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Neuromuscular response of the trunk to inertial based sudden perturbations following whole body vibration exposure

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ABSTRACT

The effects of whole body vibration exposure on the neuromuscular responses following inertial-based trunk perturbations were examined. Kinematic and surface EMG (sEMG) data were collected while subjects were securely seated on a robotic platform. Participants were either exposed to 10 min of vibration or not, which was followed by sudden inertial trunk perturbations with and without timing and direction knowledge. Amplitude of sEMG was analyzed for data collected during the vibration protocol, whereas the onset of sEMG activity and lumbar spine angle were analyzed for the perturbation protocol. Data from the vibration protocol did not show a difference in amplitude of sEMG for participants exposed to vibration and those not. The perturbation protocol data showed that those not exposed to vibration had a 14% faster muscle onset, despite data showing no difference in fatigue level.

1. Introduction

Voluntary and involuntary muscle responses collectively act to help maintain mechanical stability of the body (Stokes et al., 2000). Both systems work together in an attempt to regain equilibrium and maintain spinal stability. During an involuntary muscle response, feedback is provided by the somatosensory receptors including: muscle spindles, golgi tendon organs and cutaneous mechanoreceptors. These receptors act to effectively control muscle responses, force production, and ultimately moments about joints to provide the necessary mechanical stability. Importantly, all of the aforementioned receptors have been found to have altered responses when exposed to vibration (Arashanapalli and Wilson, 2008; Brumagne et al., 1999; Lundström and Johansson, 1986; Roll and Vedel, 1982), potentially creating negative consequences to the joint, as the muscles may not be able to achieve the mechanical stability necessary to maintain the safety of the joint. In fact, the low back has been reported as the most common body segment of complaint or injury induced by chronic whole-body vibration (WBV) exposure (Bovenzi, 2009). Significantly longer delays in the neuromuscular response have been found in occupations with WBV exposure, which may explain its association with low back pain (Arashanapalli and Wilson, 2008). In addition, these changes in neuromuscular response with vibration exposure may lead to uncoordinated muscle behavior and disturbances in stability of the trunk. Non-vibration related work has shown that uncoordinated trunk muscle response results in decrease in spinal stability, leading to increasing the potential for injury (Brown et al., 2006). In fact, even without the negative effects associated with vibration, Cholewicki et al. (2005) found that for every millisecond delay in abdominal muscle shut-off there was a 3% increased risk of developing a low back injury. Moreover, it was also found that those who were susceptible to these injuries had significant delays in their reflex responses (Cholewicki et al., 2005).

The purpose of the current study was to quantify the effects of WBV exposure on the neuromuscular responses following inertial-based trunk perturbations. This work was completed to provide a better understanding of the neuromuscular effects due to WBV and, to facilitate further knowledge of its negative implications on muscle. For this work we hypothesize that subjects that are exposed to the vibration protocol will show a delayed muscle response compared to those who are not. In addition, we hypothesize that muscles with the greatest potential to stabilize the spine and, that oppose the direction of forced motion will be activated first, in an attempt to maintain spine safety.

Abbreviations: ANOVA, analysis of variance; ISO, International Standards Organization; MVE, maximal voluntary exertions; sEMG, surface electromyography; WBV, whole body vibration.

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2. Methods

2.1. Participants

Thirteen healthy male participants (age 23.6 ± 0.9 years, height 1.8 ± 0.1 m, weight 84.0 ± 7.1 kg), who had not experienced back pain in the previous 12 months, were recuited from the University population. Each participant filled out a questionnaire to assess their back health, and only those who were deemed to be healthy were included (Agius et al., 1994). The participants were randomly assigned to one of two exposure groups: (1) participants not exposed to vibration throughout the study (non-vibration exposure group, $n = 6$), and, (2) participants exposed to vibration prior to and throughout the study (vibration exposure group, $n = 7$).

2.2. Instrumentation and data acquisition

The kinematics of the trunk, head, arms and legs were captured using a passive marker system (Vicon, Vicon Motion Systems, California) and sampled at a rate of 120 Hz. A total of 72 markers were used in tracking the body segments and their locations (Table 1). Additionally, fourteen channels of surface electromyography (sEMG) were recorded, using the placement protocol outlined in Cholewicki and McGill (1996). The following muscles were recorded bilaterally: rectus abdominis, external oblique, internal oblique, lumbar erector spinae, thoracic erector spinae, multifidus and latissimus dorsi. Disposable bipolar Ag–AgCl surface electrodes discs (Medi-trace disposable electrodes, Kendall, Mansfield, MA) were positioned parallel to each muscle's line of action, between the myotendinous junctions and innervation zones with an inter-electrode distance of 2.5 cm. The sEMG signals were amplified using 14 channels on two separate Bortec AMT-8 systems (Bortec Biomedical, Calgary, Canada, 10–1000 Hz, CMRR = 115 dB, gain = 500–1000, input impedance = 10 GΩ) at a sampling rate of 960 Hz. Both the analog and kinematic data were collected using the Vicon MXF40 hardware. Included in this set up was an integrated analog to digital converter that connected to Vicon's Nexus computer collection software (version 1.3). Based on Vicon's integrated system, we were limited to collecting the analog data to a maximum sample rate of 960 Hz, as the system forces the analog to digital sample resolution to be directly related to the camera resolution. Specifically, the analog to digital sample resolution is forced as to be a fixed multiple of 8, such that when the camera sample rate is 120 Hz, the maximum resolution for analog to digial data is 960 Hz.

A parallel robotic platform (R2000 Rotopod, PRSCo, New Hampshire, USA), was used to apply tri-axial stochastic vibrations (1–8 Hz frequencies; RMS = 0.55 m/s^2) (Fig. 1), as well as provide single axis sudden 65 mm platform displacements at an average acceleration of 0.6 g and peak up to 1.6 g (Fig. 2) in the following directions to cause trunk motion: platform forward motion causing forced trunk extension; platform rearward motion causing forced trunk flexion, platform right motion causing forced trunk left lateral bend; platform left motion causing forced trunk right lateral bend. Finally, a tri-axial accelerometer (Crossbow CXL75M3, Crossbow Technology Inc., Milpitas, CA) was placed on the underside of the robotic platform to measure acceleration and timing of the platform perturbations. To measure the WBV experienced by subjects, an accelerometer was inbedded in a rubber seat pad on which the participants were seated. The accelerometer data were collected at a sample rate of 960 Hz.

Table 1
Kinematic marker identification and placement location.

Marker	Location
1	Right Anterior Head
2	Left Anterior Head
3	Right Posterior Head
4	Left Posterior Head
5	Right Acromion
6	Right Lateral Shoulder
7	Right Distal Biceps
8	Right Mid-Deltoid
9	Right Triceps
10	Right Lateral Elbow
11	Right Medial Elbow
12	Right Forearm
13	Right Radial Styloid Process
14	Right Ulnar Styloid Process
15	Right Hand
16	Left Acromion
17	Left Lateral Shoulder
18	Left Distal Biceps
19	Left Mid-Deltoid
20	Left Triceps
21	Left Lateral Elbow
22	Left Medial Elbow
23	Left Forearm
24	Left Radial Styloid Process
25	Left Ulnar Styloid Process
26	Left Hand
27	Sternum
28	C7 Spinous Process
29	Left Ventral Scapular Boarder
30	T4 Spinous Process
31	T10 Spinous Process
32	Left Lateral to T12 Spinous Process
33	Right Lateral to T12 Spinous Process
34	Right Posterior Superior Illiac Spine
35	Left Posterior Superior Illiac Spine
36	Right Illiac Crest Apex
37	Left Illiac Crest Apex
38	Right Femur Trochanter
39	Right Proximal Anterior Thigh
40	Right Proximal Lateral Thigh
41	Right Distal Anterior Thigh
42	Right Distal Lateral Thigh
43	Right Femur Lateral Epicondyle
44	Right Femur Medial Epicondyle
45	Left Femur Trochanter
46	Left Proximal Anterior Thigh
47	Left Proximal Lateral Thigh
48	Left Distal Anterior Thigh
49	Left Distal Lateral Thigh
50	Left Femur Lateral Epicondyle
51	Left Femur Medial Epicondyle
52	Right Proximal Fibula
53	Right Anterior Tibia
54	Right Mid Fibula
55	Right Distal Anterior Tibia
56	Right Lateral Malleolus
57	Right Medial Malleolus
58	Right Anterior Foot
59	Right Lateral Foot
60	Right Achilles
61	Right Heel
62	Left Proximal Fibula
63	Left Anterior Tibia
64	Left Mid Fibula
65	Left Distal Anterior Tibia
66	Left Lateral Malleolus
67	Left Medial Malleolus
68	Left Anterior Foot
69	Left Lateral Foot
70	Left Achilles
71	Left Heel
72	Sternoclavicular Notch

2.3. Experimental procedures and protocol

Participants produced maximal voluntary exertions (MVE) for each muscle being tested, which was used later to normalize the sEMG data collected. Participants performed 3 trials of isometric MVE's of the abdominals (rectus abdominis, internal oblique and