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Effects of load carriage and surface inclination on linear and non-linear postural variability

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ABSTRACT

Understanding of inclined-work-related risk of falls and developing novel practical engineering controls for reducing this risk of falls among hilly working population remains in high demand. Standing on sloped surfaces provides a unique environment for examining the biomechanics and neural control of standing. The present investigation examined the variability of postural signals when standing on inclined surfaces and with load carriages by linear and nonlinear analysis. The purpose of this study was to determine if the sloped surface deteriorated in postural stability among healthy individuals with two distinctive kinds of load carriage methods head versus posterior load carriage. We also examined the effects of distinct magnitudes of load on these conditions. Postural control was assessed objectively using forceplates and subjectively through perceived stability ratings. The results indicate significant differences in mediolateral COP ranges, COP velocities and COP area with interaction in surface inclinations and methods of load carriage. We found that head load carriage when standing on uphill afflicted and engendered increased balance deterioration in healthy young subjects. We also found the significantly lower complexity of postural signals for head load carriage as measured by entropy. Apropos to this mean subjective perceived rating was also least in this load-bearing condition. Understanding these underlying mechanisms of postural control with load carriage strategies in humans could productively help in developing efficacious preventive strategies to reduce the incidence of falls from inclined slopes.

1. Introduction

Load carriage is one of the most physically demanding occupational tasks contributing to injury and falls as well as a major risk factor for loss of balance (Liu and Lockhart, 2013; Yeoh et al., 2013; Muslim and Nussbaum, 2015). Load carriage is involved in many industries like construction, agriculture, transportation, and warehousing; where the worker often carries loads not only at flat surfaces but also at various degrees of surface inclinations. Negotiated standing on inclined surfaces (non-neutral posture) during load carriage is a common challenge faced by many working populations and thereby places a specific demand on the neuromuscular control system. Operating in such an environment (i.e. construction and/or roof work, etc.) is challenging to the postural control system, individuals are at an increased risk of loss of balance, and potentially a subsequent fall (Sun et al., 1996; Redfern and DiPasquale, 1997; Gauchard et al., 2001; Redfern et al., 2001; Simeonov et al., 2003; Wade et al., 2004; Frames et al., 2013). Typical injuries related to falling from inclined planes with height (example roof or hills) are found to be extremely severe and require long periods of medical treatment and costs (Gillen et al., 1997). Laborers and freight, stock, and material movers, who often carry the load at various surface inclinations, have been reported as the occupations with the highest number of days-away-from-work cases reported in 2013 (BLS, 2014–2015).

In many developing countries, people routinely carry extraordinary loads supported by their heads (Head Load carriage: HLC) or back (Posterior Load Carriage: PLC) (Chow et al., 2011). Further, PLC and HLC among these workers are typically without the use of a backpack or other assistive devices (Fig. 1). PLC and HLC performance involves the non-neutral trunk poses which when adopted may increase postural sway i.e. affecting the postural stability of the person. Such traditional load carriage methods are prevalent in both domestic and occupational settings. For instance, workers at the grain storage depots, construction sites and many other places of trade and commerce, use these methods to carry the load that may be as high as 100 kg (Nag* and Sen, 1979). Both men and women laborers are engaged in such hefty load carriage activities. For example, in the underdeveloped areas of the hills in the Himalayan regions, women convey a ponderous load daily for their

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Fig. 1. Head and posterior load carriage practice among agricultural workers.

livelihood, transporting food, fuel, and fodder on risky uphill and downhill slopes (Fig. 1). Carrying a load on inclined uphill and downhill slopes often results in loss of balance and fall accidents in many outdoor work environments. Carrying an external load on the back shifts the system's center of mass posteriorly, and individuals typically adopt a forward lean to maintain balance (Goodgold et al., 2001; Grimmer et al., 2002; Hong and Cheung, 2003). Unwittingly standing on inclined planes predisposes to fall by itself (Cham and Redfern, 2002) regarding its adaptation when the load is carried at such inclined surfaces. Biomechanics research has focused largely on walking over horizontal (Perry et al., 1992), with less attention paid to inclined surfaces (Leroux et al., 2002). For instance, there are few studies that have focused on downhill walking (Sun et al., 1996; Redfern and DiPasquale, 1997), uphill walking (Kang et al., 2002, Noble and Prentice, 2008) and cross-slope walking (Damavandi et al., 2012). In seminal work on the load carriage, researchers have concentrated mostly on muscle activity patterns (Thomas et al., 1987) and physiological strain variables (Bhambhani and Maikala, 2000). The flurry of research surrounding traditional load carriage methods has been limited to experimental studies assessing the physiological cost (Minetti et al., 2006; Lloyd et al., 2010), gait (Heglund et al., 1995), a load coupled to the trunk in the form of vest or backpack (Birrell and Haslam, 2009; Liu and Lockhart, 2013) and ratings of perceived discomfort (Lloyd et al., 2010). Seminal work by researchers (Kinoshita, 1985; Goh et al., 1998; Chansirinukor et al., 2001; Hong and Cheung, 2003) has reported that significant postural adaptations occurred in response to load carriage.

Balance is the amount of postural sway (also called body sway) of the human body. Postural sway is the slight postural movement made by an individual in order to maintain a balanced position and is the total displacement at the center of mass relative to the base of support over time. The postural sway is by contraction and relaxation of muscle groups and is an indirect measure of the propensity for falls. Postural sway has been assessed for static balance and dynamic balance conditions, depending on whether the base is stationary or moving (such as standing or walking) (Spirduso and Asplund, 1995). Predominantly, increased postural sway inferred as impaired postural control, and is associated with an increased falling risk (Fernie et al., 1982; Lichtenstein et al., 1988; Maki et al., 1990; Baloh et al., 1995; Prieto et al., 1996). Since standing on inclines and load carriage induce deviations from natural posture, it can lead to increased stress in neck and low back (Chaffin and Anderson, 1984). And prolonged working in these environments may lead to postural discomfort, increased lumbosacral forces (Goh et al., 1998) and muscular pain in neck, shoulder, or low back injuries (Chaffin and Anderson, 1984). A greater amount of postural instability correlated with an increased risk of falling. The mass of an external load on the body (Ledin and Odkvist, 1993; Holbein and Redfern, 1997) and surface inclinations are the potential variables affecting body's stability limits and equilibrium.

To our best knowledge, this is the first study that specifically investigated postural stability with different methods of traditional load carriage without the use of packs or other assistive devices on inclined surfaces. Information regarding the effects of load carriage methods on balance and postural stability is sparse. Therefore the purpose of this study is to facilitate a more comprehensive understanding of the contribution of different load carriage methods at inclined surfaces to postural stability; which may help to identify effective practical interventions to facilitate injury prevention from loss of balance and associated falls while carrying the load on inclined surfaces. We hypothesized that different load carriage methods, and surface inclinations would disparately affect postural control and balance outcomes. The specific questions addressed in this study are: if there exist any mismatches between subjective perceptions of an impending loss of balance and actual (as measured by objective measures using forceplate – a gold standard assessment) risk of fall or steadiness? The main objective of this study was to investigate the effects of surface slope, load carriage, load magnitude and their interactions in the control and perception of standing balance in young healthy subjects. Understanding these underlying causes and effects on balance could be useful in developing efficacious preventive strategies to reduce the incidence of falls from inclined slopes.

2. Methods

The study recruited twenty participants (gender balanced) from Virginia Tech and the local community. Participants had no self-reported injuries, musculoskeletal disorders, neurological disorders, vestibular disease, or occurrences of falls in the past 12 months. Mean (SD) age, stature, and body mass of the male participants were 21.4 (1.5) years, 177.4 (7.1) cm, and 76.1 (8.1) kg, respectively, with corresponding values of 21.4 (2.0) years, 161.8 (7.7) cm, and 61.4 (8.9) kg for the female participants. Prior to data collection, participants completed informed consent procedures approved by the Virginia Tech Institutional Review Board.

2.1. Experimental design and procedures

A repeated-measures design was used, in which each participant