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Electromyographic activity of trunk muscles during exercises with flexible and non-flexible poles

Mauro Gonçalves[a,*], Nise R. Marques[b], Camilla Z. Hallal[b] and Jaap H. van Dieën[c]
[a]*Department of Physical Education, Bioscience Institute, São Paulo State University, Rio Claro, Brazil*
[b]*Department of Physical Therapy, Faculty of Science and Technology, São Paulo State University, Presidente Prudente, Brazil*
[c]*Research Institute MOVE, Faculty of Human Movement Sciences, VU University Amsterdam, Amsterdam, The Netherlands*

Abstract. *Objective:* Hand-held flexible poles which are brought into oscillation to cause alternating forces on trunk, are advocated as training devices that are supposed to solicit increased levels of stabilizing trunk muscle activity. The aim of this study was to verify this claim by comparing electromyographic (EMG) activity of trunk muscles during exercises performed with a flexible pole and a rigid pole.
Methods: Twelve healthy females performed three different exercises with flexible and rigid poles. EMG activity of iliocostalis lumborum (IL), multifidus (MU), rectus abdominis (RA), external oblique (EO) and internal oblique (IO), and was continuously measured. The EMG signals were analyzed in time domain by calculation of the Root Mean Square (RMS) amplitudes over 250 ms windows. The mean RMS-values over time were normalized by the maximum RMS obtained for each muscle.
Results: The IO showed a 72% greater EMG activity during the exercises performed with the flexible pole than with the rigid pole ($p = 0.035$). In exercises performed in standing, the IO was significantly more active than when sitting ($p = 0.006$).
Conclusion: As intended, the cyclic forces induced by the oscillating pole did increase trunk muscle activation. However, the effect was limited and significant for the IO muscle only.

Keywords: Electromyography, spine, stability, exercises

1. Introduction

Stability describes the ability of the human motor system to maintain equilibrium in the presence of kinematic perturbations or motor control mistakes [14]. An integrated action of three subsystems, passive, active, and neural, is required to provide stability to the human spine [20].

Ventral and dorsal trunk muscles have been shown to be co-activated to increase trunk stiffness and to contribute to spinal stability in a feed-forward manner [3, 25]. Rapid recruitment and force generation by trunk muscles under feedback control also contributes to stability [5]. Furthermore, abdominal pressure, controlled by abdominal muscle activation, can augment lumbar spine stability [4].

Several studies indicate that abnormal activation of trunk muscles is present in patients with non-specific low back pain, that feedback responses to perturbations may be delayed [8,16,17,21,26]. Furthermore, muscle atrophy and loss of strength of trunk muscles have been reported in patients with low-back pain [7]. Therefore, the search for exercises that promote better trunk muscle performance is a focus of physical therapy research and novel devices for training are frequently developed. Among the latter are several types of flexible poles or foils, which are set into an oscillation by rhythmic hand movements [1,2,7].

*Address for correspondence: Mauro Gonçalves, Avenida: 24-A, 1515, CEP: 13506-900, Rio Claro, SP, Brasil. Tel.: +55 19 3526 4345, E-mail: maurog@rc.unesp.br.

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Fig. 1. A participant performing the three exercises in standing posture.

The forces induced by the oscillatory pole are thought to perturb trunk equilibrium and as such solicit stabilizing activity of the trunk muscles over and above the level where the oscillation of the pole is occurring. In addition, the same exercise performed while standing and sitting were compared [22]. In standing, balance requirements will impose more strict constraints on hip angle. Thus muscles spanning the hip joint may need to produce cyclic forces during the exercises. Since these muscles partially span the lumbo-pelvic region, these forces might yield an additional perturbation to the system. We hypothesized that the type of pole, exercise and posture cause different levels of trunk muscles activity, with higher activity for the flexible pole than the rigid pole and higher activity in standing than sitting.

2. Methods

2.1. Participants

The participants were twelve females, aged 20.4 ± 1.9 years, right-handed, healthy and without musculoskeletal injuries or pain in upper limbs and low back during the six months before the study. The participants signed a written consent form and the study was approved by local ethics committee.

2.2. Protocol

The participants visited the lab on two days, separated by minimum of 24 and a maximum of 72 hours. On the first day, the participant was familiarized with the exercises, the postures and the both poles. On the second day, the participant performed the exercises with the flexible pole (Flexibar®) and the rigid pole (custom-made), in a random order. Both poles had the same mass (800 g) and length (150 cm).

Three exercises were performed with each pole, which consisted of setting the pole into a small amplitude cyclic motion while maintaining the positions of upper limbs and pole that are illustrated in Fig. 1: (I) approximately 90° shoulder flexion and pole parallel to the floor; (II) approximately 180° shoulder flexion and pole parallel to the floor; and (III) right shoulder flexed approximately 90° and pole perpendicular to the floor. Also, the exercises were defined in a random order.

All exercises were performed for 15 seconds, with a rest period of 60 seconds after each exercise. The rhythm of the movement was controlled by a metronome set at 5 Hz (300 bpm). The motion of the pole was primarily achieved by movements of the arm (flexion and extension of the elbow).

Each exercise was performed both while standing upright and while sitting upright. For the exercises in the sitting posture, a chair without backrest was used. The neutral posture of pelvis and lumbar spine were adopted in the beginning of the exercises and the par-

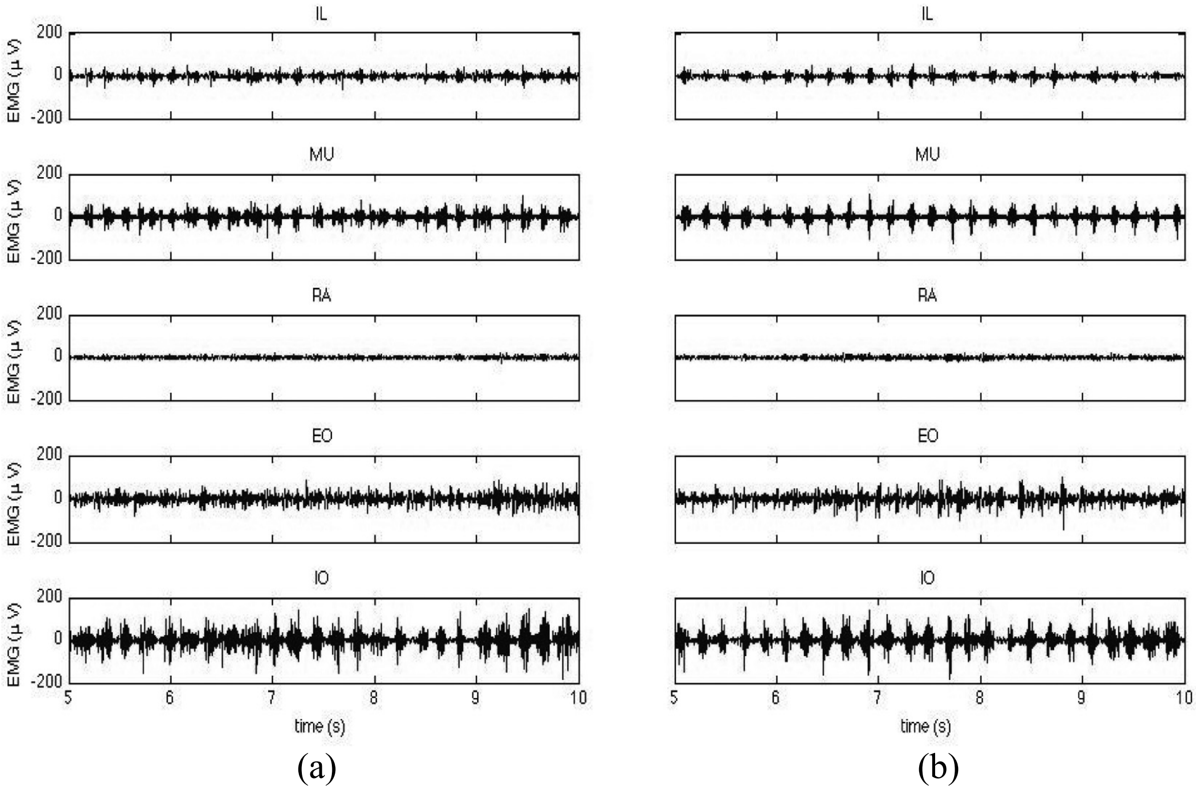

Fig. 2. Typical example of five seconds of the raw EMG signals of the five trunk muscle studied in exercise I performed while standing with a flexible pole (a) and a rigid pole (b) in the same subject. IL = Iliocostalis Lumborum; MU = Multifidus; RA = Rectus Abdominus; EO = External Oblique; IO = Internal Oblique.

ticipants were instructed to maintain the alignment of the reflective markers located on the shoulder, hip and ankle, with the latter for the standing only [18]. Visual feedback of markers positions in the sagittal plane was provided on a screen positioned in front of the participant.

2.3. Electromyography

Ag/AgCl surface electrodes of (Meditrace®) with an active area of 1 cm^2 and an inter-electrode distance of 2 cm were used in a bipolar configuration. The electrodes were positioned on the right side on the iliocostalis lumborum (IL; at 6 cm lateral to the space between the spinous processes of L2-L3, multifidus (MU; at 2 cm lateral to space between the spinous processes of L4-L5) , rectus abdominis (RA; at 1 cm above the umbilicus and 2 cm lateral to midline), external oblique (EO; at 50% of the distance between the inferior region of rib cage and anterior superior iliac spine), and internal oblique (IO; at 2 cm medial and inferior to the anterior superior iliac spine) [12,13,18]. The reference electrode was placed on the right acromion. Before placing the electrodes, the skin was shaved, abraded with sand paper and cleaned with alcohol [6].

The EMG signal was band-pass filtered between 20 Hz and 500 Hz and recorded by a sixteen-channel electromyograph of Myoresearch (Noraxon®) using MRXP 1.07 software (Noraxon®) at a sample rate of 1000 samples/s, after amplification (total gain of 2000 times: 20 times in the pre-amplifier at the electrodes and 100 times in the amplifier).

2.4. Data analysis

EMG analysis was performed using custom-made Matlab programs. EMG data collected between the fifth and the tenth second of each exercise were analyzed. The signal was processed in the time domain, by calculating the Root Mean Square (RMS) amplitude over sliding windows of 250 ms as an indicator of muscle activity. The RMS values were normalized by the mean value obtained for each muscle at all exercises performed. Then, using the PASW Statistic 17.0

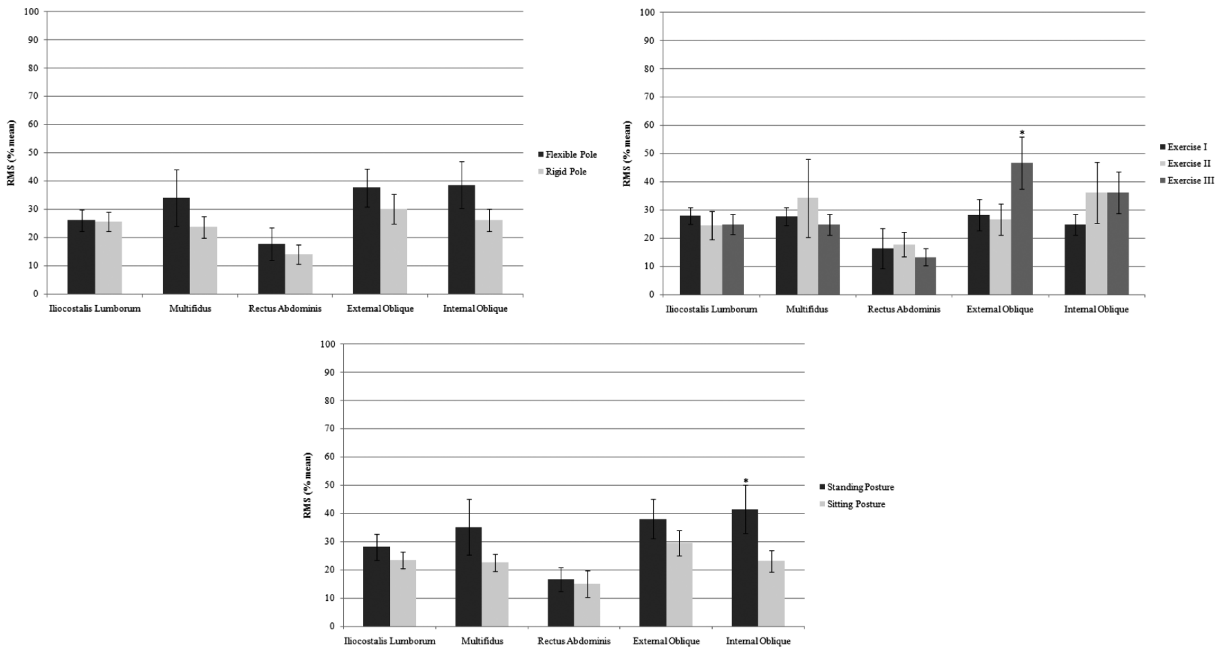

Fig. 3. (a) RMS values (%mean) of the EMG signals of all muscles studied during exercise performed with two poles averaged over postures and exercises (b) while standing and sitting averaged over poles and postures and (c) during the three exercises averaged over poles and postures. * indicates $p < 0.05$.

software (SPSS®) repeated measures ANOVAs were performed for each muscle, with pole (flexible versus rigid), posture (standing versus sitting), and exercise (I, II, III) as independent variables and normalized RMS as the independent variable. For post-hoc comparisons, paired t-tests with Bonferroni correction were used. For all statistics tests the significance level was set at $p < 0.05$.

3. Results

The exercise performed with the flexible pole clearly elicited cyclic activity in all trunk muscle measured (Fig. 3a). However, cyclic activity was also elicited when exercising with the rigid pole (Fig. 3b). In line with our hypothesis, the mean RMS values were slightly higher in all the trunk muscles, especially in IO, when exercising with the flexible pole compared to the rigid pole (Fig. 4a).

Also in line with the hypothesis, trunk muscle activity was higher in standing than sitting posture (Fig. 4b), but this effect was significant only for the IO ($p = 0.008$).

Trunk muscle activity was similar during the three exercises performed (Fig. 4c). However, the EO showed a higher activation in exercise III than in exercises I and II ($p = 0.04$ and $p = 0.04$).

4. Discussion

The flexible pole is proposed as a training device of which the vibrations transmitted to the body provide cyclic perturbations of upper limb and trunk posture [1, 11,15,24]. In line with this we found muscle activity to be higher when using the flexible pole than when doing the same exercise with a rigid, non-oscillating pole. However, this effect was small and significant for the IO only.

The IO muscle is considered an important muscle for maintaining stability of lumbar spine, because this muscle inserts, through the thoraco-lumbar fascia, on all lumbar vertebral bodies [9]. Therefore, the higher activity of this muscle, during the exercises performed with the flexible pole, could reflect an attempt to maintain the lumbar spine stability under the kinematic perturbations induced by the pole's oscillations.

As hypothesized, exercise performed in the upright standing position coincided with higher EMG activity, but this difference was significant only for the IO muscle. In line with our results, Sánchez-Zuriága et al. [22], also found more activation of IO muscle during exercises with an oscillatory blade while standing than while sitting upright. Perhaps, this result can partially be explained by the stabilizing effect of the IO on the

(a) (b) (c) (d)

Fig. 4.

sacro-iliac joints, in addition to its effects on the lumbar spine [23].

The EO muscle has the function to control the trunk rotations around the longitudinal axis [9,10]. The higher activity of this muscle during exercise III, which was performed with movements of one arm, is therefore likely required to stabilize the trunk against perturbing moments around this axis resulting from the asymmetric activity. Furthermore, the greater activity of EO, in the exercise III, could be arise from a tendency of participants to use trunk trunk twisting movements to move the arm and pole.

None of the exercises tested resulted in a substantially higher activity than the other exercises. This result differs from the findings of Moreside et al. [15], who reported that exercises with the oscillatory blade in a vertical position presented greater activity of the trunk muscles than exercises performed with the blade in a horizontal position. This disparity may be accounted for by differences in types of exercises and postures used, as well as differences in mechanical properties of the device used and possibly in intensity of exercise (EMG levels in the study of Moreside et al. [15] were substantially higher even though these were expressed in % of maximum).

This study was performed using a relatively small group of young, healthy and physically fit female participants only. While group size does not allow subgrouping, it may be important to consider potential effects of factors such as skill and motivation. Although, we controlled the frequency of the pole, differences in the amplitude of movement may have influenced muscular activation levels. Furthermore, generalization to other populations may not be warranted. Finally, the group size may have limited statistical power even though within-subject comparisons were made within a single-session, which should strongly limit error variance in the dependent variable studied.

The data of this study showed important considerations about muscular recruitment during exercises performed with oscillatory pole, which could collaborated for coaches and physiotherapist to prescribe training, prevention and treatment protocols. However, the interpretation of these results was restricted for a specific population, which was composed by young, healthy and physically fit women. In this way, the application of exercises with oscillatory pole in different populations shows like a new point to be approached by the scientific community. Furthermore, the great amount of dependent variables and the sample size could represent another limitation [2,22]. In conclusion, while exercising with a flexible pole coincided with higher levels of trunk muscle EMG activity than exercising with a rigid pole. These effects were small and significant for the IO muscle only. Although this result remains a question whether exercising with this pole is effective in training control and strength of the musculature stabilizing the spine.

References

[1] C. Anders, B. Wenzel and H.C. Scholle, Cyclic upper body perturbations caused by a flexible pole: influence of oscillation frequency and direction on trunk muscle co-ordination, *J Back Musculoskeletal Rehabil* **20** (2007), 167–175.

[2] C. Anders, B. Wenzel and H.C. Scholle, Activation characteristics of trunk muscles during cyclic upper-body perturbations caused by an oscillating pole, *Arch Phys Med Rehabil* **89** (2008), 1314–1322.

[3] J. Cholewicki, M.M. Panjabi and A. Khatchatryan, Stabilizing function of trunk flexor/extensor muscles around a neutral spine postura, *Spine* **22** (1997), 2207–2212.

[4] J. Cholewicki, K. Juluru and S.M. McGill, Intra-abdominal pressure mechanism for stabilizing the lumbar spine, *J Biomech* **32** (1999), 13–17.

[5] J. Cholewicki, S.P. Silfies, R.A. Shah, H.S. Greene, N.P. Reeves, K. Alvi and B. Goldberg, Delayed trunk muscle reflex responses increase the risk of low back injuries, *Spine* **30** (2005), 2614–2620.

[6] M. Gonçalves and F. Barbosa, Análise de parâmetros de força e resistência dos músculos eretores da espinha lombar durante a realização de exercício isométrico em diferentes níveis de esforço, *Rev Bras Med Esp* **11** (2005), 102–114.

[7] J.A. Hides, M.J. Stokes, M. Saide, G.A. Jull and D.H. Cooper, Evidence of lumbar multifidus muscle wasting ipsilateral to symptoms in patients with actute/subacute low back pain, *Spine* **19** (1994), 165–172.

[8] P.W. Hodges and C.A. Richardson, Inefficient muscular stabilization of the lumbar spine associated with low back pain. A motor control evaluation of transversus abdominis, *Spine* **21** (1996), 2640–2650.

[9] A.I. Kapandji, Fisiologia articular: tronco e coluna vertebral, 5 ed, Rio de Janeiro: Guanabara Koogan, 2000.

[10] FP. Kendall, E. Kendall and P.G. Provance, *Músculos provas e Funções*, (4 ed.), São Paulo: Manole, 1995.

[11] J.L. Lister, G. Del Rossi, F. Ma, M. Stoutenberg, J.B. Adams, S. Tobkin and J.F. Signorile, Scapular stabilize activity during Bodyblade, cuff weights, and Theraband use, *J Sport Rehabil* **16** (2007), 50–67.

[12] F.C.I Marcucci, N.S. Cardoso, K.S. Bertelli, M.R. Garanhi and J.R. Cardoso, Alterações eletromiográficas dos músculos do tronco de pacientes com hemiparesia após acidente vascular encefálico, *Arq Neuropsiquiatr* **65** (2007), 900–905.

[13] P. Marshall, B. Murphy The validity and reliability of surface EMG to assess the neuromuscular response of the abdominal muscles to rapid limb movement, *J Electromyogr Kinesiol* **13** (2003), 477–489.

[14] K.M. Moorhouse and K. Granata, Role of reflex dynamics in spinal stability: intrinsic muscle stiffness alone is insufficient for stability, *J Biomech* **40** (2007), 1058–1065.

[15] J.M. Moreside, F.J. Vera-Garcia and S.M. McGill, Trunk muscle activation patterns, lumbar compressive forces, an spine stability when using the Bodyblade, *Phys Ther* **87** (2007), 153–164.

[16] K.L. Newcomer, T.D. Jacobson, D.A. Gabriel, D.R. Larson, R.H. Brey and K.N. An, Muscle activation patterns in subjects with and without low back pain, *Arch Phys Med Rehabil* **83** (2002), 816–821.

[17] P. O'Sullivan, L. Twomey, B. Allison, J. Sinclair, K. Miller and J. Knox, Altered patterns of abdominal muscle activation in patients with chronic low back pain, *Aust J Physiother* **43** (1997), 91–98.

[18] P.B. O'Sullivan, K.M. Grahamslaw, M. Kendell, S.C. Lapenskie, N.E. Möler and K.V. Richards, The effects of different standing and sitting postures on trunk muscle activity in a pain free population, *Spine* **27** (2002), 1238–1244.

[19] P. O'Sullivan, W. Dankaerts, A.F. Burnett, G.T. Farrel, E. Jefford, C.S. Naylor et al., Effect of different upright postures on spinal-pelvic curvature and trunk muscle activation in a pain free population, *Spine* **31** (2006), E707–E712.

[20] M.M Panjabi, The stabilizing system of the spine. Part I. Function, Dysfunction, Adaption, and Enhancement, *J Spinal Disord* **5** (1992), 383–389.

[21] A. Radebold, J. Cholewicki, M.M. Panjabi and T.C. Patel, Muscle response pattern to sudden trunk loading in healthy individuals and in patients with chronic low back pain, *Spine* **25** (2000), 947–954.

[22] D. Sánchez-Zuriága, F.J. Vera-Garcia and J.M. Moreside, Trunk muscle activation patterns and spine kinematics when using an oscillating blade: influence of different postures and blade orientation, *Arch Phys Med Rehabil* **90** (2009), 1055–1060.

[23] C.J. Snijders, M.P. Bakker, A. Vleeming, R. Stoeckart and H.J. Stam, Oblique abdominal muscle activity in standing and sitting on hard and soft seat, *Clin Biomech* **10** (1995), 73–78.

[24] D. Sugimoto and P. Blanpied, Flexible foil exercise and shoulder internal and external rotation strenght, *J Athl Train* **41** (2006), 280–285.

[25] J.H. van Dieen, I. Kingma and J.C.E. van der Burg, Evidence for a role of antagonistic cocontraction in controlling trunk stiffness during lifting, *J Biomech* **36** (2003), 1829–1836.

[26] J.H. van Dieen, J. Cholewicki and A. Radebold, Trunk muscle recruitment patterns in patients with low back enhance the stability of lumbar spine, *Spine* **28** (2003), 834–841.