THE EFFECT OF HEIGHT AND POST-LANDING MOVEMENT TASK ON LANDING PERFORMANCE

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INTRODUCTION

The necessity of impact force attenuation during landing, and the mechanisms through which this may take place, has held the interest of research biomechanics for many years. As early as the 17th century, Giovanni Borelli (1680) described the nature of landing as "giving way to progressively flexing the legs to absorb and exhaust the impetus of the fall". The view that the primary goal of landing is impact force attenuation or shock absorption pervades the contemporary research literature as well. A review of injury related literature presented by Dufek and Bates (1991) demonstrates the tendency of research in this area to focus on the impact phase of landing, with movements studied in the experimental setting tending to be discrete, endpoint landings. To define landing as a culminating phase to a preceeding airborne activity with a primary role of force attenuation may be inappropriate, however, if considering landing movements that are part of a general preparatory phase of an activity. Running, for example, has been described as a series of jumps and landings (Dufek, 1988). Many aerial gymnastics stunts initiated from the ground involve a short preliminary jump-land sequence prior to takeoff (Bruggemann, 1983; Miller and Nissinen, 1987). In these respective unilateral and bilateral examples, the landing phase must culminate in a body position which is compatible with the takeoff phase of the skill. For purposes of addressing aspects of performance and injury prevention, it therefore seems useful to categorize landing into two groups: Discrete landings (a phase subsequent to an airborne activity) and Preparatory landings (a phase prior to an airborne activity). Although preparatory landings have received limited scientific attention (Bobbert et al., 1987), most of the work directed toward injury prevention, as noted by Dufek and Bates (1991), has focused on discrete landings, and possible variation in the general movement patterns associated with discrete and preparatory landings has not been addressed. It was therefore the purpose of this research to provide an initial assessment of functional differences between a discrete, stable landing and a preparatory landing represented by a drop jump (or depth jump) movement.

METHODOLOGY

Seven subjects performed three discrete, stable landings (L) and three drop jumps (DJ) performed for maximum vertical jump height, from each of four initial drop heights (15, 20, 45 and 60 cm). Prior to participation in this study, each subject reviewed and signed an informed consent form consistent with the policy on human subjects at the University of Oregon. The seven subjects represented a relatively wide range of proficiency and experience with the drop jump type movement. All landings were performed with both feet contacting a single AMTI force platform, from which the vertical ground reaction force (GRF) associated with the combined contact of right and left feet with the landing surface was recorded. Right knee joint sagittal plane angular dispacement was recorded via an electrogoniometer (Penny and Giles) attached at the knee joint. The amplified and conditioned analog signals were sampled at 500 Hz using an Aerial Perfomance Analysis System. Landing and drop jump trials were performed alternately at each height, with height conditions presented in order from least demanding (15 cm) to most demanding (60 cm). Subjects were allowed to land in any manner they deemed appropriate from the given heights for the L conditions, and to jump for maximum height for the DJ conditions. All landings and drop jumps were initiated from a raised platform of specified height, with a horizontal distance of 25cm to the edge of the force platform.

Vertical GRF variables used to evaluate landing included maximum impact force (Fmax) normalized to body mass and the landing impulse time (Timp-land) necessary to account for the downward momentum of the body. To derive Timp-land, the total body vertical momentum at contact was estimated using contact velocity (calculated from initial drop height) and subject mass. Integration of the GRF curve was performed to establish the time relative to contact at which cumulative vertical impulse sufficient to reduce landing momentum to zero was achieved. Timp-land was therefore indicative of the time period over which the landing phase could be considered complete. In addition, maximum flexion angle at the knee (Kmax) was used as a measure of the depth of the landing. Full extension of the leg at the knee was considered 0° of flexion, with flexion angle measured positively.

RESULTS AND DISCUSSION

Individual subject Pearson product correlations were performed relating initial drop height to each of the three independent variables describing landing (Fmax, Kmax and Timp-land) for the L and DJ conditions, respectively. In light of previous research indicating strategy variation among subjects (Bates and Caster, 1989) in performance of a landing task, it was deemed appropriate to conduct analyses in this initial evaluation on an individual subject basis. Normality of distribution and independence of trials was assumed for the individual subject data based upon statistical validation of these assumptions for kinetic and kinematic variables from previously collected landing data sets containing a minimum of 25 trials per subject and condition.

Individual subject condition means and standard deviations for Fmax are given in Tables 1 and 2 for the landing and drop jump conditions, respectively. Correlations beween intial drop height and Fmax were strong and positive for six of the seven subjects for both L and DJ conditions, with mean significant correlation coefficients of 0.89 and 0.87 for landing and drop jump conditions, respectively.

Non-significant correlations were observed for S2 for the L and S3 for the DJ condition. Similar results were found with respect to the Timp-land variable, with six of seven subjects exhibiting strong positive correlations for both L and DJ conditions (mean significant correlation coefficient: 0.91 and 0.87 for L and DJ, respectively). These results indicate an impact force (Fmax) increase and concomitant increase in time over which greater landing momenta were accounted for, observable for landing with and without the performance of a subsequent jump. An examination of condition means, however, reveals a tendancy toward lower Fmax values observable for the DJ conditions. Although impact forces increased with height for both landing categories, the addition of the post-landing movement task may have an effect on the absolute magnitude of impact force at any given height.

Table 1. Maximum vertical GRF for landing conditions.

		Height (cm)				
		15	30	45	60	All
S2	M	31.3	26.7	30.5	43.0	32.9
	SD	5.4	13.4	1.0	5.8	7.8
S3	M	60.2	72.9	78.7	88.4	75.1
	SD	5.7	6.3	7.7	10.2	7.6
S4	M	53.0	62.8	65.7	67.5	62.3
	SD	4.2	4.0	3.1	0.1	3.3
S5	M	25.6	43.6	50.0	60.8	45.0
	SD	4.3	3.6	6.2	4.5	4.7
S6	M	24.9	37.8	51.4	57.0	42.7
	SD	5.0	5.5	4.5	2.0	4.5
S7	M	30.0	42.2	44.3	69.7	46.6
	SD	2.2	2.0	3.7	5.7	3.7
S8	M	42.4	62.7	65.6	68.0	59.7
	SD	2.2	4.8	4.2	0.1	3.4
Mean		38.2	49.8	55.2	64.9	52.0
	SD	4.3	6.6	4.8	5.3	5.3

GRF values are given in N/kg of body mass.

Table 2. Maximum vertical GRF for drop jump conditions.

		Height (cm)				
		15	30	45	60	All
S2	M	18.9	24.7	30.0	34.2	26.9
	SD	1.1	5.4	3.9	2.2	3.5
S3	M	57.6	59.5	59.8	70.4	61.8
	SD	8.9	6.7	12.3	14.1	10.9
S4	M	34.4	43.6	54.4	66.7	49.8
	SD	2.8	3.0	8.6	0.9	4.8
S5	M	31.5	32.0	45.0	45.8	38.6
	SD	10.4	1.1	4.3	4.8	6.2
S6	M	32.9	33.4	36.6	48.3	37.8
	SD	2.3	2.5	5.0	8.5	5.2
S7	M	22.3	34.3	42.5	53.2	38.1
	SD	4.2	1.7	8.7	6.3	5.8
S8	M	18.3	33.6	43.0	64.2	39.8
	SD	0.3	4.7	1.5	4.0	3.2
Mean		30.8	37.3	44.5	54.7	41.8
	SD	5.6	4.1	7.2	7.1	6.1

Table 3. Maximum knee flexion for landing conditions.

		Height (cm)				
		15	30	45	60	All
S2	M	59.7	89.7	97.4	110.2	89.3
	SD	4.8	15.5	5.9	7.9	9.5
S3	M	58.9	64.4	70.6	76.0	67.5
	SD	4.7	1.1	2.3	3.9	3.3
S4	M	42.7	50.8	53.6	56.3	50.9
	SD	1.2	3.7	3.4	3.5	3.1
S5	M	97.6	99.1	93.2	89.6	94.5
	SD	6.4	3.2	19.0	6.3	10.6
S6	M	60.7	59.9	66.3	69.9	64.2
	SD	1.1	2.5	1.6	4.9	2.9
S7	M	72.1	76.6	77.5	76.5	75.7
	SD	3.9	2.0	3.6	2.5	3.1
S8	M	40.6	52.1	53.7	80.9	56.8
	SD	5.2	3.4	3.2	5.2	4.4
Mean		61.8	70.4	73.2	79.9	71.3
SD		4.3	6.4	7.9	5.2	6.1

Knee angles (°).

Table 4. Maximum knee flexion for drop jump conditions.

		Height (cm)				
		15	30	45	60	All
S2	M	113.5	106.2	109.8	115.5	111.3
	SD	0.2	3.6	2.3	4.5	3.1
S3	M	59.1	63.1	67.1	74.7	66.0
	SD	1.8	3.6	5.9	1.2	3.6
S4	M	65.7	73.3	70.9	71.3	70.3
	SD	3.6	1.9	2.2	4.7	3.3
S5	M	92.8	97.2	83.0	85.5	89.6
	SD	6.5	2.5	7.7	3.7	5.5
S6	M	59.7	64.3	62.6	65.6	63.1
	SD	3.5	2.0	3.0	3.4	3.0
S7	M	75.4	74.3	76.2	77.7	75.9
	SD	3.9	1.6	1.2	3.4	2.8
S8	M	79.4	88.3	90.8	79.4	84.5
	SD	6.5	0.7	6.0	10.9	7.0
Mean		77.9	81.0	80.1	81.4	80.1
	SD	4.3	2.5	4.6	5.3	4.3

The knee joint has been implicated as a major contributor to shock absorption for discrete landing movements (Schot and Dufek, 1993). Furthermore, a comparison of landing technique involving changes in knee joint stiffness conducted by DeVita and Skelly (1992) identified greater impact forces and a shorter eccentric phase for stiff landing conditions (knee flexion less than 90°). It was therefore hypothesized that greater demands placed upon the landing with increased contact velocity (or drops from greater heights) would result in an increase in the amount of knee flexion. Individual subject condition means and standard deviations for the Kmax variable are given in Tables 3 and 4 for the L and DJ conditions, respectively. For the L conditions, a positive relationship was observed between drop height and Kmax for five of the seven subjects (mean significant correlation coefficient: 0.87), with non-significant correlations observed for S5 and S7. These results suggest that increased knee flexion may be a common component of a strategy to absorb landing momentum over longer periods of time as height increases for discrete landings. The fact that Fmax also increased with height, however, indicates that the increases in Kmax did not fully account for impact velocity changes and expected increases in impact force.

For the DJ conditions, only one of seven subjects (S2) exhibited a significant correlation between drop height and Kmax. This is suggestive of a change in kinematic strategy with respect to the knee joint with the addition of the post-landing movement task. There was a tendency, though not for all subjects, toward greater flexion at the knee when performing the DJ conditions.

CONCLUSIONS

Maximum impact force was found to increase with height for both discrete and preparatory landings, though a tendancy toward modulation of this force was apparent for all subjects with respect to the preparatory landings, suggesting an influence of the postlanding vertical jump on landing kinetics. Furthermore, maximum flexion at the knee joint, which varied with drop height for the discrete landing, showed little relationship with height for the preparatory landings. A possible explanation for these results would be a dominant influence that the movement goal of maximum jump height has in specifying kinematic relationships necessary for efficient performance of the vertical jump. This may not, however, have an adverse effect on injury risk at landing, assuming maximum impact force is indicative of such injury risk. It is apparent that the success criteria of the overall movement may play an important role in defining the nature of the landing.

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