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A longitudinal assessment of myoelectric activity, postural sway, and low-back pain during pregnancy

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Purpose: The present study aimed at investigating the control of upright quiet standing in pregnant women throughout pregnancy, and whether low-back pain exerts influence on this motor task. *Methods*: Myoelectric signals from postural muscles and stabilometric data were collected from 15 non-pregnant and 15 pregnant women during upright quiet standing. Electromyogram envelopes and center of pressure metrics were evaluated in the control group, as well as in pregnant women in their first and third trimester of pregnancy. A correlation analysis was performed between the measured variables and a low-back pain disability index. *Results*: Pregnant women exhibited a decreased maximum voluntary isometric activity for all postural muscles evaluated. Additionally, the activity of lumbar muscles during the postural task was significantly higher in the pregnant women in comparison to the non-pregnant controls. The soleus muscle maintained its activity at the same level as the gestation progressed. Higher postural oscillations were observed in the anteroposterior direction while mediolateral sway was reduced in the third trimester of pregnancy. No correlation was detected between the low-back pain disability index and neuromechanical variables. *Conclusion*: This study provides additional data regarding the functioning and adaptations of the postural control system during pregnancy. Also, we provide further evidence that postural control during quiet standing cannot be used to predict the occurrence of low-back pain. We hypothesize that the modifications in the neural drive to the muscles, as well as in postural sway may be related to changes in the biomechanics and hormonal levels experienced by the pregnant women.

Key words: *electromyography, low-back pain, postural balance, pregnancy trimesters, stabilometry*

1. Introduction

Physiological, hormonal, and biomechanical changes are observed along the three trimesters of pregnancy (e.g., increased ligamentous laxity, joint instability, and decreased neuromuscular control) [2], [3], [18], [21], [23]. These modifications may be related to the occurrence of musculoskeletal disorders and deficits on both static and dynamic postural equilibrium, thereby increasing the risk of falling [1], [2], [18]. Previous postural control studies have observed that stability declines throughout pregnancy and the central nervous system of the pregnant women relies largely on visual information to maintain the upright standing [4], [16], [19].

Another factor frequently observed during pregnancy is a gradual overload of back and hip muscles. The adaptation of these muscles to postural changes may be insufficient to stabilize the sacroiliac joints and the lumbar spine [9], [13]. Moreover, about 50% of pregnant women report low-back pain along the gestation [1], [8], [22]. Despite that, Franklin and Conner–Kerr [11] reported a lack of correlation between low-back pain and postural changes commonly observed during pregnancy.

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Regarding muscle activity, most of the studies reported in the literature evaluated lumbar muscle fatigue in dynamic tasks [9], [13], [22]. Sihvonen et al. [22] observed a positive correlation between low-back pain and the activation level of lumbar muscles during flexion and extension of the trunk. However, Dumas et al. [9] performed fatigue tests during spine extension, and they did not demonstrate that the increased fatigue can be used to predict the occurrence of back pain during pregnancy. These contrasting findings justify the need of additional research linking electromyographic analysis of postural muscles and balance analysis to provide new insights into postural control during pregnancy and whether this motor task is affected by low-back pain.

The present study aimed at investigating the control of upright quiet standing in pregnant women throughout pregnancy. For the analysis, both stabilometric and myoelectric signals were recorded from pregnant women in their first and third trimester of gestation. In addition, a disability index was used to investigate if the occurrence of low-back pain influenced the postural task.

2. Materials and methods

Thirty women, 15 pregnant (25.84 ± 4.65 years; 1.62 ± 0.05 m) and 15 non-pregnant (27.73 ± 5.51 years; 59.57 ± 8.53 kg; 1.61 ± 0.06 m), participated in this study. The study was conducted in accordance with Declaration of Helsinki after approval by the local Ethics Committee. All subjects signed a written inform consent form prior to the experiments.

The inclusion criteria for the pregnant women were: (i) age between 18 and 35 years; (ii) low-risk pregnancy; (iii) first pregnancy and single fetus; (iv) the pregnant women were in the first trimester of pregnancy (the 10th to 14th weeks). Pregnant women with low-back pain were included in the study only if they reported a persistent pain for more than three weeks during pregnancy. The pregnant women who experienced low-back pain answered the Oswestry Disability Index (ODI) [9], [24]. Age-matching non-pregnant control subjects were included in the study if they reported no low-back pain (ODI equal to zero) and no history of previous pregnancy. For both groups, subjects were excluded from the study if they presented neuromuscular and vestibular system disorders, cognitive deficits, and diagnosed orthopedic pathology.

Pregnant women made two visits to the laboratory. The first visit was between the 10th and 14th (12.61 ± 0.96 week; 67.52 ± 8.68 kg) and the second one was between the 30th and the 33rd (30.38 ± 1.93 week; 76.06 ± 7.48 kg) weeks of gestation. Two participants did not attend the second visit due to complications during pregnancy; hence, they were excluded from the study. Subjects from the control group were evaluated in a single day.

For the experiment, surface electromyogram (EMG) electrodes (Ag/AgCl, 1 cm diameter) were positioned bilaterally on multifidus and longissimus muscles [9], [22], as well as on the right soleus muscle. For each muscle, a pair of electrodes (2 cm of interelectrode distance) was positioned following SENIAM recommendations [15]. EMG signals were pre-amplified (×2000), band-pass filtered (10–500 Hz), and digitized (2 kHz) by a 16-bit acquisition system (EMG System, Brazil).

Before the postural control task, the subjects were asked to perform three 10-s duration maximum voluntary contractions (MVCs) of the lumbar and soleus muscles. The subject was seated with hip, knee, and ankle joints at 90 deg. For the postural task, the participant was in an upright standing position on two triaxial force plates (OR6, AMTI, USA). Forces and moments from each platform were sampled at 100 Hz and the acquisition was synchronized with the EMG recording. The subjects were instructed to stand quietly with each foot positioned on each force plate (feet apart by ~20 cm) and arms along the body. Marks were made around the feet of each participant on a paper attached to the force platforms to ensure constant foot positioning between standing trials in both experimental sessions (i.e., first and third trimester). Each subject performed three 60-s trials with eyes open (EO condition), focusing on a target located ~2 m in front of her. In another set of trials, the subjects closed their eyes (EC condition) and performed the postural task without vision. A resting period of 2 min between each trial was adopted to avoid muscle fatigue [5].

Custom-written Matlab (The Mathworks, Inc.) programs were used in data analysis. EMG signals were detrended, full-wave rectified, and low-pass filtered to obtain the EMG envelope [7]. After the filtering process, the first and the last 5 s were discarded to avoid adaptations of the subjects and filtering effects. The intensity of muscle activation during the postural task was estimated by the mean value of EMG envelope (calculated over 50 s) normalized by the value calculated during the MVC. Forces and moments were used to calculate the anteroposterior (AP) and mediolateral (ML) center of pressure (COP) displacements for each foot. COP displacements and reaction forces were used to estimate the global COP according to the method described elsewhere [25]. The global COP was detrended, and low-pass filtered (12.50–Hz cut-off frequency). Similarly to EMG signals, the first and the last 5 s were discarded from the analyses. Several variables were measured from the AP and ML COP displacements [20]: root mean square (RMS), mean velocity (MV), and the 80% power frequency (f80) estimated from the COP power spectra. In addition, the COP area was calculated by fitting the AP vs. ML data with an ellipse encompassing 85.35% of the data [17].

Statistical analysis was carried out with the significance level set at 0.05. The Shapiro–Wilk test assessed data normality. Statistical comparisons were performed using a mixed ANOVA. The within-factor considered in the analyses was the "eyes' condition" (EO and EC), while the between-factor was "group type" (control – C; pregnant woman in the first trimester of pregnancy – P1; and pregnant women in the third trimester of pregnancy – P3). A Tukey's post hoc test was applied when a significant difference was detected in between-subject factor. An one-way ANOVA was used to evaluate the differences between groups for the ODI and the muscle activation intensities during the MVC. Furthermore, a chi-squared test was performed to verify the difference in the percentage of pregnant women with and without low-back pain among different groups. The Pearson correlation coefficient was obtained to verify the correlation between ODI and the variables measured during the postural task.

3. Results

A statistically significant difference was observed between groups for the EMG amplitudes estimated during MVC from all postural muscles ($p < 0.05$). Table 1 shows the data obtained for these muscles in each group. For all evaluated muscles the post hoc test revealed a significant difference between groups C and P1 ($p < 0.05$), as well as between groups C and P2 ($p < 0.05$). No statistical difference was observed between groups P1 and P3. Overall, pregnant women exhibited a lower maximum isometric activity in postural muscles in comparison with non-pregnant control subjects.

Figure 1 shows the mean and standard errors calculated from the normalized EMG envelopes of soleus and lumbar muscles during the postural control task. The mixed ANOVA revealed a significant within-subject effect ($F = 2.849$; $p = 0.03$). Nonetheless, the eye's condition was statistically significant only for soleus muscle ($F = 11.447$; $p = 0.002$). The between-subject factor was statistically significant for right longissimus ($F = 5.306$; $p = 0.009$), right multifidus ($F = 7.870$; $p = 0.001$), and left multifidus ($F = 7.177$; $p = 0.002$). For these muscles, post-hoc test indicated a significant difference between groups C and P1, as well as groups C and P3 (asterisks in Fig. 1b, c, and d). No difference was observed between groups P1 and P3. Additionally, no interaction was observed between the factors eyes' condition and group type.

Table 2 shows some measurements obtained from stabilometric data (see Methods for details). The mixed ANOVA revealed a significant effect for both between- and within-subject factors ($F = 2.325$; $p = 0.012$, and $F = 16.397$; $p < 0.001$, respectively). No interaction was detected between the two factors. For the eyes' condition, a significant difference was observed for all but one measure. The f80 from ML COP did not have a significant difference between EO and EC conditions ($F = 0.219$; $p = 0.642$). Differences between group types were detected for the following measures: f80 from ML COP ($F = 3.618$; $p = 0.036$);

Table 1. EMG amplitudes estimated from the postural muscles (i.e., soleus, right and left longuissimi, right and left multifidi) during maximum voluntary contractions (MVCs). Data are presented as mean±standard error

Muscle (unit)	Groups		
	C (n = 15)	P1 (n = 13)	P3 (n = 13)
Soleus (μV)	53.63 ± 6.72	33.79 ±4.22*	31.38 ± 4.13*
Right longissimus (μV)	37.86 ± 4.91	21.67 ± 4.13*	20.01 ± 3.76*
Left longissimus (μV)	39.73 ± 5.09	23.17 ± 3.78*	22.20 ± 4.44*
Right multifidus (μV)	31.32 ± 4.32	15.34 ± 2.80*	17.44 ± 2.77*
Left multifidus (μV)	31.96 ± 5.27	15.70 ± 2.11*	17.43 ± 2.70*

* Significant difference with respect to the control (C) group (Tukey's post hoc test; $p < 0.05$).

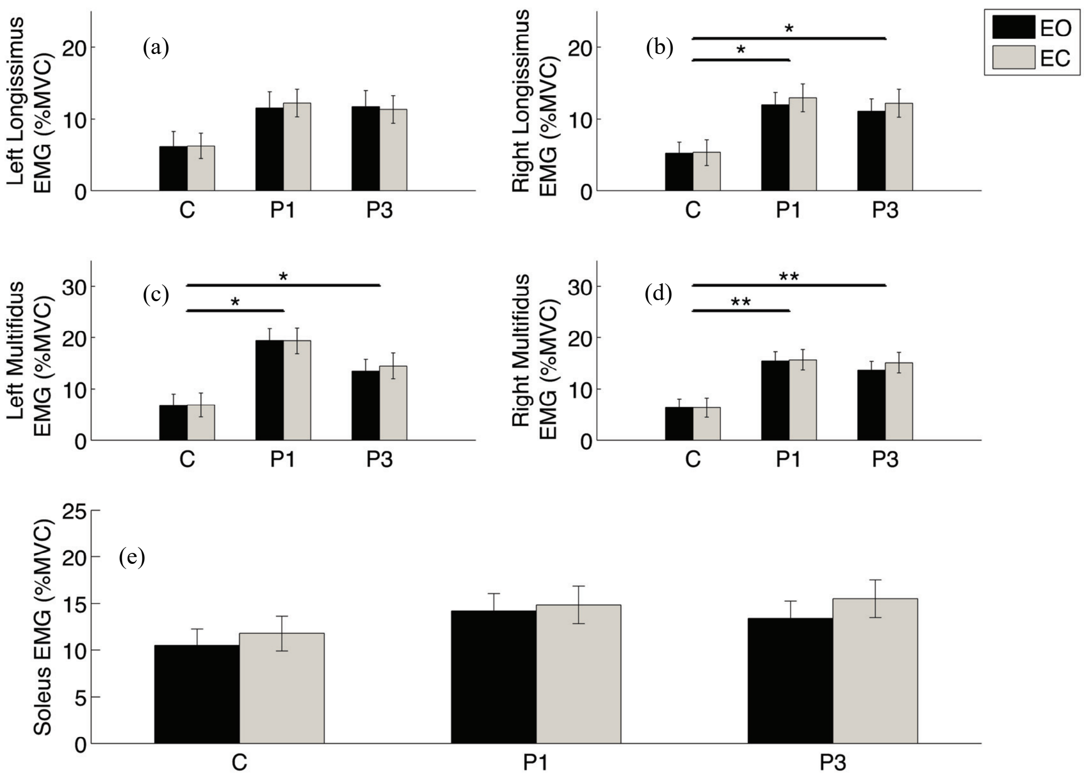

Fig. 1. The myoelectric activity of lumbar and soleus muscles during upright standing: (a) Left longissimus muscle, (b) Right longissimus muscle, (c) Left multifidus muscle, (d) Right multifidus muscle, (e) Soleus muscle. Bars with errors represent the mean value of EMG envelope (normalized by the value estimated at the MVC) and the standard error. Black bars are for the opened eyes condition while gray bars represent the closed eyes condition. Asterisks identify significant differences between groups (C – control; P1 – pregnant in the first trimester; P3 – pregnant in the third trimester)

Table 2. Stabilometric data. See methods for details regarding these measures. Data are presented as mean ± standard error

Measure (Unit)	C (n = 15)		P1 (n = 13)		P3 (n = 13)	
	EO	EC	EO	EC	EO	EC
f80_AP‡ (Hz)	0.30 ± 0.03	0.38 ± 0.04	0.27 ± 0.03	0.33 ± 0.04	0.21±0.03	0.31±0.04
f80_ML* (Hz)	0.48 ± 0.05	0.49 ± 0.05	0.35 ± 0.05	0.34 ± 0.05	0.33±0.05	0.30±0.05
RMS_AP‡ * (mm)	2.62 ± 0.18	3.28 ± 0.29	2.99 ± 0.19	3.66 ± 0.32	3.58±0.19	4.20±0.32
RMS_ML‡ (mm)	1.07 ± 0.11	1.42 ± 0.17	1.03 ± 0.12	1.20 ± 0.18	0.90±0.12	1.22±0.18
MV_AP‡ (mm/s)	4.96 ± 0.23	6.67 ± 0.46	5.11 ± 0.25	7.08 ± 0.49	5.36±0.25	7.51±0.49
MV_ML‡ * (mm/s)	3.73 ± 0.19	4.29 ± 0.24	3.03 ± 0.20	3.27 ± 0.26	2.52±0.20	2.78±0.26
Area‡ (mm^2)	51.46 ± 7.60	83.74 ± 17.44	51.98 ± 8.16	83.75 ± 18.73	61.45±8.16	98.53±18.73

‡ Significant difference ($p < 0.05$) for eyes' conditions (EC vs. EO), * significant difference between control (C) and third-trimester (P3) groups (Tukey's post hoc test; $p < 0.05$).

RMS from AP COP ($F = 4.424$; $p = 0.019$); and MV from ML COP ($F = 10.134$; $p < 0.001$). The remaining comparisons did not reach the significance level. Post hoc test applied to the three above-mentioned statistically significant measures showed a significant difference between groups C and P3. For these variables, no difference was detected between groups C and P1, as well as groups P1 and P3. It is worth noting that despite the lack of statistical significance the stabilogram area tended to increase with the progress of pregnancy.

No women in the control group had low-back pain when performing the experiments. Conversely, 3/13 (23.10%) pregnant women in their first trimester of pregnancy (P1) reported low-back pain, while low-back pain was reported by 7/13 (53.80%) pregnant women in P3 group. The chi-squared test showed that the number of women with low-back pain is statistically different among groups ($\chi^2 = 10.97$; $p = 0.004$).

The ODIs for groups C, P1, and P3 were zero, 2.77 ± 1.53, and 9.08 ± 2.99, respectively. The one-way ANOVA revealed a statistically significant difference between groups ($F = 6.390$; $p = 0.004$). Post hoc test showed a significant difference between groups C and P3 ($p = 0.003$). No significant correlation was found between the ODI and either neurophysiological or biomechanical variables.

4. Discussion

The present study investigated the myoelectric activity of postural muscles (lumbar and soleus) along with postural sway of pregnant women and control subjects while maintaining an upright standing position. The main results indicate that pregnant women had a decreased MVC for all muscles investigated. During upright standing, the myoelectric activity of lumbar muscles was higher in pregnant women than in control subjects. Some stabilometric variables changed as the pregnancy progressed, and almost all estimated metrics were increased if the subjects performed the task with their eyes closed. ODI was significantly higher in the third trimester of pregnancy, but no correlation was observed between ODI and the neuromechanical variables. In the following sections, we shall present a detailed discussion regarding these findings.

4.1. Myoelectric activity from postural muscles during pregnancy

An interesting result was the decreased muscle activity during the MVC for the pregnant women in comparison with control subjects. It is worth noting that myoelectric activity during high-intensity contractions should be interpreted with caution due to limiting factors of surface electromyogram recordings (e.g., increased amplitude cancellation, and the relative movement of electrodes and muscle fibers). However, the significant differences observed here are unlikely to be accounted for exclusively by the limitations in myoelectric signal recording during MVC, since all subjects performed these contractions in very similar conditions. A possible explanation for the decreased maximum neural drive to the muscles during pregnancy might be related to the increased neuronal inhibition due to activation of GABA receptors. Brett and Baxendale [3] argued that GABA receptors have a high affinity for progesterone metabolites. Therefore, the increased level of progesterone during pregnancy would produce the activation of GABA-mediated Cl-currents in the neurons involved in force generation.

During upright standing, the myoelectric activity of lumbar muscles in pregnant women was significantly higher than in control subjects. Despite the lower MVC, a larger proportion of the motor neuron pools innervating lumbar muscles was active during pregnancy. This increased activity of lumbar muscles would be necessary to enhance the stability of the hip joint. In fact, as we will discuss later, pregnant women exhibited an increased stability in ML direction, which may be related to this augmented muscular activity. Conversely, soleus muscle activity of pregnant women was not different from that of the control group. Therefore, the same proportion of the soleus motor neuron pool was recruited during pregnancy. Oliveira et al. [19] argued that a higher activity of soleus muscle would be expected if we assume the inverted pendulum as a model to the body biomechanics of pregnant women. Nonetheless, this was not observed in our study, suggesting that maybe a single-link inverted pendulum rotating around the ankle joint [12] is not the equivalent biomechanical model for pregnant women. The increased activity of lumbar muscles along with an unchanged activity of soleus muscle suggests that both ankle and hip joints are being controlled to provide an adequate postural balance during pregnancy.

4.2. Postural sway

A previous study has shown that pregnant women exhibit an increased postural oscillation with the advancement of pregnancy [19]. However, they found a significant increase only when the subjects performed the postural control task without vision and with a reduced support base. In addition, they reported reduced ML COP displacements when pregnant women had visual information. Part of these data was confirmed here. Irrespective of eyes' conditions, we observed a significant decrease of spectral bandwidth, as well as a reduction of the MV of ML COP displacement. An improvement of postural control in ML direction was also reported elsewhere [16]. As we discussed before, the increased lumbar muscle activity may be responsible for this higher stability in the ML direction. Moreover, an enlargement of the pelvis along pregnancy may also explain these findings [16].

The RMS value of the AP COP displacement was significantly higher for pregnant women in the third trimester of pregnancy. This result is in accordance with the findings reported by others [19], [21]. The authors referred to suggested that this increase of AP oscillations would be due to an increased ligament laxity [1], [2], [11], [14], [21], [23] that can cause a greater ankle joint instability. Another hypothesis concerns the activity of soleus muscle. We showed that soleus EMG was not statistically different between groups. Therefore, a similar proportion of motor neurons was recruited in both control and pregnant women. However, pregnant women had an increased mass, which increased the toppling torque. The increased toppling torque and a similar soleus activity would result in a more unstable system in the AP direction [6]. This hypothesis can be further explored with the aid of a computational model of the postural control system [10].

We did not find significant differences in the stabilogram area along the pregnancy, which is the opposite of what was observed in [19] when the pregnant women were with the eyes closed. Despite an increased AP oscillation, the sway in ML direction was significantly lower in our sample. This finding could explain why the stabilogram area was maintained at an approximate constant level across the groups. Nonetheless, in qualitative terms, the stabilogram area tended to increase during the third trimester of gestation.

4.3. Low-back pain index

Despite the higher number of pregnant women with low-back pain and the increased disability index, in the present study no correlation was found between ODI and the neuromechanical variables. Dumas et al. [9] did not find a correlation between lumbar muscles' fatigue and low-back pain. Moreover, Sihvonen et al. [22] did not observe significant changes in ODI along the pregnancy. Taken together these findings suggest that upright quiet standing might not be a challenging task to the pregnant women and other factors can influence the appearance of low-back pain. Also, the maintenance of ODI during pregnancy suggests that the disability caused by low-back pain is similar irrespective of the period of gestation. Future studies would explore more challenging conditions to find a neuromechanical predictor for the low-back pain during pregnancy.

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