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HOW THE CENTRAL CONTROL SYSTEM ADAPTS TO ACUTE WHOLE-BODY VIBRATION STIMULUS[12]

Deniz SIMSEK[1]
İzzet KIRKAYA[1]
A. Ruhi SOYLU[2]
Olgun UGURLU[1]
Ali Onur CERRAH[1]
Hayri ERTAN[1]

ABSTRACT

This study investigated the effects of high- and low-frequency acute whole-body vibration (WBV) on postural control ability.

Sixteen male students from the Faculty of Sport Science voluntarily participated in this study. [Methods] WBV stimuli were applied using the following parameters: (1) frequency: 30 or 40 Hz; (2) stance: static squat position; (3) amplitude: 4 mm; (4) knee flexion angle: 120°; and duration: 60 s. The medio-lateral ground reaction force (MLGRF) and anterio-posterior ground reaction force (APGRF) were measured on a force platform.

The results showed that static WBV stimulation at 4 mm in amplitude at low and high frequencies resulted in different postural adaptations ($p<0.05$). The APGRF and MLGRF were higher at 30 Hz than at 40 Hz, and a rapid exponential decline in the post-vibration values was observed within the first 10 seconds of stimulation at 30 Hz or 40 Hz at 4 mm. After the initial 10 seconds, these forces were maintained until the end of the 60-second stimulation period. The present findings support that somatosensory stimulation at 30 Hz and 4 mm induced long-term effects on the control of postural sway. Alternatively, somatosensory stimulation more rapidly adapted to the vibration at 40 Hz and 4 mm.

It may be concluded that WBV at 40 Hz and 4 mm can rapidly provide beneficial effects to the elderly, for whom postural control is very important, for the treatment of chronic conditions such as Parkinson's disease, osteoporosis, and post-menopausal conditions or for the enhancement of athletic performance.

Key words: Whole Body Vibration; Postural Orientation; Somatosensory

TÜM VÜCUT VİBRASYON UYARANLARINA MERKEZİ KONTROL SİSTEMİ NASIL ADAPTE OLUR

ÖZET

Araştırmanın amacı yüksek ve düşük frekanslı akut tüm vücut vibrasyon [TVV] uyaranlarının postural kontrol yetenekleri üzerine olan ektilerinin incelenmesidir. Anadolu Üniversitesi Spor Bilimleri Fakültesinde öğrenci olan 16 erkek çalışmaya gönüllü olarak katılmıştır. TBV uyarıları şu parametreler izlenerek uygulanmıştır: (1) frekans: 30 ve 40 Hz: (2) duruş: statik squat pozisyonu:(3)genlik: 4mm: (4) diz fleksiyon açısı: 120°: süresi: 60sn. Medio-lateral yer reaksiyon kuvvetİ (MLYRK) ve anterio-posterior yer reaksiyon kuvvetİ (APYRK) kuvvet platformu ile ölçüldü.

4mm genlikte düşük ve yüksek frekanslı TVV uyaranları farklı postural adaptasyonlarla sonuçlanmıştır ($p<0.05$). APYRK ve MLYRK eksenlerinde görülen yer reaksiyon kuvvetleri 30 Hz'de 40 Hz'den fazladır ve aynı frekanslarda 4mm genlikte gözlenen ilk 10 sn uyaranları etkisiyle vibrasyon sonrası değerler arasında hızlı bir eksponansiyel düşüş vardır. İlk 10 saniyeden sonra bu kuvvetler 60 saniyelik uyarı periyoduna kadar devam etmiştir. Bu sonuçlar 30Hz ve 4mm somatosensör uyarıların postural salınımın kontrolü üzerinde uzun etkileri olduğu sonucunu desteklemektedir. Bunu yanı sıra somatosensör uyarılar daha hızlı bir şekilde 40 Hz frekans ve 4mm genliğe adapte olabilmektedir.

40 Hz ve 4mm TVV uyarılarının sağlıklı bireylerde hızlı ve yararlı etkilerinin olduğu sonucuna varılabilir. Parkinson hastalığı gibi postural kontrolün çok önemli olduğu vakaların kronik koşullarını tedavi etmek için çıkan sonuçtan faydalanabilir. Ayrıca menapoz sonrası ya da osteoporoz gibi durumlarda fiziksel performans geliştirmek adına yararlanılabilir.

Anahtar Kelimeler: Tüm Beden Vibrasyon; Postural Oryantasyon; Somatosensör

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[1] Faculty of Sports Science, Anadolu University, Eskisehir, Turkey
[2] School of Medicine, Biophysics Department, Hacettepe University, Ankara, Turkey

INTRODUCTION

Postural control is particularly important during athletic activities because performing a motor activity during athletic activities requires maintaining balance against both external (such as walking on slippery ground, changes in light, and vibration) and internal factors (such as muscle stiffness, muscular-skeletal injuries, and fatigue) that disrupt balance. To maintain balance with the least possible effort, the most effective response should be directed toward postural changes and body sways that emerge during ongoing posture. The centre of pressure (COP), occasionally referred to as a force line, is defined as the centroid of the pressure distribution at a series of moments in time as GRF is applied over the plantar surface of the foot. The response to this force is generated via activation of the postural control system, which requires a rather complex connection between the sensory (somatosensory, visual, and vestibular) and motor systems[1-3]. Postural control is a complex motor ability that depends on the interactions between these dynamic sensory and motor processes. Additionally, balance requires the effective use of all systems controlled by the postural control system in accordance with the received stimuli. Based on this evidence, various studies have been performed to identify the role of postural stability in athletic performance and in several age-dependent chronic diseases. As a result of these studies, various methods have been developed to evaluate postural stability under dynamic and static conditions[4-5]. One of these methods is vibratory stimulation applied to the postural muscles, which significantly affects balance control processes[6]. Vibration stimuli provide proprioceptive information to the postural muscles. Proprioceptive receptors are present in the muscles, tendons, and joints. Proprioceptors provide information regarding the position of the extremities and the tension of muscles related to posture[7]. Proprioceptive receptors are among the most crucial components of the motor control system, and they include the muscle spindles (type 1a and type II) and the Golgi tendon organ (1b). The Golgi tendon organ processes the changes that occur during muscle tension[8-10]. Therefore, it provides information to the nervous system regarding the positions of the extremities relative to each other to achieve motor control. In contrast, muscle spindles perceive the changes associated with muscle length and acceleration. Moreover, the Golgi tendon organ is responsible for reflexive contractions of the skeleton muscle fibres in a given muscle (the Golgi tendon reflex)[11]. When vibration is administered to a muscle, muscle spindle priming increases, and the muscle spindle sends information regarding muscle contraction to the central nervous system[12]. When the muscles contract, the proprioceptive receptors within the muscle and the tendons send signals to change the muscle length according to the postural control system of the central control system[13, 14]. Simultaneously, the central nervous system processes all sensory signals received from separate parts of the body and sends instructions to the postural muscles to maintain stability[15]. The voluntary movements that are required to achieve postural control are initially planned in the brain. The outputs from the brain are transferred to the muscles via the pyramidal and extrapyramidal systems. Pyramidal cells are components of the premotor and parietal cortices, and they transfer information to spinal motor neurons and intermediate neurons. This information is required to voluntarily achieve postural control and perform reflexes. As a result, the postural system responds to vibrational body sway by shortening the muscle length. The effects of vibration applied to postural muscles depend on the region of application and the magnitude and duration of the vibration[16-18]. The present study evaluated the efficacy of high- and low-frequency acute whole-body vibration (WBV) on postural control ability. We hypothesized that postural control during WBV is directly associated with the frequency of stimulation.

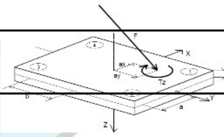
METHODS

To test the hypothesis presented above, the present study investigated the efficacy of high- and low-frequency acute WBV on postural control ability. Sixteen physically fit students (age 25.4 ± 5.3 years; weight 70.2 ± 0.01 kg; height 176.9 ± 6.7 cm) from the Faculty of Sport Sciences who had no contraindications for WBV as per the manufacturer's recommendations (epilepsy, diabetes, gallstones, kidney stones, acute inflammation, joint problems, cardiovascular diseases, joint inflammation, thrombosis, or back problems (hernias or tumours)) were included in this study. This study was approved by the local ethics committee. All subjects signed informed consent forms before enrolment. The subjects volunteered to participate in 2 testing visits separated by 24 hours. Visit 1 was a familiarization visit in which the subjects were introduced to the WBV protocols. Visit 2 consisted of vibration and force data acquisition.

The subjects were asked to perform unloaded static squats at a knee flexion angle of 120^0. Knee joint angle changes were monitored using an electronic goniometer. WBV (vertical) was randomly applied using a Compex WINPLATE (Galileo 2000, Novotec Medical GmBH, Germany) device at 30 Hz or 40 Hz at a high (4 mm) amplitude. All experimental stimuli persisted for 60 seconds, and the measurements were initiated when the subjects were comfortable performing a squat on the platform. Vibrations were applied to the subjects in a random order by dividing each of the two trials into two blocks. After each trial, the subjects relaxed for approximately 5 minutes. The positions of the feet on the platform were marked during the initial trial of each experimental session, and the subjects were asked to maintain this foot position during all trials. The subjects were instructed to direct their head and eyes forward and to distribute their weight equally between their feet.

Postural responses to vibratory stimuli were quantified as APGRF (Fx) and MLGRF (Fy) measured on the force platform (Kistler force plate 9281EA, Germany). Force data were obtained at 2000 Hz and were normalized according to the body weight. (The data calculation formula is provided in **Table 1)**.

Table 1. Force plate output signal- channel, description and calculation formulas

Output signal	Channel	Description
fx12	1	Force in X-direction measured by sensor 1 + sensor 2 
fx34	2	Force in X-direction measured by sensor 3 + sensor 4
fy14	3	Force in Y-direction measured by sensor 1 + sensor 4
fy23	4	Force in Y-direction measured by sensor 2 + sensor 3
Parameter	**Calculation**	**Description**
Fx	= fx12 + fx34	Anterior-posterior ground reaction force (APGRF)
Fy	= fy14 + fy23	Medio-lateral ground reaction force

The root mean square (rms) values of every consecutive 500 ms of post-vibration force data were calculated and normalized according to the body weight. Then, weight-normalized curves of 10 subjects were averaged for curve fitting. The first 10 s of normalized and averaged post-vibration force data were curve-fitted to the exponential equation F = k.exp (-t/T), where F is force; t is time; and k and T are positive constants. Similarly, the last 10 s of normalized and (averaged post-vibration force data were curve-fitted to the linear equation **Table 2**) F = a.t+b, where F is force; t is time; and a and b are constants.

Table 2. Averaged post vibration force data and curve-fitted to a linear equation.

		F=k*exp(-t/T)		F=a*t+b	
Frequency	**GRF**	**k**	**T**	**a**	**b**
30 Hz	AP	0,731338	119,5897	0,000709	0,601249
40Hz	AP	0,532401	44,68019	-0,00149	0,456299
Rest (non-Vib)	AP	0,362519	481,2625	-0,00075	0,389385
30Hz	ML	0,796224	147,6717	-0,00052	0,738341
40Hz	ML	0,593282	24,23348	1,54E-05	0,324823
Rest (non-Vib)	ML	0,368517	155,2292	-0,00011	0,331628

AP: Anterior-Posterior; ML: Medio-lateral; GRF: Ground reaction force

The GRF data were analysed using PASW/SPSS Version 21.0 (SPSS Inc., Chicago, IL), and the significance level was set at $p < 0.05$. Data were expressed as mean ±standard-deviation (X±SD). Before statistical analyses, all of the GRF measures were found to be normally distributed according to a Shapiro-Wilk test. Ground reaction force measurements were statistically analyzed (ANOVA) to test all frequencies before and after for each vibration interventions (non-vib, 30 Hz, 40 Hz).

Independent-sample t-tests were performed between the calculated GRF for the 30 Hz and 40 Hz.

RESULTS

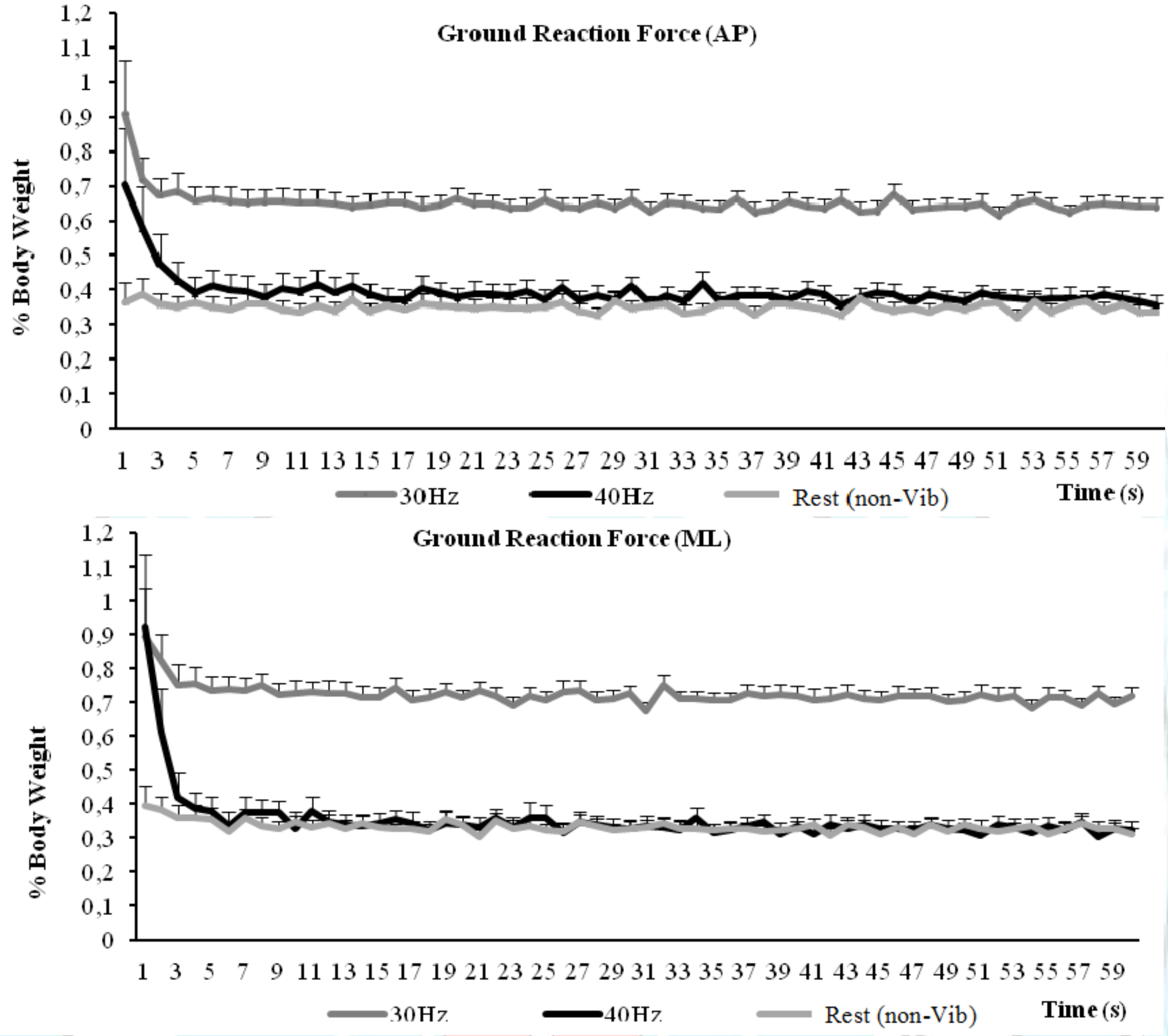


Figure 1. Mean GRFs (expressed as a percentage of body weight) and the standard error of the mean after 30 and 40 Hz frequencies and 4mm amplitude in the AP and ML axis.

The influence of acute WBV on postural control is displayed in **Figure 1**. During the rest (non-Vib) APGRF and MLGRF measurements, minimal shifts in APGRF and MLGRF were recorded. As presented in **Figure 1,** the force platform measurements obtained after WBV at both 30 Hz and 40 Hz indicated a sharp decrease in MLGRF and APGRF within the first 10 seconds. Furthermore, the findings of the present study suggested that the body struggles to adapt to maintain balance during the faster 40 Hz vibration and that 30 Hz vibration results in the prolonged use of the neural circuits to maintain postural control.

DISCUSSION

In this study, we analysed how high- and low-frequency proprioceptive input affects human balance control and postural responses to acute WBV. (As presented in **Figures 1** and **2**) force platform measurements obtained after WBV at both 30 and 40 Hz indicated sharp decreases in ML and AP GRF within the first 10 seconds. The exponential decrease in the mean AP and ML GRF rms values should be carefully interpreted. First, the rms values are a statistical measure of all subjects and might not represent the AP and ML GRFs for a single subject. Second, the time constants of the exponential decrease depend on the frequency of vibration. Third, these time constants are related to the duration of post-vibration force (higher time constants correspond to higher durations of post-vibration disturbances, and vice versa). This exponential decline can be explained by the sudden activation of the postural muscles to maintain balance against the proprioceptive stimulus. No explicit explanation for the neurophysiologic processes underlying this situation can be provided. However, previous studies have demonstrated that postural sway occurs towards the direction of the applied vibration, and this phenomenon can be explained by the correction reflex generated by the postural muscles exposed to vibration to compensate for the vibration-induced stretching of these muscles[19]. In contrast, some researchers argue that a proprioceptive network extending from the eyes to the feet underlies the changes in postural sway and postural control induced by vibration and that the afferent signals produced by all interconnected body segments are processed by the sensory system. Following WBV at different frequencies, the mechanism responsible for the sudden exponential decrease in AP and ML GRF observed during the first 10 seconds of the 60-second vibration period and the linear sway maintained thereafter could be associated with the strong and sustained activities of type 1a sensory discharge and small afferent fibres in the motor system at a postural level. Additionally, these fibres play an important role in the responses induced by vibration. Secondary endings can easily be activated by vibration. Secondary endings are well suited to detect changes in muscle length; however, primary endings react to both muscle length and the ratio of muscle length alteration to the total muscle length. Primary muscle spindle endings exhibit the predominant response during the stretching phase, and secondary endings are activated during both stretching and shortening[20]. Therefore, primary spindle endings are considered to be responsible for the acute changes in AP and ML GRF observed during the first 10 seconds of vibratory stimulation, and the secondary spindle endings are likely primarily associated with the exponential decline in AP and ML GRF observed after the first 10 seconds of vibration[5, 16]. The effects of vibration on the reflexes at the spinal level and on central motor command should be considered. Gilhodes et al.[21] reported that the primary and secondary somatosensory cortices act together with the supplementary motor region, which represent the central processing unit of afferent signals. In addition, they noted that vibration at different frequencies activates the supplementary motor region and the 4a region in the brain. The supplementary motor region of the brain is also activated before self-activated movements. Vibration stimuli affect the peripheral and central excitatory mechanisms that regulate voluntary movements[22, 23]. This response to vibration stimuli is accompanied by the activation of monosynaptic and polysynaptic afferent pathways that have the ability to activate specific hormonal reactions. The voluntary contraction following vibration activates the central and peripheral nervous systems. Therefore, WBV may serve as an effective exercise method to increase neuromuscular performance in athletes and may help maintain postural stability. This maintenance in postural stability may also enable a physically active way of life.

In conclusion, the findings of the present study suggest that the body struggles to adapt to maintain balance during higher frequencies of vibration (40 Hz) and that 30 Hz vibration results in the prolonged activity of neural circuits that maintain postural control. It may be concluded that WBV applied at 40 Hz-4 mm can rapidly provide beneficial effects to the elderly, for whom postural control is very important, for the treatment of chronic conditions such as Parkinson’s disease, osteoporosis, and post-menopausal conditions or for the enhancement of athletic performance.

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