Electromyographic Responses to Rotational and Translational Perturbations

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Electromyographic (EMG) responses of lower leg muscles to postural perturbations during standing were studied to determine the effect of perturbation type and prior knowledge on the timing and response profile of muscle activation. We hypothesized that onset latencies and variances of EMG signals from the tibialis anterior (TA) and soleus (SOL) would be affected by 1) the type of perturbation and 2) prior knowledge of the perturbation type presented. The dependent measures were EMG onset delay from perturbation, EMG magnitude, and occurrence of silent periods. Five young, healthy adults received toes-up rotation and posterior translation underfoot perturbations via a dynamic posturography platform. Perturbations were presented on three different days in blocks of sixteen trials. The first two blocks contained rotation and translation trials, respectively, and the third block contained a randomized mixture of rotation and translation trials. The results demonstrated that prior knowledge had no effect on the presence of silent periods. However, silent periods occurred more frequently in the TA for rotation trials than for translation trials. There was a significant perturbation effect on TA onset latencies and TA and SOL variances, as well as a significant block and perturbation interaction effect on the SOL variances. From these results, it appears that postural responses to rotation and translation perturbations are controlled by different motor programs, which, in turn, are modulated by prior knowledge, varying the onset magnitude of certain muscles.

INTRODUCTION

Falls are one of the most common causes of injury in the elderly.[9] In 2000, 10,300 fatal falls and 2.6 million medically treated non-fatal fall-related injuries were reported.[17] Consequently, much of today's research is devoted to developing interventions to prevent falling. For example, studies have shown that performing balance exercises regularly decreases the likelihood of falling,[8] suggesting that standing balance directly correlates with falling. Thus, to develop better falling interventions, it is necessary to better understand the human motor control system.

Silent periods have loosely been defined as cessations of activity preceding elevated EMG levels.[1] Staude et al. (2000), however, define silent periods more exactly, stating that "a segment is considered a silent period if the variance of the corresponding cluster is smaller than those of the two adjacent segments and if the variance of its predecessor is smaller than the variance of its successor".[16] Silent periods in ballistic action have been shown to be associated with the reinforcement of force and an increased motor unit synchrony prior to rapid movement.[1,4] Few studies, however, have explored how silent periods affect the short loop stretch responses and long loop voluntary responses that are often found within elevated EMG levels.[14] The effect of silent periods on EMG responses to postural perturbations has not been thoroughly investigated either. The minimal discussion of silent periods in the literature could be due to that fact that EMG responses to postural perturbations are typically averaged across many trials, masking the silent periods present in individual signals.[6,7,10,11,12,13] Additionally, silent periods may have short durations and are hard to detect.[1,4] However, new methods have been suggested for detecting silent period, as well as the onsets of other muscle activation levels.[5,15]

In previous studies the effect of sensory confusion on the stereotypical pattern has been explored. Specifically, studies have compared responses to toes-up rotation and posterior translation. These postural perturbations are designed to elicit similar stretch responses in the subject's ankle plantarflexors, but require opposite motor responses to maintain balance. In the toes-up rotation case, large responses in the ankle dorsiflexors are needed to pull the body's center of mass forward to regain balance. In the posterior translation case, on the other hand, the body's center of mass must move backward to maintain balance. As a result, a large response is needed in the plantarflexor muscles. It has been suggested that responses to these sensory confusing perturbations can be affected by previous experience. For example, Chong et al. have shown that a person's ability to respond appropriately to a rotation is decreased after experiencing a series of translations.[3] Appropriate response rates also decreased when translations and rotations were alternated.[3] However, neither the timing of the perturbations nor the order in which they occurred was randomized in Chong et al.'s study. Thus the subject always had some degree of prior knowledge. A study conducted by Mummel et al. used the same perturbation types to look into the absence of prior knowledge by comparing the magnitude of EMG responses for "expected" and "unexpected" trials.[10] However, differences in EMG onset latencies for expected versus unexpected trials were not discussed.[10] The purpose of this study is to determine the effect of perturbation type (toes-up rotation or posterior translation) and prior knowledge on the timing and response profile of muscle activation.

METHODS

Data Collection

Five young, healthy adults between the ages of 18 and 30 years (average age = 24.2, standard deviation = 1.64) were recruited. They were screened to ensure they were free of musculoskeletal, neurologic, and vestibular disease at the Eye and Ear Institute (University of Pittsburgh Medical Center, Pittsburgh, PA) as part of a larger study. Testing occurred over three separate days with a minimum of 24 hours between each testing session. The first testing day was preceded by a screening day, during which the subjects were given the opportunity to become familiar with the postural perturbations to be tested. The perturbations included a rapid toes-up rotation of 3.4 degrees and a posterior translation of 4 cm. The rotations and translations were generated as sigmoidal profiles with maximum velocities of 18 deg/s and 24 cm/s respectively. The perturbation types were designed to elicit similar stretch responses in the subject's ankle plantarflexors while requiring opposite motor responses to maintain balance.

On each testing day, subjects performed three blocks of sixteen trials. The first block contained sixteen rotation trials, the second block contained sixteen translation trials, and the third block contained eight rotation trials and eight translation trials for each testing session. For the first two blocks, subjects were informed of the perturbation type (rotation or translation). For the third block, subjects were told that both perturbation types would be present, but they were not informed of the order in which they would occur.

During the experiment, subjects stood on a dynamic posturography platform (NeuroCom, Inc., Clackamas, OR) with their ankles in line with the axis of rotation as displayed in Figure 1. They wore a harness to prevent ground contact injuries in the event of a fall. EMG signals were collected via surface electrodes placed on the tibialis anterior (TA), gastrocnemius (GAS), and soleus (SOL) muscles of the subject's dominant leg (TeleMyo 900; Noraxon, Scottsdale, AZ). Data was collected using LabVIEW (National Instruments, Austin, TX) and analyzed in MATLAB (MathWorks, Natick, MA) to locate silent periods and determine EMG latencies. Due to limited power, only the TA and SOL muscles were analyzed here.

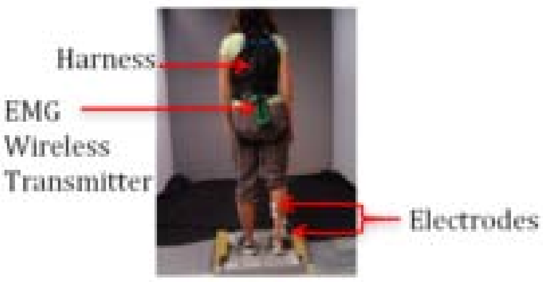

Fig 1: Experimental setup. Subject standing on dynamic posturography platform with electrodes placed on the tibialis anterior, gastrocnemius, and soleus muscles of the dominant leg.

Data Processing

To locate the silent period(s) and the onset of EMG responses, a sequential change point detection algorithm, modified from Staude et al., was used.[16] In the current study, the whitening filter suggested by Staude et al. (2000) was omitted because it tended to eliminate silent periods from the data when baseline activity was minimal. The resulting algorithm was then a two-step process: first, a sequential two window approximated generalized likelihood ratio (AGLR) test is applied to the EMG signal to determine where changes in the signal's variance occur, and second, a post-processor uses an F-test to group parts of the signal with similar variances into classes, which loosely represent different levels of muscle activation.

In the AGLR step, a fixed window slides over the EMG signal while a second, growing window increases in length until a potential change point is reached. Change points are detected at the beginning of the growing window, and after each change point is identified, the windows reset so that the growing window begins at the detected change point. This process repeats for the duration of the signal, resulting in several change times, which effectively divide the signal into segments. Potential change times are computed using the log-likelihood ratio test function,

$$g(k) = -\frac{1}{2}\left[(k - L - t_{m-1})\, \ln(\hat{\theta}_b) + L \ln(\hat{\theta}_a) - (k - t_{m-1}) \ln(\hat{\theta}_0)\right] \quad (1)$$

where k is the current time point of the leading edge of the fixed window, L is the fixed window length, t_{m-1} is the previously identified change time, $\hat{\theta}_b$ is the signal's variance within the growing window (before k - L), $\hat{\theta}_a$ is the signal's variance within the fixed window (after k –L), $\hat{\theta}_0$ and is the variance of both windows combined. A potential change time is triggered when the log-likelihood ratio exceeds a set threshold h.[16] After a potential change time is triggered, a more exact change time is found by maximizing the likelihood function between the previous change time plus L and the current potential change time,

$$\Lambda(j) = -\frac{1}{2}\left[(j - t_{m-1}) \ln(\hat{\theta}_b) + (\hat{t}_m + \Delta - j) \ln(\hat{\theta}_a)\right] \quad (2)$$

where j is the current estimated change time, t_{m-1} is the previously identified change time, Δ is the minimum number of points reserved to calculate the variance of the signal after the current change time, $\hat{\theta}_b$ and $\hat{\theta}_a$ are the signal's variance before and after the current change time, respectively, and $\hat{t}_m$ is the first time after the previous change time at which g(k) exceeds h.[16] For the current

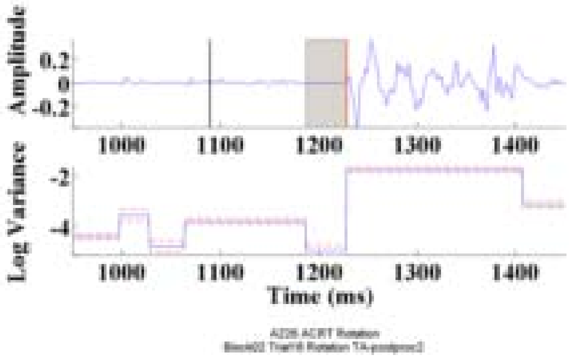

Figure 2: Typical TA results from a rotation block. Plot A shows an analyzed EMG signal annotated with the start of the platform motion (black line), a silent period (gray shaded region), and the onset of EMG activation (red line). Plot B illustrates the estimated variance profile of the analyzed EMG signal with 95% confidence interval (red dashed line).

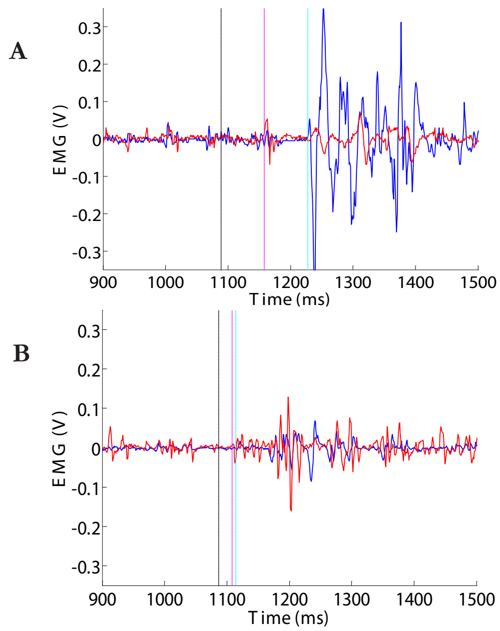

Figure 3: EMG onsets for TA and SOL in A: a rotation trial and B: a translation trial. The solid blue and red lines indicate the recorded TA and SOL responses, respectively. The dashed black, blue, and red lines indicate the onsets of platform motion, TA and SOL, respectively.

Table 1: ANOVA for EMG Onset Latencies and Variances

Effect	p-values			
	TA Lat.	TA Var.	SOL Lat.	SOL Var.
Day	0.201	0.553	0.836	0.364
Block	0.498	0.732	0.241	0.115
Day*Block	0.946	0.821	0.900	0.902
Pert	0.024*	0.005*	0.183	0.015*
Day*Pert	0.506	0.449	0.913	0.626
Block*Pert	0.495	0.743	0.269	0.002*
Day*Block*Pert	0.806	0.607	0.919	0.549

* indicates significance ($\alpha = 0.05$); "Pert" stands for perturbation

Table 2: Silent Period Occurrence (mean ± std)

Pert. Type	Muscle	Block Type	
		Single	Mixed
R	TA	31.3% ± 20.6%	37.5% ± 22.2%
	SOL	27.1% ± 7.93%	25.8% ± 8.01%
T	TA	14.2% ± 11.8%	16.7% ± 19.1%
	SOL	27.1% ± 7.93%	30.8% ± 18.8%

"Pert" stands for perturbation

study, the length of the sliding window, L, was set to 30 points, the threshold, h, was set to 10, and Δ was set to 10.

In the post-processing step, the variance was computed for each segment between successive change times. High variance segments were alternated with low variance segments until all variance values were interleaved. An F-statistic was then used to compare the ordered variances to class levels based on a significance level of α. As each segment was added to a class, the class variance was updated to include the new value as detailed in Staude et al.[16] Following the class assignments, if adjacent segments within the original signal fell into the same activation level, they were merged together, and the potential change time between them was eliminated.[16] In the current study, the significance level for the F-test was set to a value of $\alpha = 0.001$ for SOL and $\alpha = 1x10^{-11}$ for TA. A lower significance level was used for TA due to an increased signal to noise ratio.

After the raw EMG signal passed through both steps of the change point algorithm, the EMG onset, onset variance, and presence of silent periods were found for both the SOL and TA signals. The EMG onset was identified using two criteria: first, it must occur at least 20 milliseconds after the onset of platform motion, and second, it corresponds to the first increase in variance that is greater than the minimum variance of the trial plus 1% of the trial's variance range. The silent periods were identified as defined by Staude et al. (2000; see introduction) within the first 300 milliseconds following the start of the platform motion.

Statistical Analysis

A three-way repeated measures ANOVA was performed on all EMG dependent variables. The independent variables were day (1, 2, or 3), block type (single or mixed), and perturbation type (rotation or translation). Dependent variables were the EMG median latencies and variances for the TA and SOL. Silent periods were analyzed by percent occurrence within block and perturbation type and averaged across subjects.

RESULTS

Overall, the change point algorithm, combined with the EMG onset identification criteria, identified the EMG onsets and silent periods fairly accurately, as indicated by Figures 2 and 3.

For TA, the variances at the onset were larger and the latencies were longer in rotation trials than in translation trials, with across-subject mean latencies and standard errors of 132.8 ± 12.5 ms and 83.6 ± 12.5 ms, respectively. SOL latencies followed the same trend, but were not significantly different between perturbation types, with across-subject mean latencies and standard errors of 98.9 ± 14.5 ms for rotation trials and 68.2 ± 14.5 ms for translation trials. SOL variance values, however, were larger for translation than rotation trials. In addition, they were larger for translation trials in the unknown condition versus the known condition.

Table 1 displays the p-values for the median EMG onset latencies and variances for both the tibialis anterior and the soleus. As expected in the trends detailed above, a significant perturbation effect was found for the median variances of both muscles, as well as for the median onset of TA. In addition, a significant block and perturbation interaction effect was found for the median variances of SOL.

Table 2 demonstrates that the across-subject mean percent of trials in which a silent period occurred was about twice as large for TA single rotation than for TA single translation. Similarly, the percent of TA mixed rotation trials with silent periods was approximately double the percent of TA mixed translation trials with silent periods. Percentages were approximately the same across-block type and perturbation type for SOL.

DISCUSSION

As suggested previously in the literature, perturbation type and prior knowledge are believed to have an effect on motor responses to postural perturbations.[3,5] Table 1 reveals significant perturbation effects for the variances of TA and SOL and the latencies of TA. However, prior knowledge only affected SOL variances of translation trials. No prior knowledge effect was seen for rotation trials, despite the greater potential for cortical input derived from their longer latencies.[11] Additional support for the lack of significant effects in the EMG latencies comes from Thigpen's belief that the timing of response to postural perturbations "depend[s] upon intact peripheral triggering mechanisms" or spinal cord processes.[18]

Silent periods also lacked a prior knowledge effect. Table 2 shows no indication of differences between the known and unknown conditions of either perturbation type. The perturbation type effect, however, may be present. Comparing the percent of trials in which a silent period occurred for TA rotation and TA translation suggests that silent periods occur more frequently in rotation trials than in translation trials for the TA muscle. Since more force in the TA response is needed to stabilize one's position after rotation perturbations and less force is required in the TA response after translation perturbations,[3] the TA results support Aoki's suggestion that silent periods enhance the force of the initial EMG response.[1] The absence of a perturbation effect in the SOL muscle could be due to the fact that the SOL tends to respond to perturbations with an early stretch reflex.[2] This stretch reflex is generated by a spinal cord process and is initiated much sooner after a perturbation than the voluntary reflexes from cortical processes.

One limitation in this study is the small population size. Additionally, the study only considers whether or not a silent period occurs in a given EMG response, not the number of silent periods that occur or their duration. Overall, more data is required to verify the results obtained in this study and to determine if the number or duration of silent periods affects EMG onset latencies for different postural perturbations. In the future, the EMG responses obtained from the young adults in this study will be compared to EMG responses to postural perturbations from elderly subjects, which will provide greater depth and credibility to our results.

CONCLUSIONS

This study revealed that there is a significant perturbation effect on tibialis anterior onset latencies and tibialis anterior and soleus variance. A significant block and perturbation interaction effect on SOL variance was also found, and silent periods tended to occur more frequently for TA rotation than for TA translation. Overall, the results of this study are not strong enough by themselves to yield definitive conclusions regarding the effect of perturbation type and prior knowledge on the timing and response profile of muscle activation. However, further study of the questions posed here in larger and more varied populations may lead to a better understanding of the human motor control system.

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