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Athletes trained using stable compared to unstable surfaces exhibit distinct postural control profiles when assessed by traditional and nonlinear measures

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ABSTRACT

Athletes are assumed to exhibit better balance than non-athletes; however, few studies have examined the role of different types of sports on balance measures. Two athlete groups that experience divergent sport-specific balance training are stable- (i.e. basketball) and unstable-surface athletes (i.e. surfers). The purpose of this study was to quantify the effect of stable- compared to unstable-surface sports on postural stability.

Methods: Eight non-athletes (NON), eight stable-surface athletes (SSA) and eight unstable-surface athletes (USA) performed five 20-s quiet standing trials while ground reaction forces were recorded. Approximate entropy (ApEn), total excursion and root mean square distances (RMS) of the center of pressure position were calculated. Univariate ANOVAs with post hoc tests were conducted for each variable.

Results: ApEn values were lower in SSA compared to NON in the ML direction ($p = 0.012$) and USA had lower ApEn values compared to SSA in the AP direction ($p = 0.036$). The USA had smaller AP RMS compared to SSA ($p = 0.002$) while the USA had greater ML RMS ($p = 0.008$) and resultant RMS values compared to SSA ($p = 0.025$).

Discussion: These data suggest that USA and SSA may exhibit direction-specific differences in balance strategy due to feedback paradigm.

1. Introduction

Postural sway during quiet standing can be described as the continuous movement of the center of mass in the absence of an external perturbation (Strang, Haworth, Hieronymus, Walsh, & Smart, 2011). A successful balance strategy compensates for excessive or abnormal postural sway by applying forces to the support surface such that the center of mass remains over the base of support (Smart & Smith, 2001). Generally, postural sway can be viewed as a measure of the effectiveness of the neuromuscular system's ability to respond to altered center of mass location relative to the base of support (Smart & Smith, 2001). Accordingly, optimal control of posture has been suggested to be associated with minimal magnitudes of postural sway (McKeon & Hertel, 2008), and thus those with excellent motor control purportedly exhibit smaller magnitudes of postural sway compared to individuals with poor motor control. Evidence supports this notion as healthy older adults exhibit

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greater postural sway magnitudes compared to healthy young adults (Fujita et al., 2005), and that healthy adults exhibit reduced postural sway compared to adults with cardiovascular (Yamamoto et al., 2001) or neurodegenerative disease (Rocchi, Chiari, & Horak, 2002). Further, it has been shown that elite athletes exhibit smaller sway magnitudes compared to non-elite athletes or non-athletes (Lamoth, van Lummel, & Beek, 2009), and that participation in athletics is associated with reduced postural sway across the lifespan (Lamoth & van Heuvelen, 2012). Based on these ideas, it is believed that athletes have better balance than those who don't participate regularly in sports.

Because there are many different types of sport activities, it is likely that the specific demands of each sport may have different effects on balance. It has been demonstrated that trained athletes exhibit reduced postural sway magnitudes during quiet standing compared to non-athletes (Lamoth & van Heuvelen, 2012; Lamoth et al., 2009). Much work has focused on athletes that train and compete on a stable surface including the ground or floor (Cavanaugh et al., 2006; Cavanaugh, Guskiewicz, Giuliani et al., 2005; Cavanaugh, Mercer, & Stergiou, 2007; Lamoth et al., 2009; Stergiou & Decker, 2011). That is: as the athlete applies a force to the support surface, the support surface applies an equal and opposite force on the athlete and translates the athlete's center of mass relative to the point of force application. It is postulated that these athletes experience a distal-to-proximal loading pattern with fine motor adjustment for balance occurring at the distal joints including the foot and ankle (Franz & Kram, 2013a). However, not all athletes train or compete in a stable surface environment. Certain athletes, such as surfers and snowboarders, train and compete on unstable or "negative" surfaces. When these athletes apply a force to their support surface, the support surface also translates in response to the force (slips or slides) applied to it in addition to applying a force back onto the athlete. Due to the unique nature of the balance perturbations experienced by these athletes, they may be required to adopt a feed-forward postural control strategy which manifests in a proximal-to-distal motor response pattern to balance perturbations, initiated in the trunk and pelvis rather than the distal segments of the foot and ankle (Franz & Kram, 2013a, 2013b). If differences in balance performance exist between these two functionally different groups of athletes, balance training interventions may be developed to reduce postural sway magnitudes based on the unique training strategies and postural responses present in these unstable surface athletes (USA).

There are further complexities in the measurement of postural sway. Though traditional measures of postural sway are useful in providing information pertaining to an individual's limits of stability, nonlinear measures of sway variability may provide greater insight into the stability of underlying motor control. Approximate entropy (ApEn), a common nonlinear measure of variability, provides a quantitative assessment of moment-to-moment variability from which the stability of the motor performance can be inferred (Pincus, 1991; Powell, Muthumani, & Xia, 2014). Further, it has been demonstrated that nonlinear measures of variability are more sensitive to subtle changes in the characteristics of postural sway compared to traditional measures including center of pressure (CoP) excursions, resultant distance or CoP path length and sway accelerations (Cavanaugh, Guskiewicz, & Stergiou, 2005; Cavanaugh et al., 2007; Lamoth et al., 2009; Stergiou & Decker, 2011). For example, nonlinear measures of regularity are capable of detecting subtle changes in the characteristics of postural sway associated with concussion, evidenced by increased regularity and reduced approximate entropy values (Cavanaugh et al., 2005). These significant nonlinear findings have been shown to exist even in the absence of abnormal sway as indicated by traditional measures of postural stability (Cavanaugh et al., 2006; Sosnoff, Broglio, Shin, & Ferrara, 2011). Measurement of traditional and nonlinear variables of postural stability is likely to provide a more complete description of the motor performance. This may be especially important in individuals who participate in activities with complex demands on the neuromusculoskeletal system.

Therefore, the purpose of this study was to investigate the effects of different external demands on postural sway on traditional and nonlinear indices of balance during a quiet standing trial. It was hypothesized that individuals who regularly trained using a negative-surface paradigm would exhibit (1) significantly greater CoP excursions and (2) significantly greater ApEn values compared to individuals trained in a positive-surface paradigm or non-athletes.

2. Methods

2.1. Subjects

Twenty-four healthy young adults between the ages of 18 and 30 participated in this study. Participants were placed into three separate groups based on athletic training paradigm including non-athletes (NON; Age: 22.9 ± 2.5 years), stable-surface athletes (SSA; Age: 22.6 ± 3.2 years) and unstable-surface athletes (USA; Age: 23.1 ± 2.5 years). Participants were placed in the NON group if they did not participate in 30 min of recreational physical activity at least 3 days per week (Thompson, Gordon, & Pescatello, 2010). The SSA group was composed of individuals that were recreationally active in a traditional sport at least 30 min per day for three or more days per week on a stable surface. A stable surface is described as a surface on which the individual's center of mass moved in direct response to the force applied to the support surface such as a basketball floor, playing field, etc. The USA group was composed of individuals that regularly participated in sports in which the base of support moved in response to the forces applied to the surface such as a surf board or snowboard. Subjects in the USA group were only included in the study if they participated in their unstable surface sport for an average duration of 90 min per week. Subjects were excluded if they had a history of orthopedic or neurological disorder that prevented them from maintaining a stable posture. All subjects provided written informed consent prior to participation in this study.