

IMPULSE GENERATION DURING JUMPING AND LANDING MOVEMENTS

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Every foot contact provides an athlete with an opportunity to change the magnitude and/or direction of their total body momentum. During jumping and landing tasks, the body position relative to the reaction force, momentum at touchdown, the mechanical objective of the task, the individual's self selected control strategy, and the properties of the surface influence the reaction force-time characteristics applied to the musculoskeletal system during foot contact. How the reaction force impulse applied at the feet is distributed will influence both performance and mechanical loading experienced by the musculoskeletal system.

KEY WORDS: impulse, landing, jumping, impact, reaction force, musculoskeletal loading

OVERVIEW: Every foot contact provides an athlete with an opportunity to change the magnitude and/or direction of their total body momentum. How the reaction force impulse applied at the feet is distributed over time or multiple foot contacts will influence both performance and mechanical loading experienced by the musculoskeletal system. During jumping and landing tasks, the net impulse applied by body weight and the reaction force during foot contact with the surface will determine the magnitude and direction of momentum change. Differences in body position relative to the reaction force, momentum at touchdown, the mechanical objective of the task, the individual's self selected control strategy, and the properties of the surface will influence how the reaction force impulse is generated during foot contact (Farley et al., 1998; Ferris and Farley, 1997; McKinley and Pedotti, 1992; Munkasy et al., 1996; Irvine and McNitt-Gray, 1993; Mizrahi and Susak, 1982; McNitt-Gray, 1993; McNitt-Gray et al., 1994; Lees, 1981; Ozguven and Berme, 1988).

PERFORMANCE RELATED MECHANICS: The goal of foot first interaction with the ground is to effectively convert the total body momentum at touchdown to achieve a subsequent task. For example, the mechanical goal of the single leg landing performed during the take-off phase of the long jump is to convert a portion of the total body horizontal momentum generated during the run-up into vertical momentum at departure (Hay, 1986). Like the long jump, the mechanical goal of the two foot take-off of an aerial gymnastics skill, is to convert a portion of the total body horizontal and angular momentum generated during the preceding tumbling skills into vertical momentum at departure (Munkasy et al. 1994; Munkasy et al., 1997). During many of these tasks, however, athletes must first negotiate impact immediately following touchdown and then generate impulse required for the subsequent task. How they interact with the landing surface will influence their ability to generate the desired impulse during the available foot contact time and the distribution of mechanical load within their musculoskeletal system.

CONTACT DURATION: Constraints on contact duration may influence the ability of the athlete to generate and/or control total body momentum so that the mechanical objective of the task can be achieved. Time constraints may be imposed by the directions given to the subject (e.g. jump as quickly as possible), the immediacy of the secondary movement after impact, surface (e.g diving board, trampoline vs. force plate), or a requirement to maintain a hopping frequency yet jump higher (Farley et al., 1998; Ferris and Farley 1997). The momentum at contact may also limit the opportunity to apply impulse during foot contact. For example, during the take-off of the running long jump and/or tumbling take-off, the magnitude of the horizontal velocity of the total body at contact may limit the available foot contact time to generate vertical impulse required for the subsequent aerial phase of the task. During landings, a constraint may be

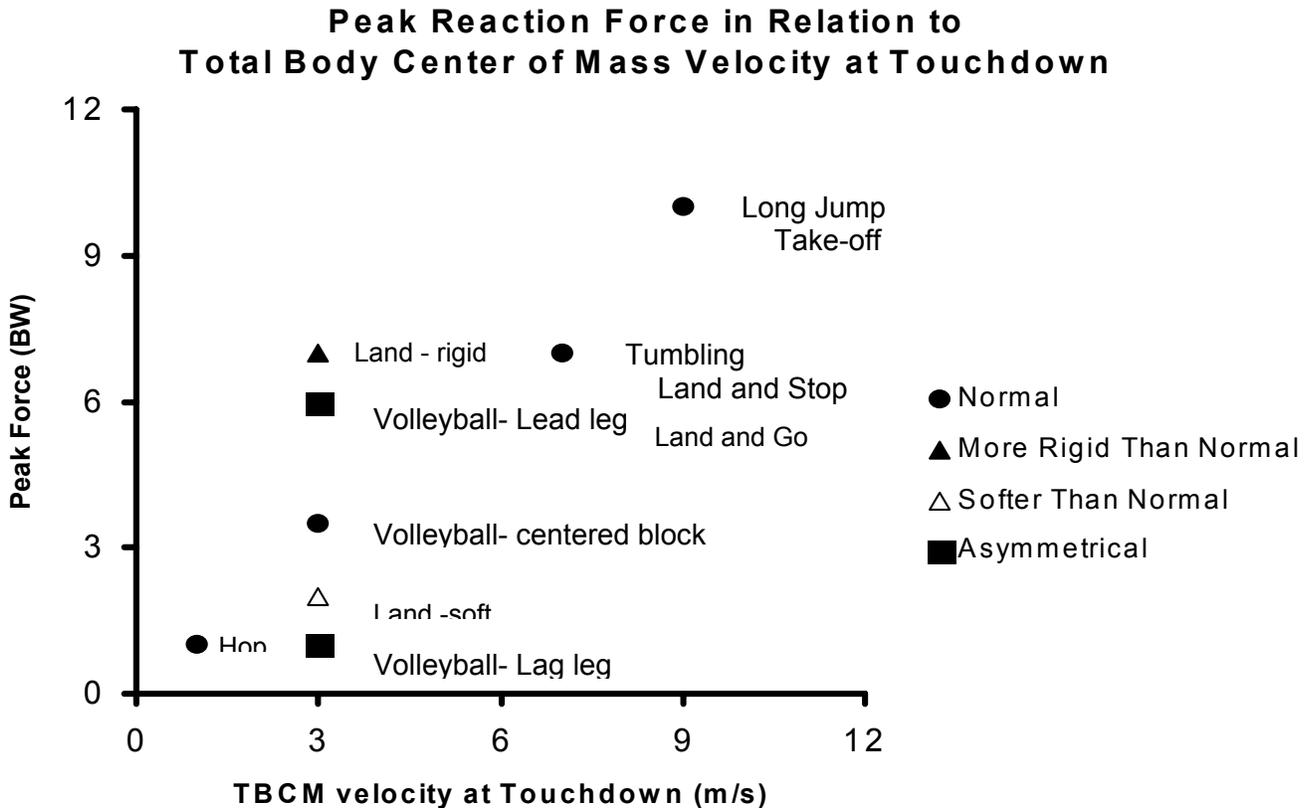
imposed on the number of foot contacts. In court or field games, restrictions on the number of foot contacts may be imposed by boundary lines imposed by the rules of the games or by the presence of an opponent. For example, a basketball player going for a loose ball may not step out of bounds or collide with an opponent and therefore may need to control their total body momentum with a single placement of their foot. Similarly, a gymnast performing a landing during competition must reduce their linear and angular momentum at contact with a single placement of their feet (Federation Internationale de Gymnastique, 1984). Failure to do so, will result in a significant reduction in their performance score. In both cases, the initial conditions at contact need to be conducive for providing adequate time to generate the linear and angular impulse necessary for controlling their total body momentum. Multijoint control of moments created by these large reaction forces experienced during foot contact presents a significant challenge to the neuromuscular system prior to and during foot contact (McNitt-Gray, 2000; McNitt-Gray et al., accepted).

MUSCULOSKELETAL LOADING: Musculoskeletal loading during landing depends on how the individual has chosen to interact with the surface. In general, the peak reaction force tends to increase in magnitude as the horizontal and/or vertical component of the TBCM velocity at touchdown increases (Hyoku et al., 1984; McNitt-Gray, 1993, McNitt-Gray et al., submitted; Nigg, 1985) (Figure 1) and level of control decreases (Bruggemann, 1987, McNitt-Gray, et al., 1992, 1993; Panzer, 1987). For example, the TBCM vertical velocity at touchdown during the tumbling take-off (Land and Go) may be less than -1 m/s yet the reaction forces experienced by each leg may be 7 BWs (Figure 1). In contrast, the landing of a tumbling skill (Land and Stop) with a TBCM vertical velocity approaching -8 m/s may result in a peak vertical reaction force of 7 BWs for each leg (Figure 1). Experimental evidence indicates human subjects can voluntarily modulate the external loading experienced during impact by as much as 8 BW (McNitt-Gray et al., 1991) by modifying their multijoint control strategy. Performance criteria also influences the landing strategy selected and may take precedence over reducing the musculoskeletal loading experienced. For example, during the landing of a volleyball block, decreasing the time to block a ball may take precedence over loading the lead leg by 5 BW more than the lag leg (McNitt-Gray et al., 1994). Landing strategies self selected by athletes also demonstrate individual preferences for internal distribution of load between joints, bone, (Zatsiorsky and Prilutsky, 1987) and recruitment of uni and biarticular muscle-tendon units (McNitt-Gray et al., accepted). Unfortunately, most epidemiological studies are retrospective and do not account for loading specific to the individual's typical movement patterns.

EPIDEMIOLOGY: To avoid injury, load experienced by the body needs to be kept in balance with the ability of musculoskeletal structures to respond to stress induced by loading. No causal relationship, however, has been proven between load and injury. Absence of stress results in degeneration or muscle atrophy, where as, one excessive load may result in acute injury (e.g. fracture, sprain) or may lead to chronic injury (e.g. cartilage damage). Repetitive loading may produce positive effects such as increased critical limits of musculoskeletal components even in compromised nutritional and hormonal environments or negative effects such as fatigue fracture, muscle soreness, or chronic pain. The high incidence of injury to the lower extremities of athletes participating in landing activities (NCAA, 1986, 1990), however, suggests the process of preparing athletes for the rigors of competition is out of balance with the ability of the body to positively adapt to the loads experienced. Epidemiology data from the National Collegiate Athletic Association (NCAA) in the United States indicate lower extremity injuries account for 55-65% of all injuries experienced by both male and female collegiate athletes involved in repetitive landing activities. These injuries result in a significant loss of training and competition time and may lead to chronic problems over time. Despite improvements in footwear, injuries to the musculoskeletal system closest to the point of contact persist (e.g. foot, shank, ankle, and knee; NCAA, 1986,1990).

SURFACES: As the velocity of the body at contact increases, the need for protective surfaces also increases. To promote effective interaction between the human body and landing surface, footwear and landing surfaces need to be designed to complement the ability of the human body to control and redirect body momentum during contact. Previous research on footwear and landing surfaces indicate humans use greater degrees of joint flexion as the rigidity of the surface increases (Clarke et al., 1983; Denoth and Nigg, 1981; Farley et al., 1998; Ferris and Farley, 1997; Gollhofer, 1987; McKinley and Pedotti, 1992; McNitt-Gray et al., 1993; Nigg and Yeadon, 1987; Nigg et al., 1988). Injury incidence and reports of pain have also been found to vary with friction characteristics of landing surfaces (Nigg and Yeadon, 1987). Although rigid body tests provide repeatable results in characterizing the impact between inanimate objects, they fail to assess the internal loading implications of strategies athletes use to interact with different surfaces (Nigg, 1990; Nigg and Bobbert, 1990). Modifications in movement patterns in response to changes in surface properties may provide insight as to surface specific injury mechanisms (McNitt-Gray et al., 1994).

LANDING STRATEGIES: Reduction of peak vertical forces, either by modifying the landing surface or by modifying the landing mechanics, has been proposed as two means of reducing the risk of injury. The magnitude of peak vertical force applied to the feet can be reduced when landing on energy absorbing surfaces (McNitt-Gray, et al., 1993) provided the human-surface interaction does not result in maximum compression of the surface. The magnitude of the reaction force may be modified by the human either by adopting a prescribed technique (e.g. increase knee flexion, Devita and Skelly, 1992) or by asking subjects to use their own self selected strategy (McNitt-Gray et al., 1990; Irvine, et al., 1992; Zatsiorsky and Prilutsky, 1987). Care must be exercised, however, when imposing a modification in landing strategy in that slight changes in mechanics may inadvertently redistribute mechanical load in a disadvantageous way. Therefore, proposed modifications in landing strategy require a thorough evaluation prior to widespread implementation.



demonstrate the tendency for peak reaction force magnitudes to increase with increases in TBCM velocity at touchdown. Landings performed using strategies more or less rigid than normal are represented by filled and open triangles, respectively. These data demonstrate the ability of an individual athlete to modify the peak reaction force by modifying their landing strategy. Differences in peak reaction forces experienced by the lead and legs of volleyball players performing a Land and Go block are represented by filled squares. These data reflect the potential for asymmetrical loading between legs during a landing. The observations presented are based on data acquired by McNitt-Gray et al. In the case of the long jump, a national level decathlete performed the long jump take-off on a force plate located at the end of the runway and landed in a sand filled landing pit. In the case of gymnastics tumbling, the force plate was located at the end of a spring floor tumbling strip preceding a foam filled landing pit. Gymnastics take-offs and landings were performed on an isolated spring floor section fully supported by one force plate.

ACKNOWLEDGEMENTS: The author would like to thank the National Science Foundation, International Olympic Committee, US Olympic Committee, NCAA, US Diving, USA Gymnastics, USA Track and Field, and Intel for their support of this research. In addition, the author would like to acknowledge Philip Requejo, Witaya Mathiyakom, Kathleen Costa, and Barry Munkasy for their assistance in the data collection and analysis phases of these experiments.

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