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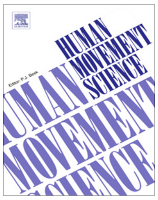

Full Length Article

Force-displacement differences in the lower extremities of young healthy adults between drop jumps and drop landings

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A B S T R A C T

We measured ground reaction force and lower extremity shortening in ten healthy, young adults in order to compare five trials of drop jumps to drop landings. Our dependent variable was the percentage of displacement (shortening) between the markers on the ASIS and second metatarsal heads on each LE, relative to the maximum shortening (100% displacement) for that trial at the point of greatest ground reaction force. We defined this as "percent displacement at maximum force" ($\%d_{Fmax}$). The sample mean $\%d_{Fmax}$ was 0.73% ± 0.14% for the drop jumps, and 0.47% ± 0.09% for the drop landings. The mean within-subject difference score was 0.26% ± 0.20%. Two-tailed paired t test comparing $\%d_{Fmax}$ between the drop jump and drop landing yielded $P = 0.002$. For all participants in this study, the $\%d_{Fmax}$ was greater in drop jumps than in drop landings. This indicates that in drop jumps, the point of maximum force and of maximum shortening was nearly simultaneous, compared to drop landings, where the point of maximum shortening followed that of maximum force by a greater proportion. This difference in force to displacement behavior is explained by linear spring behavior in drop jumps, and linear damping behavior in drop landings.

1. Introduction

Human lower extremities are called upon to fulfil different roles; acting as springs, as force absorbing dampers, or as actuators (Raynor, Yi, Abernethy, & Jong, 2002) depending upon the goal of the task required, as well as external conditions. Biomechanical outputs such as end effector position, joint torque, or ground reaction force have many contributing factors. These factors include neural input to muscle fibers, mechanical properties of muscle, connective tissues and bone, and other mechanical variables, such as limb segment or interaction torques. Historically, Bernstein (1967) proposed that since there is such multiplicity of inputs which lead to eventual outputs (such as joint torque or ground reaction force), and the effects of those inputs vary depending upon intrinsic and extrinsic conditions; that the neural load of attempting to control each of those inputs through a feed-forward control system would be too great to allow for efficient movement. Therefore, he proposed that those inputs are adjusted based upon neural information of output (Bongaardt and Meijer, 2007; Zajac & Winters, 1990). This conclusion has been supported by subsequent research in neural control (Ito, 1996). It is therefore reasonable to suspect that the biomechanical goal of a lower extremity task; whether that goal be force storage and return, force damping, or force creation, will be reflected in the behavior of output variables measured during the performance of that task.

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One category of motor task with the goal of force storage and return are those tasks in which the lower extremities (LEs) are called upon, individually or bilaterally, to act as “linear springs”. Foundational work in developing mathematical descriptions of the linear spring behavior in running and hopping was published by Blickhan (1989) and by McMahon and Cheng (1990). In both of these works, the mechanical behavior predicted through the researchers’ mathematical models coincided with what was empirically observed with humans running or hopping. Tasks requiring spring behavior of the LEs typically include high velocity bending of the hip, knee, ankle, and mid-foot (Farley, Houdijk, Van Strien, & Louie, 1998; Ferris, Louie, & Farley, 1998; Moritz & Farley, 2005; Moritz, Greene, & Farley, 2004) such as running, hopping, and jumping. Each of these is an activity in which the primary biomechanical goal of the LE’s is to store the force of the landing in order to release it for immediate recoil (Farley et al., 1998). A common task used for researching this linear spring behavior is the “drop jump”, in which an individual hops from an elevated surface and immediately rebounds vertically upon landing (Ambegaonkar, Shultz, & Perrin, 2011; Earl, Monteiro, & Snyder, 2007; Myer et al., 2005). This is sometimes called a “countermovement jump” (Bobbert, Huijing, & van Ingen Schenau, 1987)

“Drop landings” may exemplify tasks with a different biomechanical goal than drop jumps (Ambegaonkar et al., 2011; Earl et al., 2007; Myer et al., 2005). While researchers have shown that in drop jumps, the point of greatest force and greatest LE shortening, measured from the ground to the body’s center of mass (through bending of the trunk, hips, knees, ankles, and mid-feet) is simultaneous, except for some variability between trials and individuals (Farley et al., 1998; Ferris et al., 1998; Moritz & Farley, 2005; Moritz et al., 2004); in studies investigating the biomechanical behavior of the LEs in drop landings, researchers have concluded that during drop landings, rather than acting as springs, the LEs act as force dampers, absorbing rather than storing and returning the force of the landing (Kulas, Schmitz, Schultz, Watson, & Perrin, 2006; Minetti, Ardigò, Susta, & Cotelli, 1998; Puddle & Maulder, 2013). Examples of this type of task include a gymnast “sticking” a landing after a vault, a basketball player landing after catching a rebound, or a ballet dancer landing after performing a *tour en l’air* (Kulas et al., 2006).

In our literature review, we found few studies comparing drop jump to drop landings within subjects. One study which did the comparison was described by Ambegaonkar et al. (2011). They showed higher gastrocnemius and quadriceps post-landing amplitudes as measured by rectified electromyogram (EMG), and higher ground reaction forces in drop jumps compared to drop landings. These findings reflect the subjects’ requirement for greater knee and ankle muscle stiffness when the biomechanical goal is force storage and return. We found no studies described in the literature specifically comparing the sequence of maximum LE shortening relative to maximum ground reaction force between drop jumps and drop landings. A better understanding of how healthy humans adapt to different types of landings could benefit the physically active population by potentially shaping training methods and the design of force absorption products, such as athletic shoes and floors, to increase safety in activities including exercise, sports and dance (Dyhre-Poulsen, Simonsen, & Voigt, 1991; Ferris et al., 1998; Hackney et al., 2011; Hackney, Brummel, Edge, & Jungblut, 2011; Myer et al., 2005).

We hypothesized that for young, healthy adults during drop jumps, maximum ground reaction force and LE shortening would occur nearly simultaneously, as long as the countermovement jump is of amplitude sufficient that the take-off force exceeds the force of heel strike (Ball, Stock, & Scurr, 2010). By contrast, for drop landings, the point of maximum force, which is the result of heel contact (Fukano, Kuroyanagi, Fukubayashi, & Banks, 2014; Seegmiller & McCaw, 2003), would occur measurably earlier than maximum LE shortening. We propose that this difference in this behavior of the LEs during landing reflects the contrasting biomechanical goals of the two tasks; force storage and return in drop jumps, and force damping, or absorption, in the drop landings (Ambegaonkar et al., 2011; Hackney et al., 2011; Leukel, Taube, Lorch, & Gollhofer, 2012; Minetti et al., 1998; Puddle & Maulder, 2013).

2. Materials and methods

2.1. Subjects

The participants were 10 healthy young adults, (five men and five women), mean age = 24.4 ± 1.8 years, mean body mass = 74.8 ± 20.5 kg. (Data from 13 subjects were initially analyzed, but the data of three subjects were unusable due to significant differences between landing types for heights of their hops off of the platform. The criterion by which the data of those three subjects were excluded is described in detail in the ‘Data Reduction and Analysis’ section). Exclusion criteria were used both to maximize participant safety and protect against potential confounding variables related to their medical history. Therefore, we inquired whether participants had a history of surgery of the low back or lower extremity; and/or history of pain in the back or lower extremity over the month preceding the data collection. The university institutional review board approved this study.

2.2. Instrumentation

Three-dimensional motion was captured with the Vicon 612 motion analysis system (Vicon Motion Systems Inc., Lake Forest, California). This system has been shown to be a reliable and valid instrument to collect kinematic data (Barker, Craik, Freedman, Herrmann, & Hillstrom, 2006; Carse, Meadows, Bower, & Rowe, 2013). We employed a six camera system to record three dimensional LE segment length and LE segment length displacement (change in length) with a sampling rate