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Age and Features of Movement Influence Motor Overflow

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OBJECTIVES: To measure the magnitude and prevalence of motor overflow to the arm at rest during attempted unilateral arm movements.

DESIGN: Cross-sectional assessment.

SETTING: Motor physiology laboratory.

PARTICIPANTS: Healthy young (n = 20) and elderly (n = 20) adult subjects.

MEASUREMENTS: Surface electromyography (EMG) was obtained from bilateral forearm muscles during performance of 12 different unilateral finger-tapping tasks.

RESULTS: For all subjects, faster movement rate ($F = 2.56-3.30$, $P < .05$), cognitive distraction ($F = 4.09$, $P < .05$), and fatigue ($F = 15.15$, $P < .001$) were each associated with a significant increase in the magnitude of EMG in the arm intended to be at rest. In elderly subjects, tapping at maximum rate and fatigue were each associated with a further increase in motor overflow across the midline. In addition, better left hand dexterity correlated with greater motor overflow to the right hand during rapid left hand tapping ($r = 0.63$, $P < .005$). Prevalence of motor overflow was also higher in older subjects for some tasks, for example during 1 Hz tapping by the right index finger (motor overflow present in 45%, vs 15% young subjects, $P < .05$).

CONCLUSION: Several behavioral variables increase motor overflow across the midline in young and elderly adults. Motor overflow was even greater in elderly subjects with the most demanding tasks and was greater in those with better motor status, suggesting that this form of motor system change is a compensatory event of normal aging rather than age-related dysfunction. The results support the hypotheses that healthy aging is associated with an increase in the degree to which brain function is bilaterally organized. *J Am Geriatr Soc* 51:1735-1739, 2003.

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Key words: motor overflow; mirror movements; aging; healthy; compensation

Motor overflow refers to the spread of motor system output such that muscle activity occurs in muscles intended to be at rest as well as in the target muscles. This spread can be within limb or across limbs and is referred to as a mirror movement when a similar movement appears in homologous muscles across the midline. Motor overflow has been described in multiple neurological settings,¹⁻³ is normal in healthy children,^{4,5} and can be elicited in healthy young adults in settings such as fatigue, large force generation, and proximal muscle use.^{1,6,7}

Nevertheless, there has been little study of motor overflow across the midline in healthy elderly subjects. This is of interest because bilateral movements during attempted unilateral movement have generally been linked to an increase in the degree to which motor cortex activation is bilaterally organized.^{7,8} Increasing evidence suggests that cognitive and memory tasks associated with predominantly unilateral brain activation in younger subjects produce more bilaterally organized brain activation in elderly subjects, especially healthy elderly subjects.⁹⁻¹¹ A study of motor overflow can provide improved insights as to how age influences the extent to which motor system function is bilaterally organized.

The results of these investigations may have implications beyond understanding brain function with aging. Many aspects of motor system function change with normal aging^{12,13} in a manner that can influence motoric aspects of activities of daily living.¹⁴ Therapeutic programs whose content targets age-associated changes in motor function can improve subject motor status.^{15,16} Motor overflow, if common in elderly subjects and if associated with poorer motor status, might represent an additional therapeutic target.

The current study evaluated motor overflow in normal adults, half of whom were younger than 25, and half of whom were aged 65 and older. Motor overflow was measured while modifying a number of behavioral variables, some known to induce bilateral movements in young adults and some not previously explored. Features of motor

overflow were correlated with measures of motor status. The hypothesis that increased age is associated with a further increase in motor overflow was then addressed.

METHODS

Subjects

Twenty young and 20 elderly subjects were recruited. Entry criteria were right-handedness, no history of stroke, and no active neurological or psychiatric conditions. Young subjects were required to be aged 18 to 25; elderly subjects were required to be aged 65 to 85. All subjects gave informed consent in accordance with the human subjects committee of the University of Washington.

Data Acquisition

Each subject underwent a neurological examination by one of the authors to confirm normal neurological status. The number of pegs placed in the Purdue pegboard during a 30-second trial was determined for each hand for all subjects.

Bipolar surface electromyography (EMG) leads were placed over the first dorsal interosseus (FDI), wrist extensor (WE) compartment, and wrist flexor compartment of both arms for each subject. EMG signal was amplified (Nihon Kohden, Foothill Ranch, CA) and filtered from 5 Hz to 3,000 Hz. EMG data were recorded at 1,000 samples/s per channel and digitized using Labview software (National Instruments, Austin, TX) and a National Instruments analog-to-digital converter card. Bilateral wrist splints were placed, each keeping the wrist mildly extended and having a slot through which the index finger could move in the flexion/extension plane. Two Velcro straps were placed dorsally across the distal forearm and metacarpals to restrict movement to the index finger metacarpophalangeal (MCP) joint. Each splint was attached to a floor that limited the MCP to 10° flexion and a felt-lined roof that limited total range of motion to 25°.

Subjects were seated with feet flat on the floor, knees at 100°, back against the chair, elbows flexed to 90°, and forearms in pronation. The subjects were asked to close their eyes, relax, and not move, during which time baseline EMG was recorded. Next, 12 unilateral tasks were performed, each guided by a beep from an auditory metronome. Subjects were briefly trained in each task before its performance. They were informed that finger tapping was being tested, but no mention was made of, nor attention was paid to, the upper extremity intended to be at rest for each task.

Testing began with the right index finger. The first set of tasks evaluated rate, recording for 15 seconds at each rate with an approximately 10-second gap between rates. The rates tested were 1 Hz, 2 Hz, 3 Hz, and 4 Hz. The next set of tasks evaluated the opposite side by having subjects perform the same four tasks with the left index finger. Next was tapping at maximum possible rate for 15 seconds with the right index finger, then again with the left index finger; maximum tapping rate was measured at this time. To test cognitive distraction, subjects were then asked to tap the right index finger at 3 Hz while simultaneously performing the Paced Auditory Serial Addition Task (PASAT).¹⁷ The PASAT requires that subjects listen to numbers presented

every 3 seconds. After hearing each number, the subject speaks aloud the sum of that number and the number just preceding it. Subjects performed 10 PASAT calculations over 30 seconds while tapping the right index finger at 3 Hz. To test fatigue, subjects were asked to tap the left index finger at 3 Hz continuously for 2 minutes.

Data Analysis

To further remove low-frequency artifacts, EMG data were digitally filtered in the forward and reverse directions using a first-order, high-pass Butterworth filter with 20 Hz cutoff for each direction. Next, for all channels, root mean square (RMS) values were determined for the first 10 seconds of EMG recordings of each task, as well as the last 10 seconds of the 2-minute tap.

Log-transformation was applied to all EMG RMS data to produce a more normal distribution of values. Comparison of EMG data from the three muscle sites showed greatest overall movement-related activity for the WE. Therefore, only WE data were further evaluated. Results for each muscle group were divided by baseline EMG values to correct for differences in sensitivity of surface EMG across subjects. Motor overflow for each of the unilateral tasks was therefore measured as baseline-corrected RMS value in WE muscle on the side intended to be at rest.

Using separate two-way analyses of variance, the effect of each of the following four variables on motor overflow was assessed: (1) movement rate (1–4 Hz), (2) movement side (right vs left), (3) cognitive distraction (right index finger tapping at 3 Hz with vs without simultaneous performance of PASAT), and (4) fatigue (first 10 seconds vs last 10 seconds of the 2-minute tapping epoch). To determine whether a variable had a significant effect on motor overflow, the within-group effect was calculated, with young and elderly groups combined. To determine whether a difference was present between the young and elderly groups, an interaction with age group (young vs elderly) was evaluated for each variable. An omnibus alpha level of $P = .05$ was set for each of the four comparisons.

Prevalence of motor overflow was also evaluated. A chi-square test was used to compare the proportion of young and elderly subjects showing motor overflow. For these proportion analyses, two different thresholds, derived from visual inspection of recordings, were used to define the presence of motor overflow, a 10% or a 25% increase in EMG over baseline. Data were evaluated for each side, at 1 Hz and at maximum tapping rate. Finally, a Pearson product moment correlation was calculated between level of motor overflow during four conditions (right or left hand, 1 Hz or 4 Hz tapping) and two behavioral measures: maximum tapping rate and Purdue pegboard performance.

RESULTS

There were no differences in sex distribution among the 40 subjects. The mean age \pm standard error of the mean of young subjects (22.0 ± 0.4) was less ($P < .001$) than that of elderly subjects (73.9 ± 1.3). Overall, motor overflow across the midline did not entirely mirror the intended movements, consisting instead of a tonic increase in EMG without the periodicity of EMG seen in the active hand.

Rate

Tapping rate (1–4 Hz) had a significant effect on motor overflow magnitude, with greater overflow at faster tapping rates, for both the right ($F = 3.30, P < .02$) and the left side ($F = 2.56, P < .05$) (Figure 1), but the effect of tapping rate showed no significant interaction on either side with age group ($F = 0.96$ and $F = 0.45$, respectively).

The maximum tapping rate in the young group was significantly faster than that of the elderly group for both the right (5.4 ± 1.4 vs $4.8 \pm 0.20, P < .02$) and the left (4.9 ± 1.5 vs $4.3 \pm 2.0, P < .01$) sides. Furthermore, motor overflow at the maximum tapping rate was significantly greater for the elderly group for the right side ($P < .05$).

Side

Comparison of motor overflow during right and left movements was performed at two different rates. There were no significant differences between right and left sides at 1-Hz ($F = 1.91$) or 4-Hz ($F = 1.78$) tapping. There was no interaction with age group at either tapping rate ($F = 0.51$ and $F = 0.34$, respectively).

Cognitive Distraction

Motor overflow during 3-Hz right index finger tapping simultaneous with PASAT was significantly greater than that seen during the same motor task without the PASAT

($F = 4.09, P < .05$) (Figure 2). Young subjects provided correct responses on the PASAT test slightly more often than elderly subjects (7.7 ± 0.03 of 10 questions correct vs $6.6 \pm 0.04, P < .05$), but no significant interaction between age group and motor overflow magnitude was seen during cognitive distraction ($F = 0.80$).

Fatigue

Motor overflow for the first 10-second block of a 2-minute left finger 3-Hz tapping epoch was compared with results for the last 10-second block (Figure 2). Motor overflow during the last 10-second block was significantly greater than during the first 10-second block ($F = 15.15, P < .001$). Active-hand EMG was also greater after 2 minutes of tapping ($F = 18.76, P < .001$). The elderly group showed significantly greater motor overflow in the last 10 seconds than did the young group ($F = 16.67, P < .001$); active hand EMG in the elderly group was also greater in the last 10-second block than in the young group ($F = 9.36, P < .004$).

Prevalence

Results were further analyzed examining the proportion of subjects with motor overflow present, rather than the magnitude of motor overflow (Figure 3). Because results at the two different thresholds (10% and 25%) were similar, only data using the more stringent 25% threshold are presented. The proportion of elderly subjects that showed motor overflow was consistently higher than with younger subjects, although this reached significance only during 1-Hz tapping with the right index finger (young = 15% with motor overflow, elderly = 45%, $P < .05$).

Correlational Analysis

When evaluating all subjects, level of motor overflow did not correlate with maximum tapping rate or with Purdue pegboard performance. In elderly subjects, better left hand

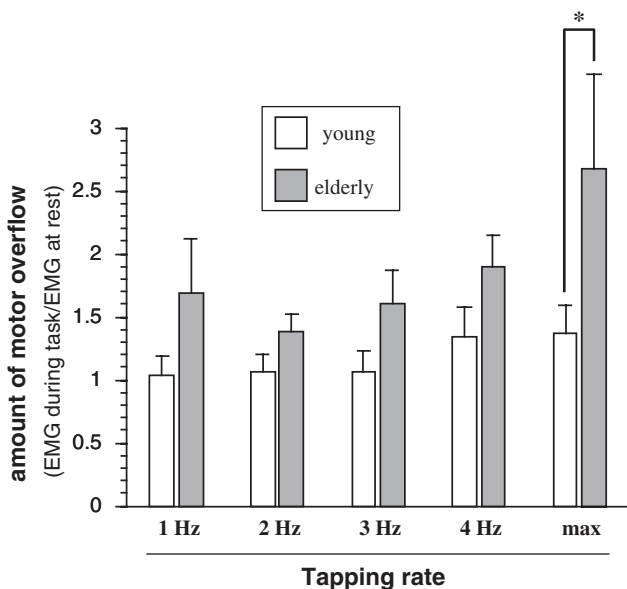


Figure 1. Amount of motor overflow in relation to unilateral index finger tapping rate, in young and elderly subjects (mean \pm standard error of the mean). The x-axis is tapping rate, with max representing each subject’s maximum rate. The y-axis is motor overflow, defined as wrist extensor (WE) electromyography (EMG) root mean square (RMS) during 10 seconds of task performance, divided by 10 seconds of each subject’s baseline (resting) EMG RMS; this value has no units because it is a ratio of two EMG measures. Greater motor overflow was found with increasing rate of tapping, with a significant age-related effect seen only at the maximum tapping rate. Averages of right and left values in WE are presented. max = maximum. * $P < .05$.

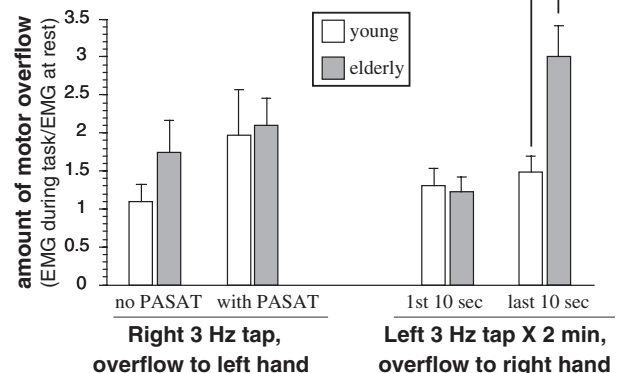


Figure 2. The effect of cognitive distraction and fatigue on motor overflow. The y-axis is the same as in Figure 1. For both young and elderly subjects, cognitive distraction due to performance of the Paced Auditory Serial Addition Task (PASAT) (left side of figure) increased motor overflow to the left hand during 3-Hz tapping by the right hand. The fatigue induced by 2 minutes of left index finger 3-Hz tapping (right side of figure) was associated with increased motor overflow to the right hand, with a significant age-related increase in elderly subjects. ** $P < .001$.

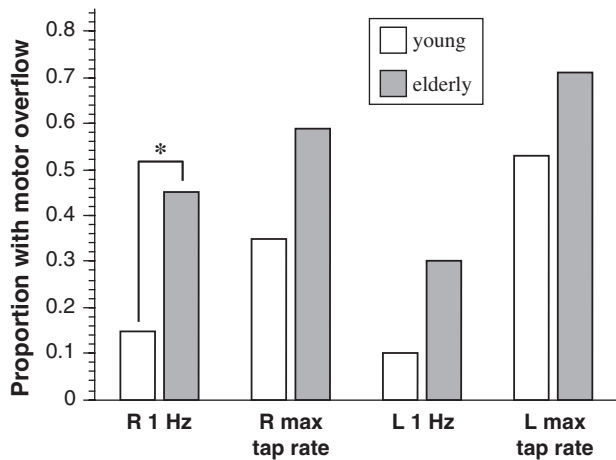


Figure 3. The proportion of subjects in each group showing more than 25% increase in motor overflow during each task is shown. Elderly subjects showed overflow more frequently than younger subjects, significantly so during 1-Hz tapping with the right index finger. max = maximum; R = right; L = left. * $P < .05$.

Purdue performance correlated with greater motor overflow to the right hand during left hand 4-Hz tapping ($r = 0.63$, $P < .005$).

DISCUSSION

In the current study, a number of variables were found to increase motor overflow across the midline in young and elderly healthy adults. Greater age was associated with a further increase in magnitude of overflow for highly demanding tasks (Figures 1 and 2) and was associated with an increased prevalence of motor overflow in some circumstances (Figure 3).

Some of the variables influencing motor overflow have been evaluated previously, although not in elderly subjects. One study⁶ found that, in healthy young adults, sustained abduction of one FDI at submaximal force was associated with increased EMG in FDI on the opposite side. The current study found a similar result, with a larger effect in elderly subjects (Figure 2), albeit with a different sustained movement and in a different arm muscle. A concurrently administered cognitive task is known to increase EMG measures of mirror movements in young adults.⁷ In the present study, this was manifest as a significant change in the magnitude of motor overflow during PASAT administration; age did not influence this effect. Side of task did not influence motor overflow, in contrast to some,¹⁸ but not all,^{1,6,19} prior studies. This may be due to use of only a single finger and low force.¹⁹

Some of the variables influencing motor overflow, such as increased age, have not been evaluated previously. In addition, tapping at increasingly faster rates was studied. Maximum tapping rate has long been known to have a strong, but incomplete, correlation with measures of contralateral motor system injury.²⁰ In the current study, maximum tapping rate was found to be associated with a more than 25% increase in motor overflow in many subjects, including the majority of young and old subjects

during the left maximum rate (Figure 3). This suggests that, when correlating motor system injury with maximum tapping rate in the contralateral arm, a fraction of the variance might be further explained by measures of EMG activity in the ipsilateral arm, intended to be at rest.

Several lines of evidence suggest that the bilateral EMG activity observed in the current study arises from an increase in the degree to which motor system activation is bilaterally organized. In healthy adults, performance of even a simple motor task is normally associated with a small degree of bilateral activation in motor cortices.^{21,22} Most of the conditions found to increase motor overflow across the midline in the current study (Figures 2 and 3) have also been previously associated with an increase in the degree to which motor system activation is bilateral.^{23–25} Also, prior studies of diseases characterized by bilateral movements during attempted unilateral movement have found bilateral motor cortex activity.^{7,8} Together, these studies indicate that most movements normally arise from activity in bilateral primary motor and premotor cortices, that certain factors can increase the extent to which the motor system is bilaterally organized, and that settings associated with a greater degree of bilateral motor system organization are often associated with a higher level of motor overflow across the midline.

One investigator has emphasized that many tasks associated with predominantly unilateral brain activation in younger subjects produce brain activation that is more bilaterally organized in elderly subjects, especially healthy elderly subjects.^{9,10} The current results support extension of this theory to the motor system, because the level of motor overflow across the midline was greater in elderly subjects for the demanding tasks. Previous human brain mapping studies are also supportive, having found that motor task performance by elderly subjects is associated with a greater degree of bilateral cortex recruitment than in subjects in their third decade.^{26,27} Nevertheless, these studies disagreed as to which brain areas showed a change, did not assess whether muscle activity was bilateral, and employed relatively slow and simple motor tasks rather than the tasks associated with the highest age-related increase in motor overflow. Future brain mapping studies exploring age-related changes in the degree to which the motor system is bilaterally organized might benefit from varying motor task complexity and from a bilateral assessment of motor behavior.

Changes in transcallosal inhibition might theoretically underlie age-related changes in motor overflow across the midline. A body of literature suggests that, during a unilateral movement, the contralateral motor cortex sends inhibitory signals to the ipsilateral motor cortex via transcallosal projections.^{7,28} With increased age, inhibitory tone may be reduced^{29,30} or sustained only by virtue of a compensatory increase in brain activity.¹¹ The observation that motor overflow is higher in the elderly during certain motor tasks suggests that further studies would find an age-related reduction of transcallosal inhibition that varies according to behavioral demands.

Many aspects of motor function change with increased age, including speed, strength, dexterity, reflexes, and arm function.^{12,13} Therapies that target these changes can improve function¹⁵ and reduce sources of morbidity such

as falling.¹⁶ The current study found that, in several cases, motor overflow across the midline is more common and of greater magnitude in elderly subjects. Three points suggest that this observation reflects normal aging rather than an important source of age-related dysfunction. First, motor overflow was also present with considerable frequency in healthy young subjects (Figure 3). Second, a significant age-related increase in motor overflow was present only for the most demanding tasks, rather than being present uniformly across all tasks. Third, elderly subjects with greater hand dexterity had higher, not lower, levels of motor overflow during left fast tapping. This suggests that the observed motor overflow indicates a useful compensation more than a sign of system decline. Also, these considerations suggest that motor overflow does not influence most motor behaviors in the elderly and therefore does not represent a logical therapeutic target as a component of programs to improve motor function in the elderly.

The design of the current study limits the extent to which it can be extrapolated. By design, none of the subjects had active neurological or psychiatric disease. Many such conditions are prevalent in the elderly and might interact with age-related changes in motor system organization. Also, subjects were enrolled without respect to baseline functional status and theoretically might not be representative of the broad geriatric population. Further studies that enroll elderly subjects with a range of functional status levels, or a range of diagnoses, might provide further insights into the clinical significance of age-related motor overflow.

The current study is concordant with previous reports^{1,18,19} that described motor overflow in the arm muscles of healthy young adults in specific behavioral settings. Current results extend these findings to healthy older adults. In the elderly subjects, motor overflow was even greater during certain tasks and was at maximum during induction of fatigue. Further studies of motor overflow with brain mapping during diverse tasks, with measurement of transcallosal inhibition, or in a range of elderly subjects might provide further insights into motor overflow across the midline in aging. Current results suggest that observed motor overflow is part of healthy aging, possibly reflecting compensatory brain events.

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