Differences in Multiple Segment Tremor Dynamics Between Young and Elderly Persons

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Background. Physiological tremor is an intrinsic and highly variable motor output that is sensitive to alteration in both neuromuscular function and/or changing task demands. Given that any tremor increase can severely influence fine motor performance, there is a requirement to clarify what factors lead to increased tremor. Identification of those factors that alter tremor may be particularly pertinent for elderly persons, who often exhibit a decline in postural control and amplified tremor. The aim of this study was to examine the effect of whole body posture (seated vs standing) on multiple segment tremor and forearm electromyogram (EMG) activity of younger and older individuals.

Methods. Fourteen older and 12 young participants performed a bilateral pointing task. Tremor data were collected using accelerometers attached to the forearm, hand, and finger segments of each arm. Surface EMG data were also collected from the extensor digitorum muscle of each arm.

Results. Although the pattern of tremor was similar between age groups, older participants exhibited increased hand and finger tremor amplitude and increased EMG activity across all postural conditions. For older individuals, tremor increases were greatest when the participant performed the task in a standing position. All age-related increases in hand and/or finger tremor were confined to increases in peak power between 8 Hz and 12 Hz.

Conclusions. From a clinical perspective, these findings illustrate that using multiple segment tremor analyses can provide additional insight into potential age-related tremor differences. Additionally, the fact that postural position had a pronounced effect on tremor in older individuals suggests that body posture should be considered as a potential confounding factor when assessing tremor differences between population groups.

The normal aging process is associated with a general decline in the functional capacity of the neuromuscular system. One motor symptom often linked with this decline is an increase in the amplitude of physiological tremor within the upper limbs (1,2), a situation which can have severe implications for the ability of any individual to perform everyday fine motor skills involving precision and/or grasping (3,4). Despite this common assumption that tremor increases with aging, very few studies have actually reported increases in tremor amplitude in elderly individuals (1,2), while others have reported subtle changes in the frequency of the major tremor peak but no increase in tremor amplitude (5–9). This lack of consensus may be due to the number of factors, including changes in neuromuscular function, associated with aging and/or differences in the specific task performed.

From a clinical perspective, there is a clear need to define: (a) whether increases in tremor are symptomatic of the normal aging process and (b) the nature of the underlying physiological reason for any tremor increase. However, given that tremor is a highly variable motor output, there is also a requirement to examine what effect changes in task demands and/or as a consequence of differing methodological practices have on tremor output. Thus, any understanding of any potential age–tremor relationship should also consider what effect different task conditions have on the resultant tremor in both young and older populations.

For example, in many experimental studies, it is common practice to only examine tremor from a single segment with the other more, proximal segments supported (5,6,9–11), despite the fact that tremor is rarely localized to a single segment during everyday tasks which require individuals to maintain the postural position of the entire limb. A recent suggestion is that examining tremor when the entire upper arm is unsupported may provide a more sensitive and realistic indicator of inherent differences between neurologically normal and clinical population groups (12–14). From a more practical viewpoint, examining tremor from multiple segments may provide further clarification of any potential age-related differences in tremor. Furthermore, the practice of measuring tremor under more real-world situations can be extended by examining what effect whole-body posture has on upper limb tremor. Although various studies have independently assessed tremor during standing (15,16) and sitting (1,8,17), there has been no direct assessment of the effect of whole-body position on tremor.

This issue has more importance when coupled with the general view that the postural capacity of the elderly individual declines with age (18,19). This decline can be manifested by a number of differing outcomes including increases in postural sway, increased cocontraction (usually with a resultant decrease in postural sway), and/or greater difficulty performing additional postural/cognitive tasks while standing (20–22). Irrespective of the specific postural changes observed, the general consensus in that most older individuals have greater difficulty maintaining an optimal
level of postural stability. Given these age-related postural differences, it may be assumed that the fundamental task of standing coupled with the need to minimize arm tremor may be more difficult for older individuals.

The aim of this study was to examine the effect of whole-body postural position (seated vs standing) on the multiple segment tremor and electromyographic (EMG) activity of younger and older individuals. It was hypothesized that: (a) the postural tremor seen in the elderly persons would be greater in amplitude than that seen in young persons, and (b) any age-related differences would be greater when the older individuals adopted a standing position.

**METHODS**

Fourteen elderly adults (age: 71.1 ± 4.3 years) and twelve young adults (age: 21.2 ± 2.7 years) volunteered to participate in this study. Young adults were recruited from the University student population. Elderly participants were recruited from the local population by using advertisements in local newspapers. All participants completed an informed consent form and medical questionnaire which categorized their current health status. All individuals reported no known neurological/cognitive disorders, impairments in vision, proprioception, or recent history of neuromuscular injury/damage that could influence performance. Potential participants were also screened to ensure that they were not using any medication that could influence tremor. All experimental procedures complied with the guidelines of the Griffith University Human Research Ethics Committee.

**Experiment and Equipment**

All participants performed eight 30-second trials of a series of bilateral pointing tasks in sitting and standing positions. Participants held both arms parallel to the ground as per our previous work (15, 23). The task goal for each condition was for each participant to focus on the index fingers and attempt to minimize the tremor there. Upper-limb tremor was measured using six precalibrated Coulbourn uniaxial accelerometers (V94-41, range ± 10 g; mass 0.018 grams; Coulbourn Instruments, Allentown, PA) and amplified through a Coulbourn strain gauge transducer coupler (V75-25A, sample rate 100 Hz). Accelerometers were attached to the forearm, hand, and index finger of each participant’s arm. Figure 1 illustrates the accelerometer placement and position of the upper limbs during testing.

Bipolar Ag/AgCl EMG surface electrodes were positioned over the belly of the extensor digitorum (ED) muscle of both arms to measure muscle activity. Electrode pairs were placed parallel to the underlying muscle fibers (interelectrode distance = 2 cm). EMG signals were amplified using Coulbourn isolated bioamplifiers (V75-02, sample rate 1000 Hz).

Prior to the experimental protocol, a baseline EMG measure for each participant was determined. Participants were seated with their forearm, hand, and finger of each arm completely supported. Six 30-second trials were performed to determine the resting levels of ED activity. The EMG signal was rectified and bandpass-filtered (2–400 Hz), and the average of the full-wave rectified EMG (AEMG) was calculated (5, 24). Subsequent analysis revealed no significant resting AEMG differences between limbs or age groups.

**Data Analysis**

All accelerometer (tremor) data were filtered using a second-order low-pass Butterworth filter (cutoff frequency 40 Hz). The EMG data were full-wave rectified and band-pass filtered (2–400 Hz) because this process provides information about the temporal pattern of grouped motor unit (MU) firing potentials (5, 24). All data processing was performed using MATLAB software (MathWorks, Natick, MA).

**Time Domain Analysis**

The specific dependent variables assessed related to the amplitude of the tremor and EMG outputs and the strength of any coupling relationships. Average tremor amplitude involved calculating the root mean square (RMS) of the tremor signal (window size 100 ms). The average of the full wave rectified EMG signal (AEMG) was used to assess the degree of muscle activation (24).

The degree of coupling between respective signals (tremor–tremor, tremor–EMG, EMG–EMG) was assessed using cross-correlation analysis (Pearson product moment) using time lags of ± 5 seconds.

**Frequency Analysis**

The specific frequency measures assessed related to the maximum amplitude (peak power) of the tremor/EMG output and the frequency at which this peak value was observed (peak power frequency [PPF]). Frequency analyses was performed on the filtered tremor and rectified EMG signals within the range of 0–40 Hz and 0–400 Hz, respectively, using Welch’s averaged, modified periodogram method using a 512 data point Hanning window. This analysis produced a frequency resolution for the tremor and EMG signals of 0.1953 Hz and 0.9755 Hz, respectively.
Separate power spectral analyses were also performed for the tremor data within four bandwidths: 0–7, 7–17, 17–30, and 30–40 Hz, because distinct tremor peaks are often reported between 2 and 4 Hz, 8 and 12 Hz, and 18 and 30 Hz (4,10,25).

A measure of proportional power for each signal was also calculated. This measure determines how the total power of any signal was distributed within a given frequency range. Proportional power measures were calculated for the tremor signal in 0.5 Hz bins (from 0 to 40 Hz) and for the EMG signal in 1 Hz bins (from 0 to 400 Hz).

To assess the strength of coupling between any two signals in the frequency domain, coherence analysis was performed and the maximum (peak) coherence value determined. For EMG–EMG comparisons, peak coherence was calculated between 0 and 400 Hz (window size, 512 data points). For EMG–tremor analyses, EMG data was downsampled to 100 Hz because both signals were originally sampled at different rates. Peak coherence was assessed for tremor–tremor and tremor–EMG relationships between 0 and 40 Hz (window size: 512 data points). To assess whether the coherence between any two signals was significantly different from zero, a 95% confidence interval was calculated (25).

**Statistical Analysis**

A multivariate repeated measures analysis of variance (ANOVA) was used to assess the effect of age (between-subject factor) and posture, segment, and limb (within-subject factors) on the dependent tremor and EMG measures. Post hoc analyses were performed using Tukey's Honestly Significant Difference test to evaluate which groups were significantly different if a main effect was obtained. All tests were performed using SAS statistical software (SAS Institute Inc., Cary, NC), with the risk of Type I error set at $p < 0.05$.

**RESULTS**

**Tremor and EMG**

**Time domain analysis.**—For all participants, tremor increased significantly from distal to proximal within limb, with finger tremor always greater than hand and forearm tremor, irrespective of postural position ($F_{5,33} = 1329.07, p < 0.05$). Similarly, hand tremor was always significantly greater than the tremor observed for the forearm ($F_{5,33} = 126.98, p < 0.05$).

In contrast, no tremor differences were seen for similar contralateral segments nor were any differences in the AEMG activity between limbs within groups. This finding indicated that the tremor and AEMG amplitude was similar between the right and left limbs for each age group. An example of the age-related differences in index finger tremor as a function of posture is shown in Figure 2.

**Frequency analysis.**—The tremor observed in all segments contained two prominent frequency peaks, between 2 and 4 Hz and between 8 and 12 Hz. As with the time domain analysis, the maximal peak power within these ranges for the index finger was always greater than that observed for the hand and forearm ($F_{5,33} = 212.86, p < 0.05$).

For finger tremor, the maximal peak power and proportional power (44%–57%) were found within the 8 Hz to 12 Hz range ($F_{5,33} = 36.54, p < 0.05$). A third, smaller peak between 18 Hz and 30 Hz was evident in the finger tremor although the power associated with this component was less than 10% of the total tremor power. Although two peaks were also seen for the hand and forearm tremor, a greater peak and proportional power were observed within the 2 Hz to 4 Hz range ($F_{5,33} = 13.36, p < 0.05$).

Similarities in the frequency profile of the rectified EMG signal were also found between groups. PPF was approximately 120 Hz (young PPF = 118–127 Hz; elderly PPF = 113–124 Hz) with the majority of the power (47%–61%) in the EMG signal between 40 and 150 Hz. An example of the differences in rectified EMG signals and frequency profiles between age groups and postures is presented in Figure 3.

**Tremor–tremor and tremor–EMG relationships.**—Correlation and coherence analysis revealed that, for all participants, the highest degree of coupling was, for the tremor, in the more distal segments (hand–finger; $r = 0.52–71$, $F_{27,162} = 13.34$; peak coherence: 0.86–0.97, $F_{27,162} = 4.89$; $p < 0.05$). The maximal coherence values were observed within the ranges where the 2 Hz to 4 Hz and 8 Hz to 12 Hz tremor peaks were observed.

While a lower degree of coupling was found between the hand–forearm segments within a single limb, only the coherence results were significantly greater than zero (peak coherence < 0.33). No significant tremor relationships were found between nonadjacent segments of a single limb (finger–forearm; $r < 0.08$, peak coherence < 0.15) or between any contralateral limb segments ($r < 0.1$, peak coherence < 0.11).

While the tremor–EMG correlation analysis results produced no evidence of any significant degree of coupling between any tremor and EMG signals ($r < 0.10$), this finding was not mirrored by the coherence results. This analysis revealed a significant degree of tremor–EMG coupling where, within either arm, the level of coupling between finger–hand tremor and the rectified EMG signal was of the order of 0.35–0.40 with coherence peaks being seen between 4 Hz and 5 Hz and between 19 Hz and 20 Hz.

No evidence of any significant coupling was observed between the rectified EMG signal and forearm tremor ($r < 0.09$, peak coherence < 0.11) nor was any significant coupling between the muscles of each arm reported ($r < 0.08$, peak coherence < 0.13). Figure 4 illustrates the general pattern of within-limb and between-limb coherence tremor results and finger tremor–EMG and EMG–EMG coherence plots.

**Effects of Age and Posture on Tremor and EMG**

Overall, significant differences in the tremor and AEMG signals were observed as a function of both age and postural position. The majority of these differences were associated
with changes in signal amplitude (mean RMS amplitude, AEMG, peak power between 8 and 12 Hz).

**Time domain analysis.**—For older participants, mean RMS hand and index finger tremor was significantly greater than that seen in the young participants under both postural conditions (finger tremor $F_{3,33} = 97.14$; hand tremor $F_{3,33} = 7.33$; $p$ values < .05). In addition, for the older participants only, hand–finger tremor increased significantly from sitting to standing ($p < .05$). No change in tremor between sitting and standing conditions was seen for the young participants. No differences in forearm tremor were found between young and elderly groups or as a function of posture. Figure 5 highlights the mean RMS hand and finger tremor for the two age groups across postures.

The AEMG values were significantly greater for the older participants in comparison to the young participants in both postural conditions ($F_{3,33} = 3.83$; $p < .05$). For older
participants, muscle activity increased from sitting to standing. No such change was found for young participants, as EMG activity did not change significantly between postures. Figure 6 illustrates the age-related differences in AEMG activity during each postural condition.

Frequency analysis.—As with the time series analysis, significant differences in tremor frequency measures between the age groups were observed as a function of posture. These differences were confined to the 8 Hz to 12 Hz tremor component for the finger and hand. No change in the 2 Hz to 4 Hz tremor peak for the hand or finger was found between conditions or groups. All age-related tremor differences were localized to the hand and finger segments only, with no alteration in the forearm tremor peaks between 2 Hz and 4 Hz or between 8 Hz and 12 Hz.

Figure 3. Representative rectified electromyogram (EMG) traces and power spectral density (PSD) plots for the extensor digitorum (ED) muscle of a young and an elderly participant. Surface EMG PSD traces were obtained from the ED muscles of the right limbs during both the standing and sitting conditions.
Across all postural conditions, the maximum peak and proportional power of both the hand and finger tremor within the 8 Hz to 12 Hz bandwidth was greater for older participants (peak power $F_{3,33} = 37.93$; proportional power $F_{3,33} = 9.81; p < .05$). Further analysis revealed that these increases within the 8 Hz to 12 Hz hand and finger tremor were greatest when the older participants adopted a standing position (all $p < .05$).

A significant age-related difference was also found in the frequency at which peak power between 8 and 12 Hz was observed (PPF) in the index finger tremor. For older participants, PPF occurred at the lower part of the 8 Hz to 12 Hz bandwidth in comparison to younger participants (elderly PPF 7.88–8.83 Hz; young PPF 9.21–9.85 Hz; $F_{3,33} = 7.39; p < .05$). However, no change in the PPF of hand tremor between 8 and 12 Hz was reported between age groups.

A similar age-related result was found for the amplitude of EMG activity where greater peak power was observed for ED activity in the index finger tremor. For older participants, PPF occurred at the lower part of the 8 Hz to 12 Hz bandwidth in comparison to younger participants (elderly PPF 7.88–8.83 Hz; young PPF 9.21–9.85 Hz; $F_{3,33} = 7.39; p < .05$). However, no change in the PPF of hand tremor between 8 and 12 Hz was reported between age groups.

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**Tremor–tremor and tremor–EMG relationship.**—While a similar pattern of coupling was observed within each limb for all participants, the cross-correlation analysis also revealed subtle differences in the coupling strength between age groups. Younger participants had a higher degree of coupling between the hand and index finger (young $r = .62–.74$; elderly $r = .52–.60$; $F_{27,162} = 6.12; p < .05$). In contrast, older participants exhibited significantly greater coupling between the hand–forearm segments (young $r = 0.01–0.11$; elderly $r = 0.24–0.30$, $F_{27,162} = 4.55; p < .05$). No differences in the cross-correlation values within groups were reported between sitting and standing positions. These correlation differences between age groups were not reflected by any significant change in peak coherence values between the young and older participants or across the two postural conditions.

**Discussion**

The aim of the present study was to examine the effect that posture had on physiological tremor and muscle activity in neurologically normal young and older individuals. The specific hypotheses tested were that: (a) elderly participants would exhibit greater postural tremor than young participants, and (b) any age-related tremor differences would be
magnified when older participants performed the task when standing.

Although similarities in the pattern of tremor were observed between groups, older participants exhibited increased tremor amplitude and EMG activity in comparison to younger participants. Furthermore, for older individuals only, both tremor and EMG activity increased significantly from sitting to standing. From a clinical perspective, the use of multiple segment tremor analyses provides a clearer delineation between young and older participants in regard to their tremor output. In addition, the increase in tremor observed when older participants adopted a standing position would suggest that consideration should be given to the body posture of the individual when examining tremor differences between population groups.

Age-Related Tremor Similarities

Several similarities in the general tremor output were observed between age groups. For all participants, postural tremor amplitude increased from proximal to distal, with tremor being greatest at the finger, a result consistent with previous reports using multiple segment tremor measures (15,23,26,27). However, this proximal-to-distal increase was not the result of a simple addition, but rather represented a nonlinear increase in tremor amplitude from segment to segment, similar to that reported previously (28).

In addition to the same proximal–distal tremor pattern, the tremor output within any segment was similar between groups. Frequency analysis revealed that the tremor in any segment consisted of two prominent tremor peaks, observed between 2 Hz and 4 Hz and between 8 Hz and 12 Hz. The presence of separate frequency peaks is important because each component arises from different underlying oscillatory sources including the mechanical resonant properties of the limb segment and its interaction with stretch reflex pathways, output from central neural structures, and (potentially) visuomotor processing (4,25,29,30).

For postural finger tremor, oscillations between 8 and 12 Hz are generated from central neural output (4,7,10,11,29,31). However, it is unlikely that 8 Hz to 12 Hz activity represents the output of any single neural structure, but rather these oscillations probably represent the summed activity between such sources as the basal ganglia, inferior olive, deep cerebellar nuclei, thalamus, and, at the spinal cord, alpha motor neurons (4,29,30,32).

The mechanical resonant properties of any segment also contribute to the tremor output seen under postural conditions (7,29,30). This frequency component of the tremor is derived from the mass (inertia) of the segment and its intrinsic stiffness. For example, lighter segments such as the index finger have a resonant component between 18 and 30 Hz, whereas heavier segments, such as the hand, forearm, and upper arm, exhibit resonant frequency outputs between 8 Hz and 12 Hz, 2 Hz and 4 Hz, and 1 Hz and 2 Hz, respectively (10,11,24,33).

A third potential origin relates to the low-frequency oscillations observed between 0 and 4 Hz, which are associated with sensorimotor control processes during voluntary actions. Previous studies examining motor output during
isometric and isotonic movements have shown that the low-frequency component of the selected motor output (below 4 Hz) can be associated with concurrent processing and integration of movement-related visual information (34–37).

On the basis of the similarities in the tremor profile of young and elderly adults, it would appear that the same underlying neurological processes and mechanical factors contributed to the postural tremor seen in both age groups. However, whereas similarities in the pattern of tremor were observed between age groups, significant differences in the amplitude of the tremor and AEMG output emerged between young and older participants.

Effects of Aging on Tremor/EMG

Overall, elderly participants exhibited significantly greater postural tremor and EMG activity than did young participants. For postural tremor, these age-related differences were restricted to increases in the amplitude measures of tremor for the hand and finger only, with increases in both mean RMS amplitude and peak power between 8 Hz and 12 Hz.

A number of potential related reasons exist for these specific age-related results. One is that any changes seen represent the consequence of needing to maintain the position of the entire upper arm against gravity. In this respect, older participants may have found this task more difficult than young participants, so the increased tremor reflected the greater task demand of holding the entire limb unsupported. Although this view has some merit, the specific nature of the changes in the tremor output would indicate that changes in underlying physiological processes between young and older participants also play a role. For example, increases in tremor amplitude were not universal across segments, with increases limited to the hand and finger segments only, and no change in forearm tremor. Furthermore, the increase in tremor amplitude was specific to the 8 Hz to 12 Hz range, indicating that changes in the output of those processes that generate tremor within this range were responsible for any age-related differences. Given that both central neural factors and intrinsic limb mechanics are involved in the generation of 8 Hz to 12 Hz tremor in the hand and finger (7,29,30), further clarification of their potential contribution is necessary.

With regard to the mechanical resonant mechanisms, the effective mass of the finger segment could theoretically be increased by strengthening the hand–finger coupling (16,33). This increased stiffness would explain the increase in tremor amplitude, but there should also be an increase in the hand–finger coupling relationship and a shift in the frequency of the 8 Hz to 12 Hz peak (PPF) (5,7,9). However, the results of this study do not wholly support this view. Although the peak of the 8 Hz to 12 Hz finger tremor was observed within a lower range of this bandwidth for older participants, no specific age-related differences in the PPF of the mechanical resonant component of finger tremor (18–30 Hz), hand tremor (8–12 Hz), or forearm tremor (2–4 Hz) were observed. In addition, correlation analysis revealed that older participants exhibited a significantly lower level of coupling between the hand–finger segments but increased coupling across the wrist joint.

Another potential explanation is that the increased 8 Hz to 12 Hz tremor may be related to a change in the common descending central drive, a position that has been proposed previously to explain changes in tremor output with aging (5,38,39). The specificity of the tremor changes, being localized to just the 8 Hz to 12 Hz oscillations within the hand and finger segments, and the corresponding EMG increase would offer more support to this view.

Overall, the results of the current study clearly illustrate that differences in tremor within the distal segments can be observed between age groups. The specific nature of the tremor changes indicates that alteration in the central neural output, either as a consequence of changes in neuromuscular function due to aging and/or the result of the requirement to hold the entire limb unsupported, is probably responsible for the increased tremor observed. The clear delineation between young and older participants in terms of their tremor also highlights that potential for using multiple segment tremor analysis to differentiate between different population groups.

Effects of Posture on Tremor/EMG

The posture adopted by each participant had contrasting effects on the resultant tremor and EMG activity. For young participants, performing the task while sitting or standing did not produce any change in tremor or EMG activity. However, older participants exhibited significantly greater tremor and muscle amplitude than their younger counterparts even during the seated pointing task. Furthermore, when the older participant performed the task while standing, both postural tremor and EMG activity increased significantly from sitting. This finding is of some importance in that it illustrates that not only do elderly persons exhibit greater tremor amplitude, but also that the simple act of trying to hold the arm outstretched against gravity while standing further exacerbates any tremor differences between age groups. This result has implications for the general measurement of tremor in different populations, especially those with more amplified tremor and/or postural control issues (for example, Parkinson’s disease patients) where there is the possibility that any tremor may be enhanced if the individual adopts a standing position.

Overall, the study highlighted specific differences in the dynamics of physiological tremor between young and older participants. These differences were localized to increases in the amplitude of the 8 Hz to 12 Hz tremor component. In addition, for older participants, both tremor and EMG activity increased from sitting to standing. Together these results demonstrate that using multiple segment measures of tremor permits a clearer delineation between young and elderly individuals. It was also shown that, for participants with amplified tremor, increasing the postural demand can have a significant impact on upper limb motor output.

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