Original

Quantitative Electroencephalography and Surface Electromyography Correlations upon Predictable and Unpredictable Perturbation in Older Adults

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ABSTRACT

Background: Quantitative Electroencephalography (qEEG) is a non-invasive method used to quantify electrical activity over the cortex. QEEG provides an accurate temporal resolution of the brain activity, making it a useful tool for assessing cortical function during challenging tasks.

Objective: This study aimed to investigate postural adjustments in older adults in response to an external perturbation.

Material and Methods: In this observational study, nineteen healthy older adults were involved. A 32-channel qEEG was employed to track alterations in beta power on the electrodes over the two sensory-motor areas. Integrated electromyographic activity (IntEMG) of the leg muscles was evaluated in response to perturbations under predictable and unpredictable conditions.

Results: The results indicated higher beta power during late-phase in the Cz electrode in both conditions. IntEMG was significantly greater in the tibialis anterior muscle during both conditions in the CPA epoch. In predictable condition, a positive correlation was found between the beta power over C4 ($r = 0.560$, $p = 0.013$) and C3 ($r = 0.458$, $p = 0.048$) electrodes and tibialis anterior muscle amplitude, and between beta power in C4 and gastrocnemius amplitude ($r = 0.525$, $p = 0.021$). In unpredictable condition, there was a positive correlation between beta power over the C4 and the tibialis anterior amplitude ($r = 0.580$, $p = 0.009$) and also it over the C3 and the tibialis anterior amplitude ($r = 0.452$, $p = 0.049$).

Conclusion: Our findings demonstrate that sensorimotor processing occurs in the brain during response to perturbation. Furthermore, cortical activity appeared to be greatest during the recruitment of the muscles upon late-phase in older adults.

Keywords
Electroencephalography; Brain Activity; Electromyography; Posture

Introduction

Electroencephalography (EEG) is a physiological test used to monitor the electrical activity of the brain. EEG offers advantages such as accessibility, low cost, widespread use, and the potential for repeated use without adverse health effects [1, 2]. This technique provides accurate temporal resolution of the brain activity in the millisecond time domain [3]. EEG is traditionally used in the evaluation of neurological conditions, but it has often been used to quantify the cortical response in relation to event-related changes and even more challenging tasks like postural control in response to perturbations.

Assessing the cortical contribution to postural control task is challenging due to difficulties in quantifying the brain activity during this task. Quantitative EEG (qEEG), a new modality, is a widely available non-invasive method to evaluate the brain's electrical activity. The emergence of quantitative qEEG has enabled the researchers to extract a multitude of variables that can be quantitatively measured. Those variables include power, frequency, and coherence between two arbitrary electrodes [4].

Retaining postural balance necessitates the interaction and integration of motor and sensory systems, including somatosensory, vestibular and visual systems [5], as well as the higher cognitive cortical regions. In contrast to the traditional outlook, which defined the postural control as an automatic process regardless of attention, there is a consensus about the role of cognition in one's balance performance [6-10].

In reality, humans are constantly confronting unexpected obstacles and forces within the surrounding environment. Hence, the capability to overcome these unpredictable situations and to preserve postural balance is significant [11]. To serve this purpose, the central nervous system applies two various strategies of anticipatory postural adjustment (APA) and compensatory postural adjustment (CPA).

The APA initiates promptly before a postural perturbation, while the CPA is activated following a perturbation to restore the individual's balance. These mechanisms, however, are under the influence of perturbation's characteristics (e.g. magnitude and predictability) or the subject's emotional and attentional states [11-14].

In the geriatric population, a postural adjustment in response to external perturbations is assumed to be of notable importance due to the high risk of falling after slips and trips [11, 14]. On the other hand, cerebral cortex is the key element in postural recovery when a predictable or unpredictable perturbation occurs [15, 16].

According to the literature, the APA occurs with a delay in the older adults following postural perturbations, [11], linked to higher muscle co-activation and greater cortical activity, particularly in the primary motor (M1), premotor, and prefrontal, supplementary motor areas as well as somatosensory cortices. These regions participate in APA as well as the planning and programming of motor tasks [17-19].

While most studies have investigated the feedback and feed-forward postural control from biomechanical and electromyographic perspectives, neuro-physiological assessments may render more in-depth evidence concerning dysregulated APA among healthy older adults. Also, the correlation between EEG recorded on the sensorimotor cortex and electromyography (EMG) activity should be helpful in understanding the cortical control of movement [20-22].

Hence, the aim of the present study was to examine and compare the effects of predictable perturbations versus unpredictable ones on activities of leg muscles and associate cortical regions in older adults.

Material and Methods

Participants

In this observational study, a convenience sample of nineteen healthy elderly subjects (60-75 years old) took part in this observational study. They were recruited from a community center for older adults through advertisement. They had independent standing and walking ability. Further inclusion criteria included scores of ≥24 out of 30 in Mini-Mental State Examination (MMSE) [23], scores <7 out of 15 in Geriatric Depression Scale (GDS) [24] and scores over 25 out of 40 in Fullerton Advanced Balance (FAB) scale to ensure a proper level of balance [25].

The exclusion criteria included any history of neuromuscular and musculoskeletal disorders, untreated vision problems, vestibular dysfunction, auditory deficits, BMI≥ 30, deformities in the spine or lower extremities (e.g. kyphosis or scoliosis), and use of medications that could affect postural balance. Consent forms were signed by all participants prior to the commencement of the study and the local medical ethics committee approved the study protocol (code: IR.SUMS.REC.1396.26).

Procedure

All subjects were requested to stand barefoot with their feet placed shoulder-width apart. Predictable (PRED) and temporally unpredictable (UNPRED) postural perturbations were applied using a custom-made load (mass = 3% of subject's body weight), releasing cable system and attached to a belt worn at the sternum level. The participants were instructed to maintain their balance after the load release.

The PRED perturbations were tested by the eyes open, while in the UNPRED perturbations, the subjects should put on sunglasses, painted in black, and wear earplugs [25]. Each condition was performed in blocks of 15 trials, with a 5- to 15-sec interval between trials and 5-min rest was provided between two conditions. Two or three practice trials were conducted prior to data collection, thus the participants could become familiar with the tests.

Quantitative electroencephalography (QEEG) measures

EEG signals were obtained using a 32-channel electrode cap (The NrSign Inc., Vancouver, Canada) based on the international 10-20 system. The impedance for all channels was maintained below 5K-Ohm with all channels referenced to the FPz electrode. The EEG raw data were sampled at 500Hz and band pass filter was set at 3-120 Hz.

Electromyography recordings

Using pre-gelled, self-adhering, Ag/Ag-Cl surface electrodes (Medico Electrodes International Ltd., India), surface EMG signals were obtained from right gastrocnemius (GAS) (one-third of the line between the head of the fibula to the heel), and right tibialis anterior (TA) (one-third of the line between the head of the fibula to and the tip of the medial malleolus) muscles. Prior to the placement of electrodes, the skin was shaved and cleaned. Disposable electrodes with a center-to-center distance of 2 cm were attached to the target muscles on the basis of the Surface Electromyography for the Non-Invasive Assessment of Muscle (SENIAM) standards for EMG data recording [13]. The EMG signals were sampled at 1000 Hz, amplified (2000×) and filtered online (10-300 Hz).

Data processing

The qEEG

The analysis of the qEEG data was performed using NeuroGuide Software (NG 2.5.5; Applied Neuroscience, St Petersburg, FL, USA). The recorded signals were visually inspected to eliminate signal disturbed by eye movement or other artifacts. Depression of the foot pedal by the examiner placed a trigger pulse on EEG signals, thus the exact moment of load release ($T_0 = 0$) was marked. This value was designated as the reference point and all EEG and EMG signals were measured based on the T_0. Data were analyzed in three-time windows, including 1-from −600 ms to -300 ms (anticipatory activity, APA1 Anticipatory Postural Adjustment); 2-from −300ms to 0ms (anticipatory activity, APA2) and, 3- from 0ms to +300 ms (early compensatory reactions, CPA1 (Compensatory Postural Adjustment)).

Each set of acquired EEG signals was averaged and the mean absolute power was calculated for beta (12.5- 25 Hz) frequency bands. Statistical power analysis was performed for three main regions, including C3, C4, and C_Z. All qEEG processing was performed using NeuroGuide Software [3, 26].

EMG

An off-line MATLAB R2015b program

(Math Works, Natick, MA) was used for data processing. Prior to analysis, EMG signals were full-wave rectified. Integrals of the EMG activities (IntEMG) were computed for three different epochs for each muscle with a 300ms time interval. Finally, IntEMGi was normalized based on the maximal muscle activity in both conditions for each muscle, (Equation 1).

$$IEMG_{NORM} = \frac{IntEMGi}{IEMGmax} \quad (1)$$

As a result, all IEMGNORM were between +1 to −1, with the positive and negative values indicating muscle activation and muscle inhibition, respectively.

Characteristics of the participants, trial procedures, and qEEG data collection and processing are described in our previous study [27].

Statistical analysis

Statistical analysis was performed using SPSS 22 (IBM, Armonk, NY, USA) and a significance level of $p<0.05$ was used for analysis. Data normality was assessed by the Kolmogorov–Smirnov test ($p>0.05$).

At beta frequency range, the absolute power was comparatively analyzed by 2-way ANOVA with location (C3, C_Z, and C4) and epochs (APA1, APA2, and CPA1) as factors both in predictable and unpredictable perturbations. Post-hoc comparisons were done where needed.

Repeated measurement ANOVA test was used for the analysis of IntEMG in three-time windows. In addition, the Pearson product-moment correlation coefficient was calculated to evaluate the relationship between the absolute power of beta and IntEMG of leg muscles.

Results

Participants

Nineteen older subjects participated in this study. The demographic data and baseline values of the participants are summarized in Table 1.

Absolute beta power

The results of absolute power beta are shown in Table 2. During both predictable and unpredictable perturbations, time × location interaction was significant. Post-hoc analysis showed that power was significantly different between APA1−CPA1 and APA2−CPA1 phases in the C_Z region compared to the C3 and C4 regions. In other words, beta power was higher in the late phase in both conditions in C_Z (Figure 1).

Table 1: Demographic characteristics of the participants

Variable	Mean±SD
Age (years)	65.55 ± 4.67
Weight (kg)	57.96 ± 7.15
Height (cm)	163.00 ± 4.86
MMSE (0–30)	27.79 ± 1.81
GDS (0–15)	1.84 ± 1.53
FAB (0–40)	35.58 ± 2.75

SD: Standard deviation, MMSE: Mini-Mental State Examination, GDS: Geriatric Depression Scale, FAB: Fullerton Advanced Balance scale.

Table 2: Results of 2-way ANOVA of absolute power for time, location and their interactions during predictable (PRED) and unpredictable (UNPRED) perturbations

		Power	
		F Ratio	P-value
PRED	Time	33.31	*<0.001
	Location	33.69	*<0.001
	Location × Time	22.69	*<0.001
UNPRED	Time	42.23	*<0.001
	Location	21.66	*<0.001
	Location × Time	23.06	*<0.001

*Asterisks show statistically significant values.

PRED: Predictable, UNPRED: Unpredictable

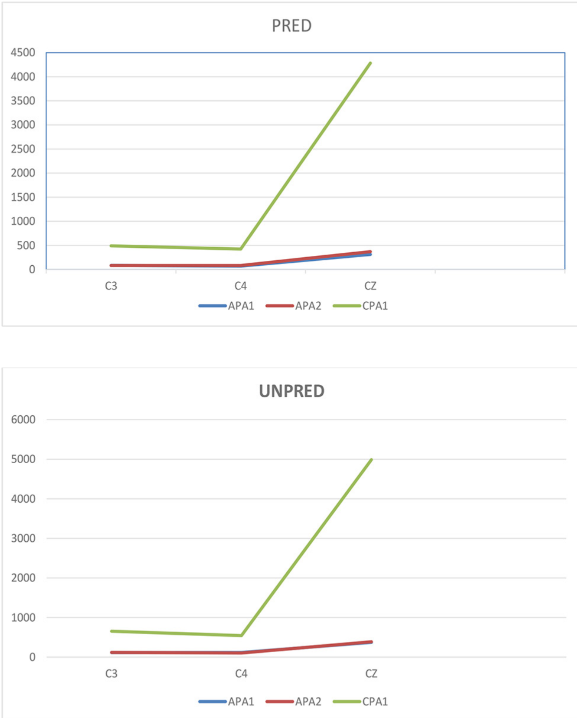

Figure 1: Interaction effect of time and electrodes location with standard error bars for power beta in predictable and unpredictable perturbations

Integrals of EMG activity

The results of the IntEMG of the muscles are shown in Figures 2 and 3. In both conditions, the tibialis anterior muscle activity increased in the CPA epoch compared to APA 1 and APA2.

Correlation between EEG activity and EMG from leg muscles

The results of the correlation between EEG and EMG activity in PRED and UNPRED perturbation are shown in Tables 3 and 4.

In PRED condition, there was a significant positive correlation between the beta power in CPA1 at the C4 (r = 0.560, p = 0.013) and C3 (r = 0.458, p = 0.048) electrodes and IntEMG for the tibialis anterior muscle in CPA1. Also, there was a significant correlation between the beta power in APA1 at the C4 electrode and IntEMG for the gastrocnemius muscle in CPA1 (r = 0.525, p = 0.021).

In UNPRED condition, there was a significant positive correlation between the beta power in CPA1 at the C4 electrode and Inte-

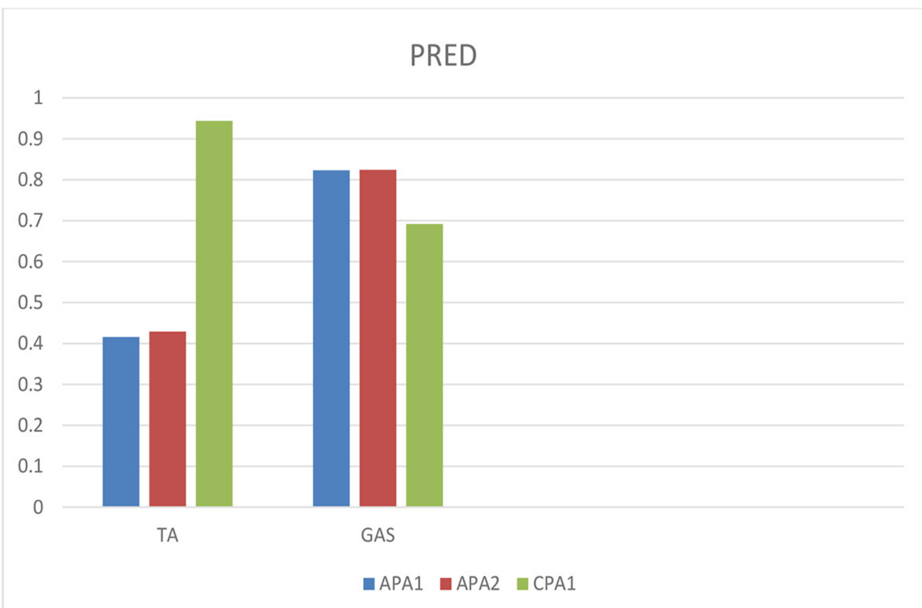

Figure 2: Mean IntEMG of tibialis anterior (TA) and gastrocnemius (GAS) muscles in predictable perturbation

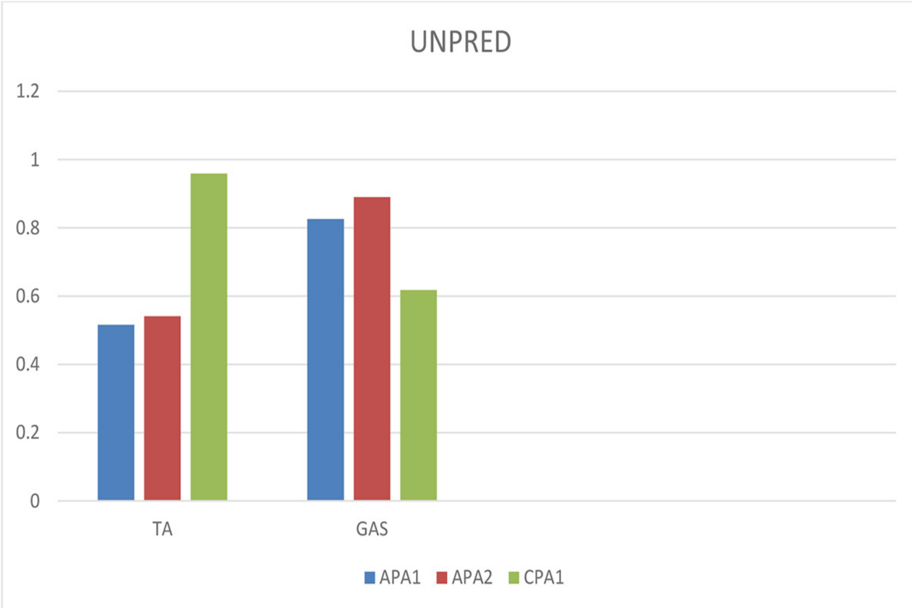

Figure 3: Mean IntEMG of the tibialis anterior (TA) and gastrocnemius (GAS) muscles in unpredictable perturbation

Table 3: Correlation between Electroencephalography (EEG) and electromyography (EMG) activity in predictable (PRED) perturbation

Variable	APA_1 TA		APA_2 TA		CPA_1 TA		APA_1 GAS		APA_2 GAS		CPA_1 GAS	
	r	P	r	P	r	P	r	P	r	P	r	P
C3												
APA_1	0.044	0.858	-0.060	0.807	0.050	0.840	0.180	0.460	-0.096	0.696	0.198	0.416
APA_2	0.149	0.543	0.030	0.904	-0.061	0.803	0.154	0.529	-0.071	0.773	0.214	0.379
CPA_1	0.260	0.283	0.280	0.246	0.458	0.048	0.000	0.999	-0.200	0.412	-0.134	0.583
C4												
APA_1	0.068	0.783	0.026	0.916	0.420	0.074	-0.251	0.301	-0.101	0.682	0.525	0.021
APA_2	0.109	0.658	0.020	0.936	-0.003	0.990	-0.186	0.445	-0.058	0.813	0.221	0.363
CPA_1	0.304	0.205	0.350	0.142	0.560	0.013	0.095	0.699	-0.070	0.776	0.138	0.574
C_z												
APA_1	-0.231	0.342	-0.259	0.285	0.040	0.872	-0.029	0.905	-0.045	0.856	0.133	0.586
APA_2	-0.163	0.506	-0.204	0.402	-0.033	0.892	-0.102	0.677	-0.056	0.819	0.210	0.387
CPA_1	0.017	0.943	0.044	0.858	0.356	0.135	-0.263	0.277	-0.347	0.146	0.068	0.781

APA: Anticipatory postural adjustment, TA: Tibialis anterior, CPA: Compensatory postural adjustment, GAS: Gastrocnemius

grated EMG (IntEMG) for the tibialis anterior muscle in CPA1 ($r = 0.580$, $p = 0.009$) and beta power in CPA1 at the C3 electrode and IntEMG for the tibialis anterior muscle in APA1 ($r = 0.452$, $p = 0.049$).

Discussion

This study primarily aimed to define beta

Table 4: Correlation between Electroencephalography (EEG) and electromyography (EMG) activity in predictable (PRED)

Variable	APA_1 TA		APA_2 TA		CPA_1 TA		APA_1 GAS		APA_2 GAS		CPA_1 GAS	
	r	P	r	P	r	P	r	P	r	P	r	P
C3												
APA_1	-0.276	0.252	-0.230	0.343	-0.161	0.510	-0.043	0.862	-0.161	0.511	0.273	0.329
APA_2	-0.273	0.257	-0.277	0.250	-0.425	0.070	0.133	0.586	-0.046	0.852	0.041	0.869
CPA_1	0.456	0.049	0.421	0.073	0.425	0.070	0.386	0.102	0.182	0.457	0.125	0.610
C4												
APA_1	-0.099	0.688	-0.060	0.806	-0.161	0.510	0.089	0.717	-0.020	0.936	0.175	0.473
APA_2	-0.163	0.505	-0.147	0.548	-0.098	0.689	0.197	0.418	0.001	0.998	0.093	0.704
CPA_1	0.422	0.072	0.419	0.074	0.580	0.009	0.297	0.217	0.175	0.474	0.267	0.269
C_Z												
APA_1	-0.287	0.233	-0.255	0.293	-0.364	0.125	-0.090	0.714	-0.114	0.642	0.052	0.832
APA_2	-0.275	0.254	-0.314	0.191	-0.125	0.610	-0.322	0.178	-0.400	0.089	-0.178	0.465
CPA_1	0.324	0.176	0.311	0.195	0.384	0.105	0.338	0.157	0.306	0.203	0.265	0.273

APA: Anticipatory postural adjustment, TA: Tibialis anterior, CPA: Compensatory postural adjustment, GAS: Gastrocnemius

power dynamics in response to PRED and UNPRED perturbation in older adults on electrodes overlaying the leg representation areas of the sensorimotor cortices (C3, C_Z, and C4).

Our findings demonstrated an enhanced spectral distribution of beta power both in PRED and UNPRED perturbation in the C_Z electrode following the perturbation onset. These results are consistent with those of previous studies that reported the highest magnitude of cortical activity in the C_Z electrode in response to external perturbation in young and older adults [28-30]. Previous studies have indicated cortical activity in late phases of postural responses to external perturbations, while the initial phase could not have been triggered by a direct transcortical loop [28, 31].

Indeed, the cerebral cortical dynamics correspond to postural balance either directly by corticospinal loops, or indirectly through specific centers in the brainstem controlling the postural balance-associated synergies. Following an unexpected perturbation, the cerebral cortex may be activated to find the optimum postural response or it may use previous experiences to select and apply the most appropriate response for the current incidence [32]. Meanwhile, the individuals' postural performance and ability are the main determinants of the strategy selected by the cerebral cortex. For example, a person suffering from balance disorders may rely on cortical loops during the late phases of postural responses to external perturbations because they may not be able to use the central set to find the optimum response suitable for the situation promptly [30].

According to our observations, the tibialis anterior muscle activity increased in the CPA epoch compared to APA 1 and APA2 during both conditions. Our results are in line with the findings of Kanekar et al., reporting that compensatory muscle activity compared to anticipatory one was more in older adults. According to these results, higher compensatory muscle activation in the elderly following large perturbations may be due to insufficient muscular activity during the anticipatory phase of preparation for perturbations. This may result in loss of balance, if not well-compensated [11].

Additionally, the results of correlative analysis suggest the correlation between EEG recorded from the C3 and C4 electrodes and EMG recorded from gastrocnemius and tibialis anterior muscles in both PRED and UNPRED conditions. Mochizuki et al. showed that the activity prior to the perturbations may not be related to the cortical activity following perturbation, while it can be attributed to altered central set just before the onset of a perturbation [28].

Previous studies have noted that the changes in beta power over premotor and motor areas correspond to fast and immediate movements. Meziane et al. stated that these changes were symmetrical over the two hemispheres [26]. This symmetricity might result from the complexity of the movements since the complexity of a task increases the probability of symmetrical bilateral activation [33]. Moreover, older individuals require higher activation of the cortex to achieve a certain performance level in comparison with their younger peers, which might be another underlying mechanism of the symmetrical activation pattern.

Sainburg et al. revealed that the left sensorimotor area may regulate the predictive and feed-forward mechanisms, while the right sensorimotor may be responsible for the online and feedback processes [26]. Consequently, both left (dominant) and right (non-dominant) sensorimotor areas may act in concert by reciprocal control to generate prompt and efficient movements.

Conclusion

The present research could demonstrate at least one key pattern in sensorimotor processing which occurs in the brain in response to an external perturbation. Cortical activity over our regions of interest appeared to be greatest during recruitment of the muscles upon late phase postural adjustment response in older adults. Further investigations on the correlation between cortical as well as subcortical regions and muscle activity may extend our insight into the central mechanisms, involved in external perturbation tasks.

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Conflict of Interest

None

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