Age Differences and Changes in Midline-Crossing Inhibition in the Lower Extremities

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Background. The effects of crossing the body midline on the lower extremities of individuals 65 years of age and older was investigated.

Methods. The subjects were 10 individuals 65–79 years of age, 10 individuals 80 years and older, and 10 individuals 20–35 years. The total testing phase consisted of 2 sets of 30 trials per leg on 2 days. The subjects performed trials that involved movements ipsilaterally, contralaterally, and directly in front of the anterior superior iliac crest of the leg being tested. Reaction time and movement time scores were recorded.

Results. Individuals 65 years of age and older were found to exhibit slower reaction times to movements in a contralateral direction when compared with movements made in the ipsilateral direction whereas individuals 80 years of age and older were also found to exhibit slower reaction times to movements in a contralateral direction when compared with movements made in the midline and ipsilateral direction.

Conclusions. These findings indicate that the effects of midline-crossing inhibition on the lower extremities re-emerge in individuals 65 years and older, whereas in early development this effect disappears by 8 or 9 years of age.

There is a striking lack of homogeneity among older age groups (individuals 65 years of age and older) as abilities and functions of these persons do not decrease in the same way with aging (1,2). Comparisons therefore are sometimes markedly varied from one individual to another. This is not to say, however, that individuals in this age range do not experience some uniformity with respect to broad structural and functional changes of the human body such as reaction times (RTs) (3). Authors who follow a life-span developmental approach (4,5) view the developmental continuum of life as a complex system that is affected by many intervening and controlling elements. In this manner, the life-span developmental model views the later stages of adulthood (60 years and older) as one aspect of human development. During this time there are a variety of changes in functioning that may or may not occur as a result of the aging process. These changes are labeled age-related changes and are often assumed to be the effect of the aging process. One of these age-related changes may be reflected in movements that cross the midline of the body.

Cross-lateral integration is a developmental milestone attained by the age of 8 or 9 years (6). Attainment of this milestone has been explained in the context of spatial orientation enhancement, body scheme development, and bilateral coordination (7–9). Failure to attain this milestone is referred to as cross-lateral or midline crossing inhibition (MCI). Any type of hesitancy in reaching, stepping, or looking across the midline of the body is referred to as MCI.

The phenomenon referred to as cross-lateral or midline crossing alludes to any motor action that results in looking, reaching, or stepping across the body’s midline. The phenomenon of midline crossing problems dates back to 1920 when Head established that brain-damaged adults exhibited the effects of MCI (10). Since that time many authors have investigated the effects of crossing the midline of the body upon RT and movement time (MT) scores (11–16).

As individuals mature and progress through the continuum of life processes, a regression toward exhibiting former inhibitory effects such as MCI may be evident. The fact that MCI is present in individuals with mild and moderate levels of mental retardation may be explained by their lack of attainment of certain developmental milestones or stages (14). Bashore and associates argue “that the slowing induced by older age is not generalized, but rather is both task-dependent and process-specific” (Ref. 17, p. 263). Therefore, in the present study, response selection of a contralateral nature that uses the lower extremities has developmental implications in the context of the response-processing paradigm.

The developmental continuum model of MCI is illustrated by studies that have shown that the following populations exhibit MCI: very young children (16, 18–20), young children with learning disabilities (21), and adults with moderate levels of mental retardation (14).

From reported differences and anecdotal observations, midline crossing (contralateral movements) appears to represent more complex movements than ipsilateral movements in particular populations and as a result may require greater neurological organization than ipsilateral movements (15). A previous pilot research by this paper’s authors (22) utilized the population 55 years and older and established that crossing the midline of the body with the upper extremities results in slower reaction RTs and MTs for the population 80 years of age and older. Results of this pilot data indicated that MCI of the upper extremities in the population over 80 years old required more response-processing time and greater neurological organization than was
necessary for movements that did not cross the midline of the body.

Interestingly, Peters (23) suggests that lower-extremity assessments of foot preference may be less susceptible to the bias of a right-sided-oriented society. Peters (24) also asserts that lower-extremity classification of footedness may provide greater insights into motor performance than an examination of handedness. At the present time, most of the information concerning MCI is based on upper-extremity research, with the exception of the study of Surburg and Eason (15).

The present study follows a developmental continuum model of response processing and MCI. The present lower-extremity study is an extension of the authors’ pilot research (22), the study of Surburg and Eason (15), and the preceding assertions made by Peters (23,24). The present study compared temporal components of processing and movements with the lower extremities of individuals of normal intelligence who are 65 years and older. If vestiges of MCI are once again evident in the development continuum of life, then slower RT and MT responses could suggest that older adults need modifications in such lower-extremity controlled daily activities such as the operation of machinery (i.e., automobiles).

**Methods**

**Subjects**

Twenty apparently healthy, nondisabled elderly subjects comprised the subject sample: 10 subjects in the age range of 65–79 years (5 men and 5 women) \( M = 68.9 \text{ years}, SD = 4.53 \text{ years}, \) where \( M \) is the mean and \( SD \) is the standard deviation, and 10 in the age range of 80 years and older (5 men and 5 women) \( M = 83.2 \text{ years}, SD = 2.90 \text{ years}. \) Ten subjects in the age range of 20–35 years comprised the sample with an equal number of male and female subjects \( M = 26.4 \text{ years}, SD = 4.53 \text{ years}. \) All subjects did not manifest perceptual–motor difficulties and were free of hip and lower-extremity orthopedic or neurological surgery. They were also free of visual impairments (i.e., senile cataracts) after correction (glasses or contacts). All subjects were not taking the following medications: calcium channel blockers or beta blockers. Subjects were minimally to moderately physically active: walking, slow jogging no more than 3 miles 4 times per week, swimming no more than 4 times per week, and bicycle riding (stationary or moving) no more than 4 times per week. All subjects in this study were from a small city in the Midwest and were recruited on a voluntary basis without the benefit of financial remuneration. Adults from local retirement neighborhoods and the surrounding residential community participated in this study. Informed consent was obtained from all subjects in compliance with Human Subjects protocols at Indiana University.

**Instrumentation**

The choice response time task consisted of two components: RT and MT. The apparatus consisted of an initiate pad, three target pads with a red 12-V light-emitting diode (LED) directly behind each pad, a yellow catch-trial light positioned 8 cm directly in back of the center target pad’s LED, and an auditory initiating signal (between 1000 and 2000 Hz). One target pad was positioned 35.6 cm directly in line with the initiate pad. The other two target pads were situated 35.6 cm from the initiate pad on the same horizontal plane and at a 45-deg angle to the right and the left of the initiate pad. All pads were 7 cm \( \times \) 10 cm in diameter and covered with a thin (1.5-mm) layer of black rubber padding. The speaker that provided the auditory initiating signal was housed at the other end of the apparatus board along with the yellow catch-trial light. The apparatus was interfaced with a laptop computer that regulated stimulus sequencing, preparatory intervals, and recorded RT and MT data (see Figure 1). This 286 portable laptop computer was interfaced with the response time apparatus. The computer-generated randomized numbers for each block of trials with a new random sequence for each set of trials, which determined stimulus selection and preparatory interval presentation. RTs and MTs were recorded by the laptop’s on-board computer timer, with time recorded in milliseconds.

**Procedures**

For RT and MT measurements the subject was positioned in the chair with his/her trunk at a 90-deg angle to the subject’s thighs and the thighs at a 90-deg angle to the subject’s...
legs. The subject’s hands were positioned in the lap. The initiate pad was positioned in line with the subject’s anterior superior iliac crest of the lower extremity being tested. The foot not being tested was positioned on the floor adjacent to the foot initiate pad of the foot being tested. Before the first trial was initiated and midway through each trial sequence, the researcher peered around the tester/subject divider to ensure that the subject was in proper body alignment.

Each subject in the aforementioned seated position faced the MCI Apparatus and depressed a foot initiate pad following an auditory initiating signal. The time between the subject’s placing the foot on the initiate pad and the auditory initiating signal was predicated on the subject’s hearing the auditory initiating signal and placing the foot on the initiate pad, which started each testing sequence. The average time for this procedure was 4 seconds. The subject broke contact with the foot initiate pad after the illumination of a red LED, which was located behind a target pad. Touching the target pad with the foot completed the response task. The elapsed time from the stimulus onset to breaking contact with the initiate pad constituted RT. The elapsed time from breaking contact with the foot initiate pad until making contact with the target pad constituted MT. Preparatory intervals of 1.5, 3.0, and 4.5 seconds were part of the testing protocol. A preparatory interval was the elapsed time between depression of the initiate pad and illumination of a light stimulus (the LED). Three catch trials were given during each testing session. A catch trial consisted of the auditory initiating signal presentation, subject placing the foot on the initiate pad, and the illumination of the yellow catch-trial light. No movement was to be made. The catch trials were necessary to diminish anticipatory responses and enhance the response nature of the task. Each subject participated in a preliminary 20-minute session that included one testing session for each leg. Each subject then engaged in two 30-minute testing sessions on two different days.

Using a random stratified assignment system, each subject performed nine trials that involved movements ipsilaterally, nine contralaterally, and nine trials directly in front of the anterior superior iliac crest of the leg being tested. There were three catch trials in each testing session, one for each direction. The total testing phase consisted of each subject’s participating in 4 separate sessions of 30 trials for each direction. The test administrator was 3.6 m from the subject and the MCI Apparatus. Touching the target pad of the lower extremity being tested. The initiate pad was positioned in line with the subject’s anterior superior iliac crest. Legs were positioned in the lap. The subject’s hands were positioned in the lap. The initiate pad was positioned in line with the subject’s anterior superior iliac crest of the lower extremity being tested. The foot not being tested was positioned on the floor adjacent to the foot initiate pad of the foot being tested. Before the first trial was initiated and midway through each trial sequence, the researcher peered around the tester/subject divider to ensure that the subject was in proper body alignment.

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Statistical Analysis
The mean of nine trials for each direction was used as the dependent variable for both RT and MT. A subject × trial analysis of variance (ANOVA) model was used to calculate the intraclass correlation coefficients to assess the reliability of each dependent measure for all age groups under each testing condition. Data were subjected to an ANOVA. A 2 (foot) × 3 (age) × 3 (direction) ANOVA with repeated measures on the last two factors was used for the data analysis. When significant *F* values were found for the independent variables of interest, appropriate post hoc tests were then implemented. The criterion of statistical significance level was set at .05. When appropriate, analyses of significant interactions were conducted. The Tukey test was used to determine differences between means (25).

Results
A subject × trial ANOVA model was used to calculate the intraclass correlation coefficients to assess the reliability of each dependent measure for all age groups under each testing condition. Intraclass correlation coefficients for the two testing days for all three experimental groups ranged from .93 to .99 for RT data and from .96 to .99 for MT data. MTs and SDs for each age group within each direction are illustrated in Table 1. The results of the analysis of variance for RT data were significant main effects for age, *F*(2,27) = 27.51, *p* < .05 and direction *F*(2,54) = 106.29, *p* < .05. The only significant interaction effect was age by direction, *F*(4,54) = 21.83, *p* < .05.

Significant results of the simple main-effects analyses for age within direction were ipsilateral *F*(2,81) = 18.26, *p* < .05, midline *F*(2,81) = 17.44, *p* < .05, and contralateral *F*(2,81) = 45.64, *p* < .05.

Post hoc analysis concerning the direction of the movements determined that for movements made in the ipsilateral direction, the RTs for the 80-years-and-older group were significantly slower than the RTs for both the 65–79-year-old group and the 20–35-year-old group. Also, the RTs of the 80-years-and-older group were significantly slower when movements were made in the body midline direction than for subjects in the two younger aged groups. Finally, concerning the contralateral direction, RTs for the 65–79-year-old group were found to be significantly slower than the RTs of the 20–35-year-old group, whereas RTs for the 80-years-and-older group were significantly slower than the RTs for both of the two younger aged groups.

The results of the simple main-effects analysis of dire-

<table>
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<tr>
<th>Group</th>
<th>Aged 20–35</th>
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<th>Aged 80+</th>
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<tr>
<td>(MT)</td>
<td>245</td>
<td>62</td>
<td>255</td>
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Notes: RE = Reaction time, MT = movement time, IPSI = ipsilateral, MID = midline, CONTRA = contralateral, SD = standard deviation.
*Denotes a significant difference between this age group and the other two age groups.
†Denotes a significant difference between this age group and group c, aged 20–35 years.
tion within age were that for two of the three age groups [65–79 years \( F(2,81) = 3.57, p < .05 \), 80 years and older \( F(2,81) = 11.78, p < .05 \)] significant simple effects were found.

Post hoc analyses concerning the age groups determined that movements made in the contralateral direction for the 65–79-year-old age group were significantly slower than in the ipsilateral direction. Results of the 80-years-and-older group were that movements made in the contralateral direction caused RTs to be significantly slower than both ipsilateral and midline movements. Analyses of the 20–35-year-old group’s RTs found no significant differences among directions.

The results of the analysis on MT data were significant main effects for age, \( F(2,27) = 6.39, p < .05 \) and direction, \( F(2,54) = 44.98, p < .05 \). The only significant interaction effect was age by direction, \( F(4,54) = 4.99, p < .05 \).

The results of the simple main effects analysis for age within direction were that for each of the three movement directions [ipsilateral \( F(2,81) = 7.33, p < .05 \), midline \( F(2,81) = 6.35, p < .05 \), contralateral \( F(2,81) = 5.45, p < .05 \)], significant \( F \) values were found.

Post hoc analyses concerning the direction of the movements determined that for all three movements (ipsilateral, midline, and contralateral) the MTs for 80-years-and-older were significantly slower than the MTs for both 65–79-years and 20–35-years age groups. The MT results for the three experimental age groups are found in Table 1. The results of the simple main-effects analysis for direction within age showed no significant \( F \) values.

**Discussion**

**Reaction Time**

The present study demonstrated that subjects 20–35 years of age exhibit no MCI effects, subjects aged 65–79 years exhibit MCI effects compared with the ipsilateral direction, and finally, subjects aged 80 years and older exhibit MCI effects compared with both the ipsilateral and midline conditions. These findings certainly lend credence to the developmental continuum model of MCI, which maintains that vestiges of MCI become evident once again in the later stages of the developmental continuum of life and that RT, as a component of the response-processing paradigm, is sensitive enough to detect this remnant of an earlier stage of development.

Individuals 80 years and older were significantly slower than those individuals in the other two age groups for all three movement directions. These results were to be expected according to previous research detailing the gradual decline in RT performance as age increases (26–32). Recently Li and colleagues (33) reported, for both lower- and upper-extremity movements, slower RT performance with increasing age. In like fashion, the 65–79-year-old group was significantly slower than the 20–35-year-old age group. Therefore, for the contralateral direction, the slowing with age phenomenon was intensified in that the individuals 65–79 years old were significantly slower than the individuals aged 20–35 years. This last finding did not hold true for the ipsilateral or the midline directions. It is this finding that further supports the hypothesis that contralateral movements are more complex in nature than ipsilateral or midline movements and are thus reflected in longer RT scores (34).

The reemergence of the effects of MCI on the lower extremities in individuals aged 65 years and older reflects a regressive step leading away from bilateral coordination and toward more unilaterally organized movement. The inhibition of the effects of MCI in normally developing children is hypothesized to be brought about by the formation of commissural neural circuits that integrate and coordinate activity on the two sides of the body (35). In individuals aged 65 years and older the commissural neural circuits may be starting to deteriorate, thus disallowing the integrative abilities involved in crossing the midline of the body to no longer be as effective as they were in younger years.

As Botwinick (36) reports, because research shows no difference between old and young subjects in the length of neuromuscular pathways or in transmission time, the slowdown in RT with age and with more complex tasks such as contralateral movements must be central in origin. The present study’s results are in agreement with previous research indicating that RT requiring more response processing time is vulnerable to the aging process (37). The age effect on RT becomes more apparent as the movement required for making the response becomes more complex (28,38). Grew (28) notes that as movement complexity increases, older people require progressively more time after interpretation of the signal to prepare for the response to the signal, whereas younger individuals appear to interpret the signal and prepare for the response simultaneously. The results of the present study are consistent with the findings of the investigation of Larish and Stelmach (39), which found that movements of the upper extremities made in the contralateral direction were associated with longer RTs than for movements made in the ipsilateral direction. This finding was more prominent under the reprogramming conditions in which an already constructed motor program has to be restructured when an unexpected response must be executed (Ref. 39, p. 336). Larish and Stelmach (39) suggested that their findings are related to task complexity that is inherent in movement patterns of a contralateral nature. The effect of movement complexity on RT has been interpreted as relating to the time necessary to prepare the movement during the response-programming stage (40). According to Keele (41), when a rapid, goal-directed motor action is to be performed, the necessary motor commands are structured and organized before the movement actually begins and is referred to as response programming. The results of the present study seem to indicate that as an individual ages the ability to program a response to a contralateral movement becomes an increasingly more difficult task represented by longer RTs.

While the slowdown in response programming (movement organization) is considered as the primary reason for the MCI effect observed from RT data for the older individuals, another possible explanation is related to the delay in the decision-making process. The lower stimulus–response compatibility, which is inherent in the condition of contralateral movement, could cause greater problems in response selection for the older subjects compared with that
for the younger subjects. However, the present study is unable to discriminate between these two possibilities.

The leg used in the study was not found to influence RTs. The actuality that leg preference is not of significance in the present study is in disagreement with previous upper-extremity research involving 13–14-year-old subjects (34). However, the fact that the present study’s findings are not in agreement with the study of Brunt and colleagues (34) may be explained in part, given that the present study involved individuals 65 years of age and older who utilized the lower extremities and investigation by Brunt and colleagues (34), which involved subjects 13–14 years of age who manipulated the upper extremities. Brunt and colleagues (34) established hand usage and laterality of response to be variables that impose degrees of difficulty to response organization in the upper extremities in children. The present study did not detect a greater difficulty of response organization between the right and the left legs. Interestingly, the study by Brunt and colleagues (34) indicated that the knowledge of which hand to use played a dominant role in the planning of a forthcoming movement. The subjects in the present study were given instructions before testing concerning which leg to move, thereby lessening the response difficulty level. A possible explanation for the results of this study is that, as the normal individual ages, the lower extremities are used solely for the purposes of transportation without the primary or exclusive use of only one leg. The functional use of the right leg in individuals aged 65 years and older is not utilized more or less than the left leg and is therefore not trained for faster reactions or movements.

Surburg and Eason (15) have developed an MCI Index that can be used as an assessment technique on a group or an individual basis. The MCI Index is a ratio of the contralateral RT divided by the ipsilateral RT. For example, in this study the group MCI Index for the 80-years-and-older group was 1.19, for the 65–79-year-old group the index was 1.14, and for the 20–35-year-old group the index was 1.00.

The results from this study suggest that when adults aged 65 and older are using their lower extremities, they will react more slowly when they are to move across the midline of the body (in the contralateral direction). Considering this fact, the individuals aged 65 years and older might choose to reposition themselves if safety or speed are at stake in order to make movements on the same side of the body instead of movements across the body midline.

Movement Time

Individuals in the 80-years-and-older group were significantly slower than those individuals in both of the other age groups for all three movement directions. These results were to be expected, considering the fact that, as an individual ages, the muscle mass decreases, the number of normally functioning muscle fibers is reduced, and there is a loss of the elastic properties of the connective tissue (42). Despite the obvious decreases in muscular strength and endurance that occur with age, differences in movement speed between younger and older individuals are also hypothesized to be a function of changes in the central nervous system and not solely because of muscular deterioration. There is also a slowing of sensory and motor fibers past the age of 50 years (43). All of these factors may interact to slow MT responses as the individual ages.

The results of this study did not find a statistically significant MCI effect for MT. Eason and Surburg (44) contend that certain movements that are very complex in nature, such as crossing the midline of the body, require more processing time. This complexity issue may be addressed in the context of visuomotor processing. Berlucchi and associates (45,46) maintain that the use of an extremity, in their case the arm, on the same side of a stimulus requires less processing time than the responding extremity on the contralateral side of the visual stimulus. With the same-side condition, only one hemisphere is used; for contralateral situations, two hemispheres are needed for this processing event. Interaction between two hemispheres requires more processing time than the single-hemisphere process. The work of Berlucchi and colleagues is most applicable for the MT phase when a series of events must take place before contact with the initiate pad is broken. Once contact is broken and the leg is moved to the target pad, there is very little central nervous system processing related to this task. Although elderly individuals are slower in RT, as noted in the preceding paragraph, inhibition and complexity are not operant factors for the MT phase of this task.

There were no significant differences between the ipsilateral and midline directions in the parameters RT or MT within each subject group (see Table 1). These results support the idea that no direction effect was present, which might confound the contralateral (with midline crossing) versus midline and ipsilateral (without midline crossing) comparison. Therefore the authors argue that the differences observed among the contralateral direction (with midline crossing) and ipsilateral and midline directions (without midline crossing) are due solely to MCI effect.

In conclusion, MCI was evident in RT for adults 65 years of age and older with a methodology incorporating a choice response task in the context of an information-processing paradigm. This method was able to detect inhibitory responses involving reaction movements of the lower extremities. Application of this protocol could be implemented to detect degenerative changes with such conditions as Huntington’s disease. Additionally, individuals providing services to individuals aged 65 years and older need to consider this lower-extremity slowness in reaction and response times when activities involve crossing the body midline along with a general slowing of movement times.

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