Journal of Motor Behavior, Vol. 45, No. 4, 2013
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RESEARCH ARTICLE

Motor Inhibition in Aging: Impacts of Response Type and Auditory Stimulus

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Abstract. The authors examined the effects of response types and the presentation of auditory stimulus on motor inhibition. Continuous responding tasks were conducted with 27 younger adults and 39 older adults. The results indicated the following: (a) response type significantly affected error rates in older adults, (b) the presentation of an auditory stimulus facilitated responses and decreased reaction times in both younger and older adults, (c) the presentation of an auditory stimulus also increased error rates in older adults, and (d) the effect of response type on error rate remained in experiments conducted under different conditions in older adults. This suggests that in older adults, movement and the associated nervous excitation have significant effects on motor inhibition.

Keywords: aging, inhibitory function, motor control, stimulus response

This study's purpose was to analyze the effects of aging on motor control with a specific focus on failure in motor inhibition among older adults, and to analyze its characteristics. Motor control involves the specific and intentional manipulation of various items. Failure in motor control, which can be described as an error of involuntary incorrect manipulation (Potter & Grealy, 2008; Reason, 1992) is a considerable problem in everyday life. For the purpose of supporting everyday living of older adults, understanding the characteristics of motor control in older adults is important.

The issue of inhibitory function in older adults was first proposed as a hypothesis by Hasher and Zacks (1988). Since its proposal, this hypothesis has been extensively examined from the perspectives of cognitive control problem. Examples include early studies by Connelly, Hasher, and Zacks (1991); Hamm and Hasher (1992); and Hartman and Hasher (1991), as well as more recent studies, such as those by Morrone, Declercq, Novella, and Besche (2010) and Vallesi, Hasher, and Stuss (2010).

In contrast, fewer studies have examined the effects of aging on inhibitory function as an associated motor control problem. They include research demonstrating aging effects on prepotent motor inhibition (Kramer, Humphrey, Larish, Logan, & Strayer, 1994; Nieuwenhuis, Ridderinkhof, de Jong, Kok, & van der Molen, 2000; Potter & Grealy, 2008; Trewartha, Endo, Li, & Penhune, 2009) and research demonstrating lesser effects of aging on low-level motor inhibition (Hartley & Kieley, 1995; Maylor & Henson, 2000). In addition, recent research has reported that low-level motor inhibition is also affected by aging (Hartley, 2001; Schlaghecken, Birak, & Maylor, 2011; Schlaghecken & Maylor, 2005).

In this study we examined the effects of aging on motor inhibition from the perspectives of interlateral inhibition in the primary motor areas and diffusion of nervous excitation. Both of these perspectives have been previously indicated in the research and each perception will be discussed in detail.

Research has shown that the left and right cerebral hemispheres of the primary motor areas inhibit each other's function through the corpus callosum (Grillner, 1981). For example, when manipulating an object in both hands, while one hand is active, the activity of the other hand is inhibited. Further, when the functionality of one hemisphere declines due to brain injury, its inhibition towards the other hemisphere diminishes (Kobayashi, Hutchinson, Theoret, Schlaug, & Pascual-Leone, 2004; Ward & Cohen, 2004). Thus, it can be inferred that problems of motor control are affected by the interlateral inhibition between the left and right hemispheres. If the interlateral inhibition of the primary motor areas generally declines with age, its impact may be observed in motor inhibition among older adults. For example, given a motor task of manipulating a switch continuously between the left and right hands, it can be hypothesized that the motor inhibition on the opposite side to the one operating the switch should decrease in older adults making the task more difficult.

Moreover, research into activation patterns of the brain in the process of task performance indicates that nervous excitation tends to diffuse in older adults (Heuninckx, Wenderoth, Debaere, Peeters, & Swinnen, 2005; Nielson, Langenecker, & Garavan, 2002). For example, Heuninckx et al. demonstrated that there are regions that are additionally activated during motor task performance in older adults. Furthermore, it has been shown that while the right prefrontal region is strongly activated during response inhibition in younger adults, activation is diffused into the prefrontal regions on both sides and the parietal region in older adults (Cabeza, 2002; Nielson et al., 2002). This additional activation in older adults can be considered to be compensating for declined function (Cabeza et al., 1997; Hutchinson et al., 2002). There is also a hypothesis that this diffusion is an indication of dedifferentiation of functions (Cabeza, 2002; Li, Lindenberger, & Sikstrom, 2001). At any rate, the effects of nervous excitation diffusion on motor control are largely still unknown.

Taking all these into consideration, it could be hypothesized that while performing a continuous responding task using both hands, decreased motor inhibition on the

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contralateral side makes the task more difficult in older adults when compared with younger adults. Moreover, in situations conducive to nervous excitation, the tendency would be increased. Hence, this research was aimed to first confirm the effects of aging on motor inhibition failure, using a simple motor task of manipulating both hands continuously according to a presented stimulus. At the same time, it was aimed to compare and analyze the effects of two factors that were presumably related with nervous excitation on motor inhibition, specifically, the effects of different response type and the effects of an auditory stimulus.

Concerning each response type, differences in motor inhibition were compared through the use of two types of response buttons. The first type of response button could be operated with relatively small pressure, while the second operated by gripping with the entire palm using a certain amount of pressure. It was anticipated that a response induced by an entire palm, compared to a response induced by the fingertips, would trigger more extensive nervous excitation (Hutchinson et al., 2002; Penfield & Jasper, 1954).

Moreover, the effects of the presentation of an auditory stimulus concurrently with visual stimulus on motor inhibition were analyzed. It is known that on simple response tasks, such as to press a button on presentation of a stimulus, concurrent presentation of visual and auditory stimuli facilitate response (Fischer, Plessow, & Kiesel, 2010; Kiesel & Miller, 2007; Miller, Franz, & Ulrich, 1999). It was anticipated that simultaneously stimulating multiple senses with a concurrent presentation of visual and auditory stimuli would increase nervous excitation. Further, it was assumed that a different type of nervous excitation would be observed.

In summary, the hypotheses were as follows: generally, more frequent failures in motor inhibition were expected in older adults than in younger adults; moreover, response inhibition when grasping with an entire palm was expected to be more difficult than for a relatively small movement only using the fingertips. Similarly, concurrent presentation of visual and tone stimuli was expected to increase nervous excitation by stimulating multiple senses, thereby making motor inhibition difficult in older adults (Experiment 1).

After confirming the anticipated results as mentioned previously, in Experiment 2, the experimental tasks in Experiment 1 were conducted under incompatible conditions in terms of stimulus–response compatibility. Participants were asked to operate the left switch on presentation of stimulus on the right, while they were asked to operate the right switch upon presentation of stimulus on the left (Diamond, 2002; Kornblum, Hasbroucq, & Osman, 1990). By reversing the compatibility between visual stimulus and response, response inhibition was expected to be more difficult in younger and older adults generally (Christ, White, Mandernach, & Keys, 2001). This study was designed to analyze the differences between results obtained in this condition and those in Experiment 1. These procedures were thought to clarify the variables that were closely related to the impacts of aging.

EXPERIMENT 1

Method

The purpose of Experiment 1 was to confirm that motor inhibition on the side that should not respond on a continuous responding task using left and right switches was more difficult in older adults than in younger adults, as well as to examine the effects of response type and auditory stimulus. Groups of younger and older adults were compared to analyze whether the effects of these two factors on motor inhibition were similar or different.

Participants

Participants were 27 young adults (16 men, 11 women; *M* age = 20.8 years, *SD* = 1.7, age range = 18–25 years) and 39 older adults (21 men, 18 women; *M* age = 71.0 years, *SD* = 3.9, age range = 66–83 years). All the older adults were registered with a human resource center for seniors, and usually engaged in jobs, primarily light duties. Each participant was offered a compensation of approximately $10, which included transportation fees for participating in the experiment. According to self-reports, all the participants were in good health, with the exception of chronic illnesses. All of the older adults received old-age benefits, and lived in the community independently. The mean score on the Mini-Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975) of the participants was 28.1 (*SD* = 1.39), ranging from 25 to 30. All the older adults had at least 12 years of education, with the mean of 14.8 years (*SD* = 2.5 years). There was no statistically significant difference in the years of education between younger adults (*M* = 15.3 years, *SD* = 3.9 years) and their older counterparts, $t(65) = 0.73$, $p = .47$. All the younger adults were college students majoring in psychology, who participated in the experiment voluntarily. Participants provided written informed consent prior to the experiments. All the younger and older adults were right-handed. The Institutional Review Board of the university where the first author is affiliated had approved the study in advance.

Apparatus and Procedure

A location discrimination task of pressing two response switches located to the participant's left or right according to the location of a stimulus presentation was conducted individually. The apparatus consisted of two response buttons, a display, and a PC. The response buttons were of two types. One was a micro switch (operational pressure 10 g; Micro Light Switch #58500, Tash Inc., Roseville, MN) that could be operated with an index finger. The other was a grasp switch (operational pressure 300 g; Grasp Switch #58760, Tash Inc., Roseville, MN) that could be operated by grasping a cylindrical grip with the entire palm.

The stimulus was presented on a liquid-crystal display (19LCD-AD195GB, I-O DATA, Kanazawa, Japan), and the entire experiment was performed with a PC (dynabook satellite A50S, Toshiba, Tokyo, Japan). The speakers were placed approximately 30 cm away from the bottom center of the display on both sides, and each volume was set at the same level.

First, a fixation stimulus was displayed at the center of the screen, followed by a red circle (4.5 cm in diameter) displayed at random to either the left or right of the fixation stimulus at a visual angle of 10.7°. The distance of the fixation point from the participant was approximately 50 cms. The odds at which the stimulus appeared on the left or right side was 50%. The participants were asked to press (or grasp) the response button on the same side as the stimulus as quickly and accurately as possible after the stimulus was displayed. They were instructed to lightly place (or hold) their hands on the respective response buttons during the experiment. Pressing the response button upon stimulus presentation represented the end of a trial, and the next trial was initiated after a specific interval. Three response stimulus intervals between the previous response and the next stimulus of 500, 1500, and 2500 ms were used randomly. Prior to the experiment, eight practice trials were administered. The experiment consisted of two blocks, each composed of 16 trials, presented in sequence. There was an interval of approximately five seconds between the blocks. A pilot study suggested that a maximum of 50 trials per session was the limit for older adults if the task required maintaining a grip pressure of 300 g.

In approximately half of the trials, an auditory stimulus, not linked to the location of the visual stimulus, was presented simultaneously with the visual stimulus. Following the study by Fischer et al. (2010), a tone of 700 Hz was presented for 150 ms so that it was perceived at approximately 70 dB at a distance of 50 cm from the speakers. The auditory stimulus was programmed to be delivered seven, eight, or nine times in a 16-trial block. Older adults were tested on their ability to hear the auditory stimulus during practice trials.

The previous procedure was conducted twice for each response type. The order in which the response types were administered was counterbalanced.

Data Analysis

The number of error responses and reaction times of each participant were recorded, and the number of error responses was converted to an error rate. The mean reaction time for correct responses was identified for each condition for each participant, after removing values beyond the range of $M \pm 2\,SD$ as anticipatory and inattentive responses. Error rate for each condition was analyzed using a three-factor mixed analysis of variance for age (young–old), response type (micro–grasp), and tone (on–off). Reaction times were analyzed similarly. Additionally, Table 1 summarizes the test results in the manner that corresponds to the hypothesis and the focus of the analysis. Effect sizes were estimated by using partial eta squared (η_p^2).

TABLE 1. Comparison of the Effects of Aging, Auditory Stimulus Presentation, and Response Type in Each Experiment (Error Rates)

	Condition	Younger	$<_a$	Older
Experiment 1 compatible				
	Tone off versus tone on	n.s.$_b$		$<_c$
	Micro versus grasp	n.s.$_d$		$<_e$
	Condition	Younger	$<_f$	Older
Experiment 2 incompatible				
	Tone off versus tone on	n.s.$_g$		n.s.$_h$
	Micro versus grasp	n.s.$_i$		$<_j$

[a]$F(1, 64) = 15.36, p = .000$, [b]$F(1, 64) = 0.08, p = .784$, [c]$F(1, 64) = 18.08$, p = .000, [d]$F(1, 64) = 0.13, p = .718$, [e]$F(1, 64) = 6.92$, $p = .011$, [f]$F(1, 64) = 5.35, p = .024$, [g]$F(1, 64) = 1.64, p = .189$, [h]$F(1, 64) = 1.77$, p = .189, [i]$F(1, 64) = 0.60, p = .441$, [j]$F(1, 64) = 8.08$, $p = .006$.

Results

Figure 1 displays the results of the analysis of error rates. Depending on the conditions, the mean error rates of older adults ranged from 2.4% ($SD = 4.6\%$) to 8.9% ($SD = 10.3\%$). The mean error rates of younger adults were at the 1% level in all the conditions. Statistical tests showed that the main effect of age was significant, $F(1, 64) = 15.36$, $p = .00$, $\eta_p^2 = .194$. However, the main effect of response type was not supported, $F(1, 64) = 1.97$, $p = .165$, $\eta_p^2 = .030$, and no significant interaction was supported between age and response type, $F(1, 64) = 3.85$, $p = .054$, $\eta_p^2 = .057$. The main effect of auditory stimulus was significant, $F(1, 64) = 8.60$, $p = .005$, $\eta_p^2 = .118$. Interaction between age and auditory stimulus was significant, $F(1, 64) = 6.29$, $p = .015$, $\eta_p^2 = .089$. An analysis of the interaction shows that there was no significant difference by auditory stimulus in younger adults,

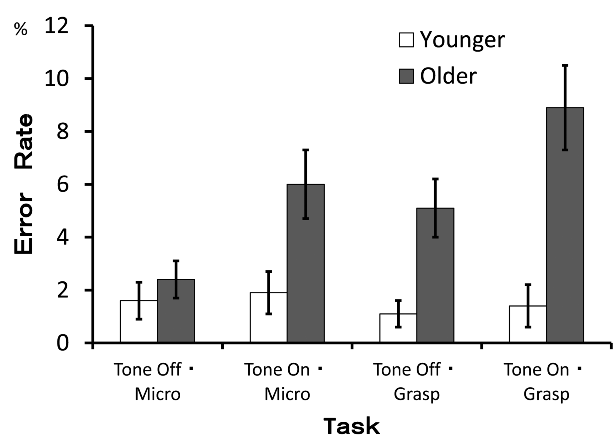

FIGURE 1. Mean error rates in Experiment 1 (compatible condition). Error bar indicates standard error.

$F(1, 64) = 0.08, p = .784$. $\eta_p^2 = .000$; however, that there was a significant difference by auditory stimulus in older adults, $F(1, 64) = 18.08$, $p = .000$, $\eta_p^2 = .217$. Interaction between response type and auditory stimulus was not significant, $F(1, 64) = .00$, $p = .986$, $\eta_p^2 = .000$. Secondary three-way interaction among age, response type, and tone stimulus was not significant, $F(1, 64) = .06$, $p = .937$, $\eta_p^2 = .000$.

Table 1 displays the results of the analysis of the effects of auditory stimulus and response type by age group of older and younger adults to test the hypothesis. As shown in Table 1, statistically there was no significant difference in error rates due to differences in auditory stimulus and response type in younger adults; however, in older adults differences were seen. When an auditory stimulus was presented simultaneously with the visual stimulus, and when the higher pressure grasp switch was used, error rates increased.

The mean reaction times are presented in Table 2. Depending on the conditions, the means in the older group ranged between 342 ms (SD = 88 ms) and 591 ms (SD = 147 ms), while in the younger group, they ranged between 267 ms (SD = 30 ms) and 360 ms (SD = 33 ms). Statistical analysis resulted in a significant main effect of age, $F(1, 64) = 28.61$, $p = .000$, $\eta_p^2 = .309$. The main effect of response type was not supported, $F(1, 64) = 3.34$, $p = .072$, $\eta_p^2 = .050$; however, the interaction of age and response type was supported, $F(1, 64) = 5.889$, $p = .018$, $\eta_p^2 = .084$. An analysis of the interaction shows that there was no significant difference by response type in younger adults, $F(1, 64) = 0.15$, $p = .699$. $\eta_p^2 = .002$; however, that there was a significant difference by response type in older adults, $F(1, 64) = 11.06$, $p = .001$, $\eta_p^2 = .147$. The main effect of auditory stimulus presentation was significant, $F(1, 64) = 57.11$, $p = .000$, $\eta_p^2 = .472$. Nonsignificant interactions were also revealed between age and auditory stimulus, $F(1, 64) = 3.79$, $p = .056$, $\eta_p^2 = .056$, and between response type and auditory stimulus, $F(1, 64) = 2.38$, $p = .128$, $\eta_p^2 = .036$. Moreover, secondary three-way interaction among age, response type, and tone stimulus was not significant, $F(1, 64) = 1.719$, $p = .195$, $\eta_p^2 = .026$.

TABLE 2. Reaction Times (ms) and Standard Deviations for Each Condition

			Younger		Older	
			M	*SD*	*M*	*SD*
Experiment 1						
Compatible	Micro	Tone off	285	25	413	120
		Tone on	267	30	390	122
	Grasp	Tone off	291	40	384	99
		Tone on	271	43	342	88
Experiment 2						
Incompatible	Micro	Tone off	360	33	591	147
		Tone on	353	40	572	138
	Grasp	Tone off	355	43	551	112
		Tone on	342	43	533	98

Discussion

Although the task concerned simple location discrimination, there was a significant difference between the error rates in the older and younger groups. On the task for which the participants were asked to press (grasp) the switch consecutively with both hands, older adults made errors of responding on the contralateral side (not the side on which visual stimulus was presented) more frequently than their younger counterparts. This seems to support the hypothesis that there are aging effects. However, as shown in Figure 1, the error rates in older adults differed significantly depending on the response type and presentation of auditory stimulus. Conversely, younger adults were not affected by the response type or presentation of auditory stimulus.

The effect of different response types was significantly different between younger and older groups. In the younger group, there was little difference in the error rates for different response types. In contrast, in older adults, differences in response type had a significant effect on the error rate. It is noteworthy that the grasp switch, which required grasping movements with the palm, was associated with higher error rates in comparison to the micro switch. This could be manipulated with only a fine finger movement.

Experiment 1 was administered in a condition in which participants were asked to press the switch on the ipsilateral side as the stimulus presentation, in other words, the stimulus and movement were compatible. Nonetheless, there were frequent errors of pressing the opposite side of the stimulus presentation. What are the implications of this?

A clue might be found in an experiment conducted by Luria (1961). Luria demonstrated that there is a period in human development when motor inhibition becomes difficult once movement is initiated due to diffused nervous excitation. In this experiment, participants pressed switches continuously, and therefore, their task could be described as a go or go task. In such tasks, nervous excitation might diffuse more easily than in a go or no-go task. In the grasp switch condition, under which the participants grasped the switch with the entire palm to turn it on, the diffused nervous excitation was possibly higher. According to the brain map of sensory and motor areas prepared by Penfield and Jasper (1954), the area that is concerned with the hands is much larger than other areas. Naturally, all of this area must have been used to control the movement under the grasp switch condition.

Then, why was the effect of the response switch type not observed in younger adults? One plausible explanation concerns the effects of mutual inhibition function between the left and right hemispheres of the brain. According to Kobayashi et al. (2004), human motor cortices inhibit each other through the corpus callosum. In addition, Ward and Cohen (2004) indicated that the balance of interlateral inhibition between the cerebral hemispheres is lost in cerebral vascular disease. Therefore, it is possible that the mutual inhibition function was active in younger adults as they performed the experimental task of pressing switches with each of their hands, which controlled nervous excitation. Conversely, in older adults, the interlateral inhibition function could have been weak.

With regard to reaction time, younger adults were not affected by response type, while in older adults the effect of response type was evident. Grasp switch requires a greater operational pressure than the micro switch. The fact that this switch was associated with smaller reaction times appears to indicate that there is greater nervous system excitation in the grasp switch condition among older adults.

The effect of aging was evident in the effects of auditory stimulus. Auditory stimulus presentation affected reaction times in both younger and older adults. In both age groups, the presentation of auditory stimulus simultaneous to visual stimulus had facilitating effects on the response. There was no difference between the older and younger groups in this regard. However, as shown in Figure 1, the rates of errors of pressing the switch on the contralateral side of the specified side in older adults were higher when the auditory stimulus was presented. It is plausible that the presentation of an auditory stimulus facilitated the movements in both hands in older adults, impeding inhibition of movement on the contralateral side of the stimulus presentation as a result. Conversely, among younger adults, while auditory stimulus did facilitate response, it only affected the hand movement on the side on which visual stimulus was presented.

EXPERIMENT 2

Method

The purpose of Experiment 2 was to examine the change in motor inhibition when the stimulus–response compatibility, which was in place during the tasks in Experiment 1, was altered. In Experiment 2, participants operated the left hand switch when visual stimulus was presented on the right side, and right hand switch when visual stimulus was presented on the left. It was anticipated that both in older and younger adults, response itself would be more difficult when compared to Experiment 1. The experiment aimed at displaying the effects of response type and auditory stimulus presentation on response inhibition under this condition.

Participants

The same participants were recruited as used in Experiment 1. To minimize the influence of Experiment 1, Experiment 2 was carried out after a period of 1–2 weeks following the initial experiment.

Apparatus and Procedure

The apparatus and procedures were identical to those used in Experiment 1 with the exception that the participants were instructed to press the response button on the opposite side of stimulus presentation. While Experiment 1 was conducted under stimulus–response compatibility, the locations of the stimulus and response were incompatible in Experiment 2.

Data Analysis

The methods of data analysis were identical to those in Experiment 1.

Results

In Experiment 2, reaction times were shown to be generally larger than in Experiment 1, $t(65) = 15.37$, $p = .000$, $r = .89$. Although there was no statistically significant difference in error rates, $t(65) = 1.965$, $p = .054$, $r = .24$, error rates increased in all the conditions. Thus, it can be inferred that under the conditions in which Experiment 2 was conducted, responding to the stimulus was more difficult than in Experiment 1 owing to the incompatibility between the locations of stimulus and response, as well as the influence of task switching.

Results of the analysis of error rates showed mean error rates fluctuating between 5.2% (SD = 5.7%) and 9.2% (SD = 9.6%) in older adults. In younger adults, the mean fluctuated between 3.1% (SD = 3.9%) and 5.4% (SD = 4.8%) depending on the conditions (see Figure 2). Statistical analysis revealed that the main effect of age was significant, $F(1, 64) = 5.35$, $p = .024$, $\eta^2_p = .077$. In addition, the main effect of response type was also significant, $F(1, 64) = 5.83$, $p = .019$, $\eta^2_p = .083$. There was no significant interaction between age and response type, $F(1, 64) = 1.49$, $p = .27$, $\eta^2_p = .023$. The main effect of auditory stimulus presentation was not significant, $F(1, 64) = 3.37$, $p = .071$, $\eta^2_p = .050$. Nonsignificant interactions were also seen between age and auditory stimulus presentation, $F(1, 64) = .018$, $p = .893$, $\eta^2_p = .000$, and response type and auditory stimulus, $F(1, 64) = .00$, $p = 1.00$, $\eta^2_p = .000$. Secondary three-way interaction

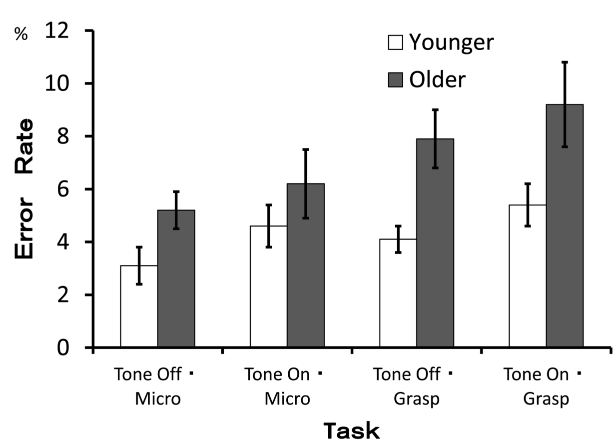

FIGURE 2. Mean error rates in Experiment 2 (incompatible condition). Error bar indicates standard error.

among age, response type, and auditory stimulus was also not significant, $F(1, 64) = .05$, $p = .823$, $\eta_p^2 = .001$.

Table 1 summarizes the effects of auditory stimulus presentation and different response types. As described in Table 1, error rates were generally higher among older adults than in younger adults in Experiment 2, as in Experiment 1. In addition, older adults were affected by response type, but the effect of auditory stimulus presentation was no longer significant. In younger adults, neither the effect of auditory stimulus presentation nor response type was significant.

Mean reaction times for each condition are displayed in Table 2. In the older group, the means ranged between 494 ms ($SD = 99$ ms) and 538 ms ($SD = 145$ ms) depending on conditions. In the younger group, the means ranged between 329 ms ($SD = 44$ ms) and 342 ms ($SD = 40$ ms) depending on conditions. Statistical analysis showed that the main effect of age was significant, $F(1, 64) = 81.29$, $p = .000$, $\eta_p^2 = .559$, as well as the main effect of response type, $F(1, 64) = 7.56$, $p = .008$, $\eta_p^2 = .106$. However, there was no significant interaction between age and response type, $F(1, 64) = 3.37$, $p = .071$, $\eta_p^2 = .050$. The main effect of auditory stimulus presentation was significant, $F(1, 64) = 12.75$, $p = .0001$, $\eta_p^2 = .166$, although the interaction between age and auditory stimulus presentation was not significant, $F(1, 64) = 1.38$, $p = .244$, $\eta_p^2 = .021$. Additionally, the interaction between response type and auditory stimulus was not significant, $F(1, 64) = .16$, $p = .690$, $\eta_p^2 = .003$. Finally, secondary three-way interaction among age, response type, and auditory stimulus was not significant, $F(1, 64) = .47$, $p = .498$, $\eta_p^2 = .007$.

Discussion

In Experiment 2, in which the locations of stimulus and response were incompatible, the error rates in older adults were generally higher when compared with those in younger adults. Moreover, older adults showed higher error rates in operating the grasp switch than operating the micro switch, as in Experiment 1. It can be considered that as reaction time generally increased when the locations of stimulus and reaction were incompatible, the effect of response type remained constant. Therefore, the effect of response type on error rate appeared rather robust.

In contrast, the effect of auditory stimulus presentation on error rate was no longer significant. The tendency toward shorter reaction time when tone stimulus was presented was confirmed as in Experiment 1. Considering these, the effect of tone stimulus was not robust enough to cause an increased error rate.

In contrast, error rates in younger adults were not affected by either auditory stimulus presentation or response type, consistent with the results from Experiment 1.

To summarize Experiment 2, older adults continued to be strongly affected by response type. It is possible that nervous excitation triggered by different senses, such as auditory stimulus presented simultaneously with visual stimulus and motor-related nervous excitation triggered by the operation of a switch have different systems of inhibition. It was inferred that inhibition of motor-related nervous excitation was especially susceptible to the effects of aging.

GENERAL DISCUSSION

The results of this study indicate the significant effects of different response types and nonvisual stimuli in researching changes in movement inhibition associated with aging. In previous studies, a visual stimulus was presented and manipulated on computer display as the independent variable. There has been significant accumulation of knowledge from such studies, but the response that was required has been to press specific keys on a PC keyboard. It is assumed that younger adults are less susceptible to the effect of response type. However, there is the possibility that older adults are influenced significantly by the response type than the younger adults.

In addition, what can be inferred from the results of the two experiments is that mechanisms that cause errors are different from errors due to the influence of different response types to those due to auditory stimulus presentation. Nervous excitation related to movement causes the first type of errors, whereas the second was affected by different senses. In particular, nervous excitation caused by movement appeared to be a significant factor in motor inhibition in older adults. However, in this study we did not examine the nervous system directly, and instead, demonstrated correlation of variables at the behavioral level. Neuroscientific investigation on aging effects in movement inhibition should be warranted in the future.

It is possible that the weakness in interlateral inhibitory functions in older adults that was examined in this research relates to inhibition of return in older adults. Recent studies have shown that inhibition of return increases in older adults (Poliakoff, Coward, Lowe, & O'Boyle, 2007; Tsuchida, 2005). An increase in inhibition of return is considered to be an exception while inhibitory functions overall decrease in older adults, but the results of this study suggest a possibility that decreased interlateral inhibitory functions prompt contralateral responses in older adults. It is plausible that this accentuated inhibition of return that resulted in delayed ipsilateral response. This also requires future research.

This study's purpose was to examine aging effects on motor control. Younger and older participants were compared as to whether their motor inhibition was affected by response type. In addition, the effects of an auditory stimulus presented simultaneously with a visual stimulus on motor inhibition were examined. The results indicated the following: (a) the response type significantly affected error rates in older adults, (b) the presentation of an auditory stimulus facilitated responses and decreased reaction times in both younger and older adults, c) the presentation of an auditory stimulus also increased error rates in older adults more significantly than in younger adults, and (d) among older adults, the effect of response type on error rate remained in experiments conducted under different conditions. These findings suggest that among older adults, movement and the associated nervous excitation have significant effects on motor control.

ACKNOWLEDGMENTS

The authors would like to extend a special thanks to Ken'ichiro Tsushima for his help in the data collection.

FUNDING

This research was supported by Grant-in-Aid for Scientific Research (C) No. 22530728, 25380901 in Japan.

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Received February 1, 2013
Revised April 17, 2013
Accepted May 12, 2013