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Comparison of pre-contact joint kinematics and vertical impulse between vertical jump landings and step-off landings from equal heights

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ABSTRACT

Although impact phase differences between vertical jump landings (VJL) and step-off landings (STL) may be related to task-specific pre-contact strategies, pre-contact mechanics are rarely examined. Thus, pre-contact kinematics and vertical ground reaction force (vGRF) impulse were examined between VJL and STL. Ten health adults (20.9 ± 1.6 yrs; 167.8 ± 4.2 cm; 68.5 ± 7.15 kg) performed 15 VJL and 15 STL from equal heights. Limb (lead; trail) by task (VJL; STL) ANOVAs ($\alpha = 0.05$) compared hip, knee, and ankle joint angles 150 ms pre-contact, 100 ms pre-contact, 50 ms pre-contact, and at ground contact. Joint angular displacement was also evaluated between 150 ms pre-contact and ground contact. vGRF impulse was compared during the loading (ground contact to peak vGRF) and attenuation (peak vGRF to end of impact) phases. Greater hip flexion angles occurred during STL versus VJL at each event except 150 ms pre-contact ($p \le .004$). Trail limb knee flexion angles were greater at each event when compared to the lead limb during STL ($p \le .019$). Greater trail limb knee flexion angles occurred during STL versus VJL at all four events ($p \le .018$), while greater plantarflexion angles occurred at all four events during VJL versus STL ($p \le .034$). During STL, greater trail limb plantarflexion angles were detected at each event versus the lead limb ($p < .001$). Lesser hip, lead and trail limb knee displacement occurred during STL versus VJL ($p < .05$). Greater vGRF impulse was detected during the loading phase of VJL ($< .001$), while greater vGRF impulse occurred during the attenuation phase of STL ($p = .025$). These tasks are characterized by distinct pre-contact kinematic strategies and post-contact kinetics. The task utilized in practice should reflect the requirements of the population of interest.

1. Introduction

The attenuation of vertical ground reaction force (vGRF) during landing has received much attention from researchers and practitioners (Bressel & Cronin, 2005; Dufek & Bates, 1990; Harry, Barker, Mercer, & Dufek, 2017; James, Bates, & Dufek, 2003). As such, researchers continue to supplement the literature to provide human performance professionals with a better understanding of the manner in which performers strategically attenuate vGRF during landing. Much of the available literature examining vGRF attenuation strategies comes from studies using step-off landings (STL) as a surrogate task for vertical jump landings (VJL) due to anecdotal similarities between the tasks (James et al., 2003; Nordin & Dufek, 2016; Rowley & Richards, 2015; Zhang, Bates, & Dufek,

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2000). However, recent research comparing VJL to STL has shown that greater peak vGRF magnitudes, greater loading rates, and more rapid loading times occur during STL in comparison to VJL from equal heights (Afifi & Hinrichs, 2012; Harry, Freedman Silvernail, Mercer, & Dufek, 2017). These kinetic and temporal differences coincide with different lower body segment and joint angular positions during the impact phase (Chiu & Moolyk, 2015; Harry et al., 2017). This evidence threatens the validity of the use of STL as a highly-controlled surrogate task for VJL, while also suggesting the performance of STL might increase the risk for performance error.

The selection of a specific pre-contact strategy describes a performer's attempt to appropriately position the body (Gambelli, Theisen, Willems, & Schepens, 2015; Santello, 2005) and efficiently anticipate impact (Santello, 2005). The strategies employed depend upon the mechanical and neural control abilities of the participant/sample and the specific demands of the task (Bates, 1996; Caster & Bates, 1995; Dufek, Bates, Stergiou, & James, 1995). Despite the influence pre-contact strategies can have on kinetic outcomes during impact, pre-contact kinematics are rarely examined in combination with kinetic outcomes. If the joints are in a flexed/dorsiflexed position prior to ground contact and are not sufficiently displaced into a more extended/plantarflexed position at ground contact, a lesser functional range of motion will be available during the impact phase. Consequently, lesser joint displacement/functional range of motion throughout impact can produce greater peak vGRF magnitudes, greater vGRF loading rates, and increased joint loading (Begalle et al., 2015; Devita & Skelly, 1992). While these parameters are often linked to injury risk, it is also possible that altering these parameters by way of a specific pre-contact strategy can lead to different task performance outcomes.

Although previous studies comparing VJL to STL detected greater peak vGRF magnitudes, loading rates, and faster peak vGRF loading times (Afifi & Hinrichs, 2012; Harry et al., 2017), a causal relationship between peak vGRF parameters and injury has been difficult to identify (Bisseling & Hof, 2006; McNitt-Gray, 1993; Nigg & Bobbert, 1990). Further, peak vGRF parameters alone do not quantify how effective a participant's pre-contact strategy is at influencing the actual performance of the landing task (decreasing center of mass momentum to zero). Based on the impulse-momentum relationship, evaluating vGRF impulse (area under the vGRF time-history) describes a performer's ability to change their center of mass momentum (Robertson, Caldwell, Hamill, Kamen, & Whittlesey, 2013) upon ground contact. Mechanically, a greater vGRF impulse magnitude indicates a greater change in center of mass momentum. By dividing the post-contact phase into "loading" and "attenuation" sub-phases, the effects of both the pre-contact strategy and the response to ground contact can be determined. Specifically, any difference in vGRF impulse between VJL and STL during the loading sub-phase would indicate the task-specific pre-contact strategies influenced the performer's ability to stop downward motion immediately upon ground contact (Nordin, Dufek, James, & Bates, 2016). Subsequent differences in vGRF impulse between VJL and STL during the attenuation sub-phase would then reveal task-specific response strategies to impact with the ground. Therefore, evaluating vGRF impulse could expose issues relative to the training outcomes currently expected following repeated performance of either STL or VJL.

Bilateral analyses are uncommon in the landing literature despite previous suggestions that they are necessary when evaluating two-footed landings (Niu, Wang, He, Fan, & Zhao, 2011; Schot, Bates, & Dufek, 1994), particularly when comparing VJL to STL (Harry et al., 2017). Specific to STL, pre-contact asymmetry is unavoidable because one limb (lead limb) must move forward to initiate the movement while the opposite limb (trail limb) quickly moves into position to create a symmetrically-oriented position at ground contact. Although it has been shown that asymmetrical knee joint angular positions occur at ground contact during STL but not during VJL (Harry et al., 2017), the asymmetry was not shown to coincide with limb- or task-specific differences in the peak vGRF magnitude (Harry et al., 2017). Nonetheless, varied protective mechanisms at the ankle joint have been shown to occur as a result of asymmetrical mechanics during the post-contact phase of STL (Niu et al., 2011). While vGRF impulse can quantify the influence of a pre-contact strategy on task performance, the consequences of kinematic asymmetries as they relate to injury potential during STL might also be revealed by bilaterally evaluating vGRF impulse as opposed to the discrete peak vGRF parameters evaluated previously (Harry et al., 2017).

The purpose of this investigation was to bilaterally compare pre-contact joint angular positions, pre-contact joint angular displacements, and post-contact vGRF impulse between the lead and trial limbs during VJL and STL from equal heights. Based on the expectation that different levels of impact preparedness/anticipation exist between VJL and STL (Afifi & Hinrichs, 2012; Harry et al., 2017), it was hypothesized that different lower-extremity hip, knee, and ankle joint angular positions and displacements would be detected between tasks. Additionally, it was hypothesized that asymmetrical joint angular positions and displacements would occur during STL but not during VJL. Finally, it was hypothesized that different vGRF impulse magnitudes would be revealed between tasks and asymmetrical vGRF impulse magnitudes would be detected during STL but not VJL.

2. Material and methods

2.1. Participants

Ten healthy, recreationally active adults (five males, 25.0 ± 1.6 yrs, 176.5 ± 4.2 cm, 79.7 ± 7.1 kg; five females, 20.8 ± 1.6 yrs, 167.8 ± 4.2 cm, 68.5 ± 7.1 kg) volunteered to participate in this investigation. This sample size was determined using an a priori power analysis (G * Power 3.1) based on the non-fatigued knee angle data at ground contact of Edwards, Steele, and McGhee (2010) with a proposed effects size of 1.16, power $(1 - \beta)$ of 0.95, and an alpha level of 0.05. The data evaluated in this study were a subset of data recently evaluated to compare VJL to STL relative to discrete impact phase joint kinematics and peak vGRF parameters (Harry et al., 2017). All participants were free of any injuries, and were actively participating in jump-landing movements for at least six months prior to the start of the study. Informed written consent was provided in accordance with the Institutional Review Board at the site of data collection.