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An ergonomics evaluation of the vibration backpack harness system in walking

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ABSTRACT

Many studies in backpack design have been focused on reducing trunk muscle activity and improving overall comfort while the wearers (college students and outdoor enthusiasts) were walking. However, little work has done on combining the vibration with harness system design. The purpose of the present study was to evaluate the effect of the vibration backpack harness system on trunk muscle activity and overall comfort in walking. There were four vibrators sewn in the four different positions of our harness system. Subjects were asked to support a load (20% body weight) on their backpack while performing 5-min walking trials on the treadmill (speed = 1.6 m/s) with different frequencies of vibration (0 Hz, 28 Hz, 35 Hz, 42 Hz). The objective measures of trunk muscle activity (electromyography) were obtained during the walking task. Subjects also were asked to complete subjective ratings of comfort. The results of the objective measures in this study had shown that the vibration function had a positive effect on reducing muscle activity for upper trapezius (UT), but not for erector spinae (ES). From the data of the two subjective surveys in our study, the comfort level of no-vibration state (0 Hz) was worse than vibration state (28 Hz, 35 Hz, 42 Hz) for both muscles, and when the frequency was 35 Hz, the comfort of the harness system was higher than the other three frequencies. The findings of the present study support that backpack with low frequency vibration has a positive effect on reducing trunk muscle activity and improving overall comfort level for wearers in walking.

Relevance to industry: Observations of present study is beneficial in assisting wearers to reduce muscle activity and improve overall comfort in walking according to the vibration backpack harness system. New backpack design criteria for harness systems are discussed to optimize production strategies. The wearers could be students, outdoor enthusiasts and old people.

1. Introduction

As a common form of load carriage, backpacks have been an indispensable part in people's daily life. Many researchers have studied the effects of the posteriorly mounted loads on the muscle activity and comfort of the spine and low back. There was a significant proportion of this research had been focused on the use of backpack by students (Hong et al., 2008; Bauer and Freivalds, 2009; Ramadan and Al-Shayea, 2013). Often these studies evaluated the backpack use and their impact on the local muscle. The use of backpack by wearers in wilderness activities such as recreational hiking (Simpson et al., 2011; Stuempfle et al., 2004) and the use of backpack by military personnel (Knapik et al., 2004; Pal et al., 2014)have also received some attention in the literature.

Concerns have been raised over recent decades about the habitual heavy backpack carriage and the prolonged duration leading to the spinal symptoms such as fatigue, muscle soreness, shoulder pain, back pain, numbness and even spinal deformity (David et al., 1997; Negrini and Carabalona, 2002; Sheir-Neiss et al., 2003). Therefore, numerous biomechanics and physiology studies emerged to find the backpack design to reduce trunk muscle activity and improve overall comfort in walking (Simpson et al., 2011; Lafiandra and Harman, 2004). The most of the backpack designs have focused on the harness. A harness could transfer a significant proportion of the load directly to the pelvis. The muscle forces supporting the load were reduced by transferring more of the backpack load directly to the pelvis (Southard and Mirka, 2007). Lafiandra and Harman (2004) showed that about 30% of the vertical force of the backpack transfers to the hips

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by using a hip belt with a framed backpack. A further limitation of backpacks without a strong hip belt was that the pressure exerted on the shoulders by the straps from the backpack itself. Holewijn (1990) showed that the load could be transferred to the waist with a flexible frame to reduce the pressures on the skin of the shoulder since the waist was three times less sensitive to skin pressure than the shoulder region. Reid et al. (2004) showed that adding lateral stiffness rods to the lateral edges of the suspension system of the backpack could transfer some of the vertical load from the back and shoulders to the hips, which decreased the vertical force applied to the torso.

While numerous studies on backpack harness system design were concerned about transferring force to reduce trunk muscle activity, none of them studied other methods to improve overall comfort in walking. Massage was often used in an attempt to counteract the unpleasant sensations that accompanied strenuous physical exertion, as well as to hasten the recovery process (Beard et al., 1964; Cafarelli et al., 2008). As one way of the massage, vibration (shaking) was a pre-event technique to stimulate the target muscle groups prior to competition (Benjamin and Lamp, 2005). The procedure involved tremulous movement resulting in a shaking of the body region massaged (Moraska et al., 2005). The purpose of vibration was to facilitate muscle relaxation and increase circulation (Benjamin and Lamp, 2005; Fritz et al., 2000). Increased blood flow was reputed to be a major effect of percussive vibratory massage (Cafarelli et al., 2008). This was thought to be achieved when the increased intramuscular pressure caused local venous emptying (Wiktorsson-Moller et al., 1983). Cafarelli et al. (2008) found that percussive vibratory massage delivered with an electromechanical device had the ability to retard progressive fatigue, increase muscular endurance and reduce muscle activity.

Some studies on vibrator stimulation suggested significant therapeutic effects for pain reduction (Jacobs, 1960; Goats, 1994). Some more studies focused on vibrations' application in sport (Issurin, 2005; Mancinelli et al., 2006). Results from published literature supported a positive trend for vibration massage to benefit athletic recovery and performance (Moraska et al., 2005). The application of vibration in sport had a long history, but this training modality research was in its infancy. There were two varieties of vibration training: (1) whole body vibration which could be performed during muscle activity and (2) local vibration applied during strength and flexibility exercises (vibratory stimulation) (Issurin, 2005). The first one employed an approach where very intensive and prolonged vibrating loads were combined with unloaded exposure or with moderate physical efforts (Delecluse et al., 2003; Torvinen et al., 2002); the latter exploited intensive muscular efforts accompanied by local vibrator stimulation (Nazarov and Spivak, 1987; Kuksa, 1990). A more appropriate approach for the sport practice was based on the application of vibration to the entire limb or even to the whole body (Issurin, 2005; Mischi et al., 2009), and in therapy and clinical settings vibrator stimulation were applied to the local muscle or tendon (Issurin, 2005). Therefore, local vibration for muscles was applied to be studied in walking with backpack harness system.

In this study, a new backpack harness system with vibration function was designed. There were four vibrators sewn in the four different positions of the harness system to provide local vibration stimulation to upper trapezius (UT) and erector spinae (ES). An ergonomics evaluation of the vibration backpack harness system was investigated according to objective and subjective methods. The objective measures of muscle activity were obtained by Electromyography (EMG) (Hong et al., 2008; De Luca, 1997). Subjective comfort and discomfort were assessed using the comfort questionnaire including scales for local perceived discomfort for the new backpack harness system (Kuijt-Evers et al., 2007; Southard and Mirka, 2007). The specific aim of this study was to develop the new backpack harness system for supporting the wearers, such as college students and outdoor enthusiasts and to evaluate this system in various vibration frequencies. It was hypothesized that the vibration backpack harness system (a design with four vibrators) would reduce trunk muscle activity while the wearer was walking. It was also hypothesized that the advanced harness would improve overall comfort level, and a particular improvement in the comfort of the shoulder region was expected.

The paper was organized as follows: In Section 2, we gave an introduction to the methods we used in the study. We presented the experimental results in Section 3 and discussions in Section 4. Finally, we summarized the key conclusions of the study in Section 5.

2. Material and methods

2.1. Subjects

In our study, fourteen subjects (age = 24 ± 3 years, height = 172.0 ± 5.2 cm, weight = 60.1 ± 5 kg) were selected from male college students. All subjects underwent medical examination with special consideration of their musculoskeletal and nervous systems. Before the experiment, the subjects were requested not to participate in any physical activities which might introduce tiredness. The experimental procedures were reviewed and approved by the local human ethical clearance committee and all subjects signed the informed consents.

2.2. Apparatus

As shown in Fig. 1, the new vibration backpack harness was a modification of an external framed pack including a harness and a mock-up container. This harness was chosen because it featured many characteristics (a hip belt, lateral stiffness bars, load lifter straps, padded shoulder straps, an adjustable harness for varied torso lengths and a padded lumbar support). There were four vibrators (M31E-2, MITSUMI, Japan) sewn in the four different positions (two in the left and right shoulder straps, two in the lumbar support) of the harness to vibrate UT and ES on both sides. Low-intensity vibration with a 15–50 Hz frequency had a positive physiological effect (Issurin, 2005), and vibration levels needed to be different obviously for evaluation. So the selected three vibration frequencies were 28 Hz, 35 Hz and 42 Hz, which resulted in approximately 1–2 mm displacement. The force of application was approximately 3–5 N (Kouzaki et al., 2000). Due to a linear relationship between the frequency and voltage of the vibrators, three corresponding voltages (3.5 V, 5 V, 6.5 V) were output to the vibrators by a DC power supply. The external container used in the experiment was a wooden mock-up that was dimensionally accurate in terms of size (21 cm × 21 cm × 50 cm), weight (10 kg), balance (mass evenly distributed throughout the volume) and it was hollow in order to add different loads. The mass on the back was 20% body weight (the weight of the container + additional loads) (Li et al., 2003; Singh and Koh, 2009). The container was secured to the frame of the harness and the addition of lateral stiffness rods. In order to make equal force to the both sides of body, the three-dimensional position of the center of mass of the container should relative to the spine. This was accomplished by centering the load on the spine, tightening the harness so that the load fit snugly against the back. Due to anthropometric variability in the subject pool, the position of the top of the container varied between subjects. We adjusted the height of the top of the