On the Correlation between Force Plate Data and EMG in Various Standing Conditions

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Abstract - *Force plate data and EMG activity were analyzed to quantify the swaying motion of normal subjects during various standing conditions, namely, double-supported, eyes open (DS-EO); single-supported, eyes open (SS-EO); and single-supported eyes closed (SS-EC). Foot-ground reactive forces and leg muscle EMG activity were measured separately for each of the supporting legs. The acquired data were divided into epochs of 1 sec for which the root mean square (RMS) and the mean frequency (MNF) of the power spectral density (PSD) were calculated. The results showed that in SS standing the correlations between RMS EMG of the ankle and hip muscles and the reactive forces increased compared to DS standing.*

Keywords: Postural sway - Foot-ground reaction forces - Leg muscle activity – Correlation

1. Introduction

The regulation of balance during upright stance involves continuous muscular activity, associated with body sway in the sagittal, coronal and transverse planes. The analysis of body sway typically involves monitoring of the foot-ground reaction forces and of the kinematics of the various body segments and body center of gravity as well as the leg muscle activity (electromyography – EMG) [1-3]. Bilateral measurements of the foot-ground reactive forces in standing have been used in previous studies to characterize the individual sway activity of each leg and the sway activity of the legs in relation to each other [4]. The present study investigates the relationship between postural sway and muscular activity under different standing conditions. The question posed is whether the association between foot-ground reactive forces and muscle activity varies as a function of the conditions imposed on balance control by reducing the base of support and or the availability of visual feedback.

2. Material and Methods

The foot-ground reaction forces and EMG of the muscles of the lower extremities were measured during tests of upright standing, each lasting 30 s, of which the central 20 s were actually sampled and processed. Five normal volunteers (aged 27 – 36 years) were instructed to stand still in each of the following positions: double-supported, eyes open (DS-EO); single-supported, eyes open (SS-EO); and single-supported eyes closed (SS-EC). For the DS-EO position, the subjects were asked to stand still with each leg on a separate force plate and with their eyes fixed on a mark three meters in front of them at eye level. Positioning of the feet was similar for all the subjects and was symmetrical in relation to the line separating the force plates. Spacing between the subject's feet was set to 30 cm. For the single supported positions (SS-EO, SS-EC), the subjects were asked to stand on one leg, as still as possible with their dominant leg on one platform and their contra-lateral knee flexed upward. The force plates (Kistler, type Z-4304) were collaterally installed to enable adjacent positioning of the left and right feet in DS standing. The temporal variations in the vertical (VR), anteroposterior (AP) and mediolateral (ML) direction of the foot-ground reaction forces were on-line digitized at 100 samples/s. The force-plate data were filtered by a digital, low-pass, 2nd order, butterworth filter with a cutoff frequency of 50 Hz.

Surface EMG signals of the muscles of the lower extremities were recorded by means of an eight-channel surface electrode system. For the DS-EO position, EMG data were recorded from the tibialis anterior (TA), medial gastrocnemius (GA), quadriceps femoris (QU) and gluteus medius (GM) muscles from both legs.

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For the SS-EO and SS-EC positions, EMG data were recorded from the TA, GA, QU, GL and also the peroneal (PE) muscles of the supporting leg. The EMG electrodes were placed 2 cm apart, over the muscle belly, and aligned with the longitudinal axis of the muscle. One reference electrode was placed on the antero-lateral surface of the shank, 10 mm below the level of the patellar-tendon. Each pair of EMG electrodes was connected to a 20–500 Hz, band-pass, butterworth amplifier. The EMG signals were on-line digitized at 2000 samples/s in parallel to the force-plate data.

The acquired force-plate and raw EMG signals were de-trended to compensate for long-term drift and their DC levels were set to zero. Each signal vector was then divided into epochs of 1 s for which the root mean square (RMS) and mean frequency (MNF) of the power spectral density function (PSD) were calculated. The PSD function was estimated by using the Welch's averaged periodogram method. Note that, over the entire recording period (20 s), each of the above RMS and MNF values forms a column vector with N=20 components, where each component corresponds to a 1-s epoch time window of the sampled signal. The 1-s RMS and MNF values of the myoelectric activity were correlated with the corresponding RMS and MNF values of the force plate data, using the Pearson's correlation coefficient with the significance level set at $p < 0.05$. For the sample size N=20, the threshold value for significance was 0.3783.

Differences between the standing positions DS-EO and SS-EO and SS-EO and SS-EC were tested for the mean values of the RMS and MNF of the force plate and EMG results by using the student's t-test. The statistical significance was set at the 0.05 level.

3. Results

Table 1 summarizes the mean and standard deviation (SD) values of the RMS and MNF of the force plate and EMG data. For DS-EO standing, the mean RMS force values were below 0.7 N for the horizontal (AP and ML) components and below 5.2 N for the vertical component. The mean RMS values for the displacements of the COP were below 0.4 cm. The mean EMG RMS values were below 8.5 % of maximal voluntary contraction (MVC). Differences between the dominant and the nondominant leg were not significant ($p > 0.05$). The mean RMS values of the horizontal components of force and the ML component of COP increased by more than 3-fold ($p < 0.01$) in SS-EO compared to DS-EO standing. A more moderate, but still significant, increase ($p < 0.05$) was noticed in the mean RMS values of the vertical force and the AP component of COP. In SS-EC standing, a further increase ($p < 0.05$) in the horizontal (AP and ML) components of force and COP was noted. The mean EMG RMS increased significantly ($p < 0.01$) in SS-EO as compared to DS-EO. The mean RMS values of all muscles increased further in SS-EC standing. However, only the increases in the PE and the QU muscles were significant ($p < 0.01$). Figure 1 summarizes the occurrence of significant correlations between the RMS values of the force plate data and the RMS values of the EMG as a percentage of the total number of tests that were made for each of the three standing conditions (DS-EO, SS-EO and SS-EC). For the DS-EO standing, the occurrence ranged from 8.3 % (GL vs. VR force) to 50 % (TA vs. AP force). No significant correlation was found between the ML component of force and the EMG of the GL. Interestingly, significant correlations between the TA and the AP force were found to be more frequent (50 %) during the DS-EO task than during the SS-EO (33.3 %) or the SS-EC (42.1 %) tasks. Note that the EMG of the PE was not measured in DS-EO standing. During SS-EO standing, the significant correlations were observed most frequently (63.3 %) between the ML-force and the QU-EMG and between the ML-COP and the TA-EMG. During SS-EC standing, significant correlations were observed most frequently (73.7 %) between the TA-EMG and ML-force and between the QU-EMG and the AP-force. The latter was shown to increase from 50 % in SS-EO standing to 73.7 % in the SS-EC task. Significant correlation coefficients were also found frequently (68.4 %) between the TA-EMG and ML-COP and between the GL-EMG and the ML-force (68.4 %). The correlation between the MNF of force-plate data and that of the EMG activity was typically below the level of significance (occurrence below 25 %).

4. Discussion

The measured reactive forces and muscle EMG activities patterns allow to determine the following parameters:

1. Mean RMS and MNF values of the fluctuations (around baseline) of the components of force and COP, defined to express the sway of the right and left sides of the body.
2. Mean RMS (% MVC) and MNF of the EMG, defined to express the muscle activity of the right and left legs.
3. Occurrence of significant correlations between RMS and MNF of the force plate data and the RMS and MNF of the EMG, defined to express the degree of synchronization of muscle activity.

Mean RMS	Mean MNF

							[Hz]	
	DS-EO	DS-EO	SS-EO	SS-EC	DS-EO	DS-EO	SS-EO	SS-EC
Force [N]	*(dom.)*							
AP	0.6 (0.2)	0.7 (0.2) NS	2.5 (1.0) †	3.1 (1.5) ‡	2.0 (0.3)	2.1 (0.3) NS	2.4 (0.3) †	2.5 (0.5) NS
ML	0.6 (0.2)	0.7 (0.2) NS	3.6 (2.0) †	5.2 (2.9) ‡	1.8 (0.3)	1.9 (0.3) NS	2.3 (0.3) †	2.5 (0.5) NS
VR	4.5 (1.1)	5.1 (2.7) NS	6.3 (3.5) †	10 (16) NS	4.4 (1.2)	4.1 (1.3) NS	4.9 (1.3) NS	4.7 (0.5) NS
COP [cm]								
AP	0.3 (0.1)	0.4 (0.1) NS	0.6 (0.2) †	0.8 (0.3) ‡	2.2 (0.8)	2.8 (1.4) NS	1.7 (0.6) †	1.6 (0.3) NS
ML	0.2 (0.3)	0.2 (0.1) NS	0.6 (0.1) †	1.0 (0.6) ‡	8.6 (3.7)	8.1 (2.2) NS	1.6 (0.6) †	1.5 (0.2) NS
EMG (% MVC)								
TA	3.5 (3.6)	1.6 (0.7) NS	26 (20) †	33 (27) NS	132 (24)	135 (5.0) NS	121 (14) NS	117 (23) NS
GA	8.4 (8.8)	6.4 (4.9) NS	58 (32) †	64 (33) NS	137 (20)	136 (11) NS	109 (18) †	97 (17) ‡
QU	1.2 (1.0)	2.0 (2.2) NS	8.0 (3.5) †	15 (7.4) ‡	108 (18)	115 (13) NS	112 (18) NS	104 (14) ‡
GL	3.4 (2.0)	2.5 (2.1) NS	11 (8.0) †	15 (16) NS	75 (36)	85 (28) NS	95 (9.0) NS	83 (11) ‡
PE	---	---	46 (26)	70 (26) ‡	---	---	116 (17)	110 (14) NS

Table 1: Mean and standard deviation (SD) values of the RMS and MNF of the force plate data and EMG (*dom.* = dominant leg). Significance levels of the differences: † ($p < 0.05$) between DS-EO and SS-EO; ‡ ($p < 0.05$) between SS-EO and SS-EC. NS = not significant.

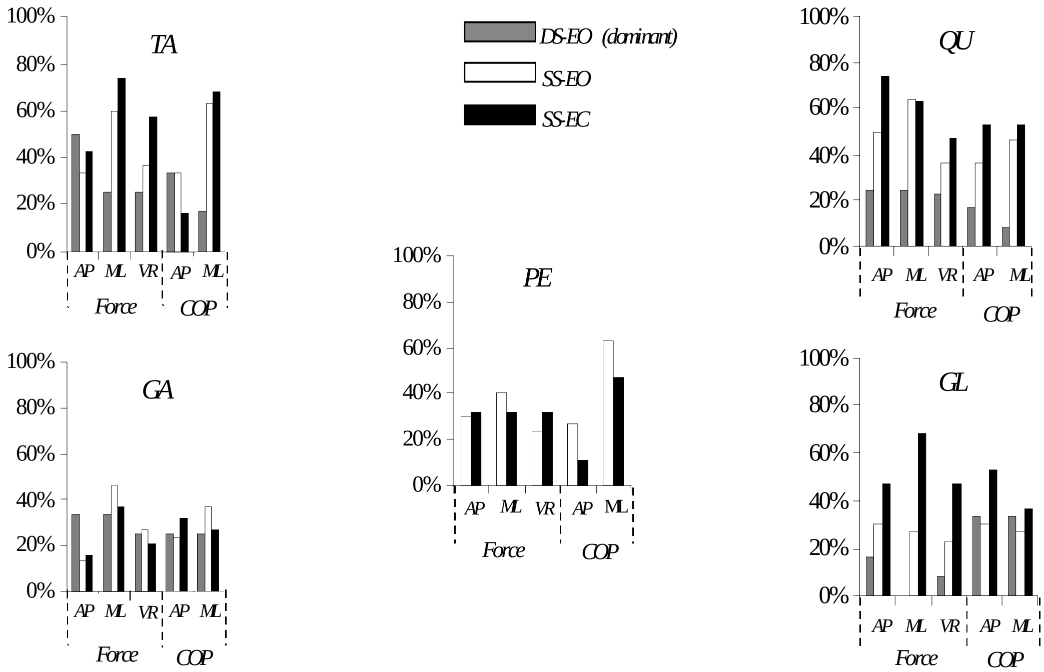

Figure 1. Occurrence of significant correlations between the RMS values of the force plate data and the RMS values of the EMG as a percentage of the total number of tests administrated for each of the three standing conditions.

The present results convincingly demonstrate "positive" correlations between the extent of body sway and the magnitude of muscular activity in all tested muscle. However, different standing conditions were shown to produce different correlation patterns between specific body sway directions and specific muscles. For example, the correlation between sway activity of the AP force and EMG activity of the TA muscle was found to be more frequent during double-supported standing (50 %) than during single-supported standing (40 %). On the other hand, the occurrence of significant correlations between the TA EMG and ML force increased substantially increased from double to single-supported conditions (from less than 30 % to more than 60 %). Similar increases in the frequencies of positive significant correlations were observed between the QU EMG and the AP and ML components of force and COP and between the GL EMG and the ML component of force. This implies that during double supported stance where the width of the base of support in the AP and ML is relatively of the same order, balancing activity is more dominant in the ankle than in the hip. A narrow base of support in the ML direction will decrease balance activity in the ankle and increase balance activity in the hip in the AP direction, while increasing balance activity of both the ankle and the hip in the ML direction. Similar findings have recently been reported by Gatev et al [2]. It can therefore be concluded that with reduced redundancy of the system, the degree of synchronization of muscle activity is increased. This will result in a general increase of the correlation between the RMS EMG of the stabilizing muscles of the ankle and hip and the reactive force.

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