$) whereas a trend towards a negative correlation is seen in young adults (right panel: $r=-0.38$, $n=21$). Note the difference in scale for motor inhibition in the two plots since the range was significantly different between young and older subjects.

Table 1

Comparison of RT Measures According to Age Group

Characteristic	Older Adults	Young Adults	p-value
Basic Cognitive Tasks, mean $\pm$ SD (ms)	(n=22)	(n=23)	
Sensorimotor Speed	260 $\pm$ 57	235 $\pm$ 28	.07
Motor Congruous	436 $\pm$ 52	339 $\pm$ 36	<.001
Motor Incongruous	592 $\pm$ 151	367 $\pm$ 39	<.001
Perceptual Congruous	570 $\pm$ 98	415 $\pm$ 76	<.001
Perceptual Incongruous	605 $\pm$ 99	422 $\pm$ 68	<.001
Inhibition Tests, mean $\pm$ SD (ms)			
Perceptual Inhibition	35 $\pm$ 44	7 $\pm$ 22	.01
Motor Inhibition	156 $\pm$ 110	28 $\pm$ 31	<.001
Dual Task Differences (DTD), mean $\pm$ SD (ms)	(n=20)	(n=21)	
DTD, averaged over light conditions	30 $\pm$ 34	42 $\pm$ 37	0.29
Seated auditory choice RT	560 $\pm$ 114	486 $\pm$ 79	.01
Standing auditory choice RT	577 $\pm$ 118	531 $\pm$ 111	.18
Seated visual choice RT	537 $\pm$ 101	456 $\pm$ 83	<.01
Standing visual choice RT	550 $\pm$ 98	471 $\pm$ 81	<.01

Note. RT = reaction time, SD = standard deviation.

Perceptual inhibition is scored as perceptually incongruous RT – perceptually congruous RT. Motor inhibition is scored as motorically incongruous RT – motorically congruous RT. DTD is computed by subtracting the visual dRT from the auditory dRT (Equation 5). The individual dRT scores and computed by subtracting the appropriate seated dRT from the standing dRT (see Equations 3 and 4). The p-values are for post hoc tests comparing age groups, see text for tests of other differences.

Table 2

Correlations of Inhibition Scores versus Dual Task Difference Scores by Postural Condition and Age Group

Postural Condition (Platform condition/Visual condition)	Older Adults (n=20)		Young Adults (n=21)	
	Perceptual Inhibition	Motor Inhibition	Perceptual Inhibition	Motor Inhibition
Average of 4 Light Conditions	0.51*	0.48*	-0.02	-0.38
Average of 2 Dark Conditions	-0.22	-0.26	0.19	0.14
Fixed Floor/LIGHT	0.51*	0.28	0.05	-0.34
Fixed Floor/VSR	0.36	0.25	-0.02	-0.38
Sway-Referenced Floor/LIGHT	0.47*	0.56*	0.01	-0.26
Sway-Referenced Floor/VSR	0.35	0.34	-0.10	-0.38

Note. The DTD (dual-task difference) is a measure of the differential dual-task effect between auditory and visual information processing tasks and is equal to the auditory choice dRT minus the visual choice dRT. Correlations marked with asterisks are significant at the $p=.05$ level. LIGHT refers to eyes open in the light with a fixed visual environment whereas VSR refers to a visual-sway referenced scene.