A Subsequent Movement Alters Lower Extremity Muscle Activity and Kinetics in Drop Jumps vs. Drop Landings

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Ambegaonkar JP, Shultz SJ, Perrin DH. A subsequent movement alters lower extremity muscle activity and kinetics in drop jumps vs. drop landings. *Journal of Strength and Conditioning Research.* 2011; 25(10): 2781-2788.

Abstract:

Drop landings and drop jumps are common training exercises and injury research model tasks. Drop landings have a single landing, whereas drop jumps include a subsequent jump after initial landing. With the expected ground impact, instant and landing surface suggested to modulate landing neuromechanics, muscle activity, and kinetics should be the same in both tasks when landing from the same height onto the same surface. Although previous researchers have noted some differences between these tasks across separate studies, little research has compared these tasks in the same study. Thus, we examined whether a subsequent movement after initial landing alters muscle activity and kinetics between drop landings and jumps. Fifteen women performed 10 drop landings and drop jumps each from 45 cm. Muscle onsets and integrated muscle activation amplitudes 150 milliseconds before (preactivity) and after landing (postactivity) in the medial and lateral quadriceps, hamstrings, and lateral gastrocnemius and peak and time-to-peak vertical ground reaction forces were examined across tasks ($p <= 0.05$). When performing drop jumps, subjects demonstrated later ($p = 0.02$) gastrocnemius and lesser lateral gastrocnemius ($p = 0.002$) and medial quadriceps ($p = 0.02$) preactivity followed by increased postactivity in all muscles ($p = 0.006$), with higher peak vertical ground reaction forces ($p = 0.04$) but no differences in times to these peaks ($p = 0.60$) than drop landings. The later gastrocnemius activation, higher gastrocnemius and quadriceps postlanding amplitudes, and higher ground reaction forces in drop jumps may allow subjects to propel the body vertically after the initial landing vs. simply absorbing impact in drop landings. Our results indicate that in addition to landing surface and height, anticipation of a subsequent task changes landing neuromechanics. Generalizations of results from landing-only studies should not be made with landing followed-by-subsequent-activity studies. Landing exercises should be incorporated based on sport-specific demands.

Keywords: onset | amplitudes | preactivity | ground reaction force

Article:

INTRODUCTION

Landing is common in human movement (16,29,30) and plays an essential role in successful sport performance (8,22). Controlling body segments during landing offers significant challenges to the individual to absorb and distribute impact loads (i.e., ground reaction forces) produced on ground contact (8,22). In sports, athletes often perform isolated landing actions with no subsequent motion (e.g., gymnasts performing a dismount), landings followed by a subsequent action (e.g., rebounding in basketball) or both. Drop jumps and drop landings are also common components of sport and exercise training programs. Accordingly, drop landings and drop jumps have both been used as landing tasks to study injury risk factors and performance-related issues (2,5,10-13,17,18,23,25,34).

Lower extremity muscle activation is needed to successfully perform landing tasks (9,14,35). Previous researchers suggest that muscle onsets and prelanding (before ground contact) muscle activity amplitudes depend on the expected time of ground impact based on the drop height and landing surface characteristics (3,28). Postlanding (after ground contact) muscle activity amplitudes depend on a combination of preprogrammed central control (based on previous experiences) overlapping with reflex mechanisms that are influenced but not controlled by stretch reflex mechanisms. (9,20,28). Therefore, if individuals land (a) from the same height, (b) onto the same surface, (c) with sufficient practice and experience, they should have similar muscle onsets, prelanding and postlanding amplitudes, and ground reaction forces. However, some prior work examining drop landings and drop jumps in different studies have found differences in landing biomechanics across the tasks. For example, when Shultz et al. (34) compared the energy absorption in their drop jump task with prior research on energy absorption in drop landing tasks (6,38), they found that drop jumps required greater contributions in energy absorption at the hip and ankle, with lesser contributions from the knee as compared to drop landings. Leukel et al. (18) also noted postlanding muscle activity differences between drop landings and drop jumps.

Given these conflicting observations in previous research, it is surprising that little research has actually examined landing lower extremity muscle activity and kinetics between drop landings and drop jumps in the same study. Specifically, whether the anticipation of a subsequent movement (the second jump) in a drop jump influences muscle onsets and prelanding and postlanding muscle activity and kinetics during the initial landing as compared to the single landing in a drop landing was still unclear.

Therefore, our purpose was to compare lower extremity muscle activity and kinetics between the initial landings of drop landings and drop jumps.

METHODS

Experimental Approach to the Problem

All testing was performed in a single session using a controlled laboratory research design. Subjects were asked to complete each of 2 landing tasks to examine differences in muscle timing and pre and postlanding activation amplitudes and differences in peak and time to peak ground reaction forces between the 2 tasks.

Subjects

Fifteen healthy women (21.2 ± 4.1 years, 167.4 ± 8.6 cm, 67.4 ± 13.5 kg) participated in the study. Approval was obtained from the university's Institutional Review Board for the protection of human subjects for all study procedures. Appropriate informed consent was obtained from all subjects. Subjects had no history of recent surgery, injury, or chronic pain in the lower extremities for 6 months before data collection and had no pre-existing conditions that affected their ability to land or jump. This study was part of a larger project examining neuromuscular responses and kinetic differences in female athletes, and thus, all subjects in the current study were women. All subjects had extensive jumping and landing experience, because they were a combination of university-level basketball players and dancers. All subjects were physically active at least 3 $d \cdot wk^{-1}$ for the 3 months before the study.

The preferred leg was determined by asking subjects to perform 3 single-leg landings from a 45-cm box. The height of the landings (45 cm) is consistent with jump heights used in previous literature (19,21,26,27,34) All measurements were taken on the subjects' preferred landing extremity, defined as the leg preferred by subjects to perform single-leg landings from the 45-cm box.

Task Familiarization

The same investigator demonstrated the 2 landing tasks for the subjects. For the drop landing, subjects were asked to stand on the 45-cm box, extend their nonpreferred leg and then drop off the box, performing a double-leg landing with 1 foot on each forceplate (Figure 1). Throughout the landing trial, they were asked to look forward and keep their hands on their hips at all times. Subjects were also asked to maintain their balance upon landing and not to move off the forceplates until told to do so by the investigator. For the drop jumps, subjects were instructed to land onto the forceplates with a similar technique as described above and as soon as they made ground contact immediately perform a vertical jump for maximal height and land back again onto the forceplate, remaining in that position until told to step off by the investigator. Sufficient practice was allowed for subjects to become comfortable with each task.

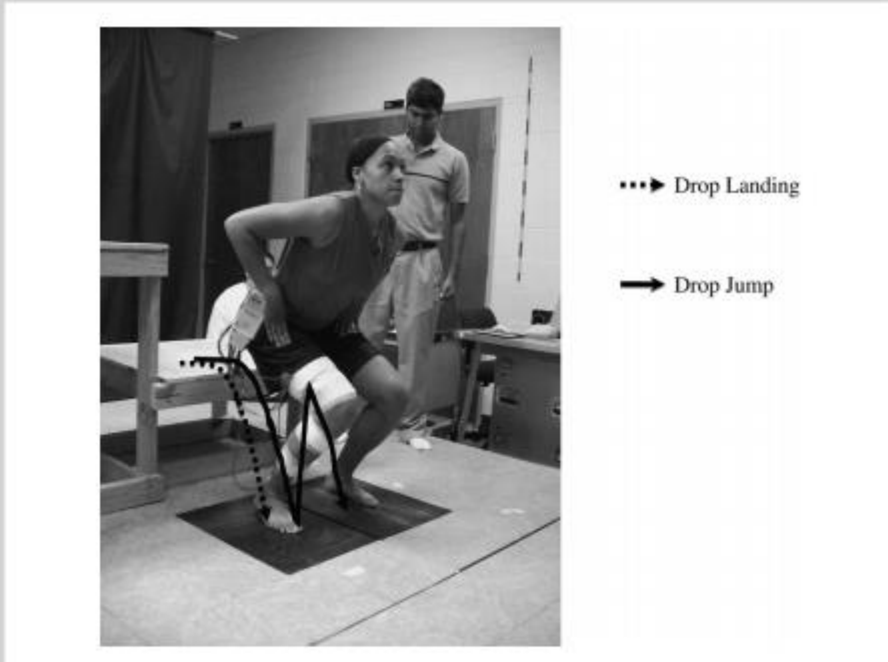

Figure 1. Performance of the drop landing and drop jump tasks.

Data Collection

Surface electromyography (sEMG) recorded muscle activity using a 16-Channel Myopac System (Run Technologies, Mission Viejo, CA, USA). The sEMG unit specifications are described elsewhere (1,2). Bipolar, Ag/AgCl surface electrodes (Blue Sensor N-00-S; Ambu Products, Ølstykke, Denmark; skin contact size 30 × 22 mm) with a center-to-center distance of 20 mm were placed perpendicular to the muscle fibers over the midbelly of the medial and lateral quadriceps, medial and lateral hamstrings, and lateral gastrocnemius muscles of the preferred leg after shaving and wiping the area with alcohol to reduce skin impedance as described elsewhere (1,2,33). The reference electrode was attached over the flat anteromedial bony aspect of the ipsilateral tibia, midway between the tibial tuberosity and the intermalleolar point (1,2). Absence of crosstalk between electrodes was confirmed with manual muscle testing using the scope mode of the data acquisition software before actual data collection. To prevent any pulling or twisting of the wires during activity that potentially could affect the sEMG signal, the electrodes and wires were secured to the skin using stress loops with prewrap and regular white athletic tape (1,2,33).

Subjects then performed maximal contractions of each muscle to record the Maximal Voluntary Isometric Contraction (MVIC) for normalization purposes while seated in a Biodex dynamometer (Biodex Medical Systems Inc.; Shirley, NY, USA). The lower extremity was secured with the hip at 90° flexion, and the knee at 30° flexion for all trials, with the resistance pad placed at the midshaft of the tibia. Subjects kept their arms crossed over their chest holding the shoulder pads at all times. Three trials were conducted for each of the 3 muscle groups. The quadricep muscles were tested by asking subjects to kick out with their leg as hard as possible for a period of 5 seconds, trying to extend their knee that was secured at 30° of knee flexion. For the hamstring muscles, the subjects were asked to bend their knee as hard as possible for a period of 5 seconds, trying to flex their knee while it was secured at 30° of knee flexion. For the gastrocnemius muscle, the subjects were asked to plantar flex their foot as hard as possible for 5 seconds into the hands of an assistant, who offered isometric manual resistance in the direction of dorsiflexion. A 60-second rest interval was given between each trial (1).

Subjects then performed 10 each of double-leg drop landings and drop jumps from the 45-cm box in the manner described above. All testing was done during the daytime in the spring semester. We did not specifically control for hydration or food for several reasons as follows: The activity tested was a primarily short-term activity, that is, each landing lasted 2–3 seconds, and 60-second intervals were allowed between tasks. Further, given the repeated-measures within-subject research design (single session) used in the study, if food and hydration were to affect an individual subject, they would have affected the subject equally for both tasks. We also counterbalanced the task to mitigate any systematic prior training effect. All subjects were allowed to practice both tasks to familiarize themselves with the tasks before actual data collection.

Previous test–retest reliability from our laboratory for 10 randomly selected subjects tested on separate days where the exact same procedures were repeated indicated that intraclass coefficient ($ICC_{2,k}$) values were good (0.71–0.86) for the muscle activation amplitudes and biomechanical measures but somewhat lower (0.61–0.76) for the muscle onsets. Still they were accepted because similar reliability values (ICC = 0.63–0.81) have been previously reported for onset times during isometric knee extension, a much more restricted activity (37). No other feedback was provided to subjects in between trials. A 60-second rest interval was provided between the 2 tasks. Subjects were asked to repeat the trial if they lost their balance or if their hands came off their hips at any point during any trial.

Force data were collected at 1,000 Hz using a type 4060 nonconducting forceplate (Bertec Corporation; Columbus, OH, USA). The sEMG signals were synchronized with the forceplate, and a foot contact threshold of 10 N (initial ground contact) was used to trigger simultaneous recording of sEMG and forceplate data for 500 milliseconds before ground contact and 150 milliseconds after ground contact. All data were acquired, stored, and analyzed using Datapac 2K2 Lab Application Software (Run Technologies; Mission Viejo, CA, USA).

Data Processing

For the MVIC trials, the sEMG signals were first digitally processed using a centered root mean square algorithm with a 100-millisecond time constant. The first and last seconds of each trial were discarded before analysis to assure steady state results. The maximum peak integrated signal acquired over 150 milliseconds from the 3 MVIC trials for each muscle was used to normalize the sEMG data. For the landing trials, the sEMG signals during the tasks were digitally processed and full-wave rectified with a band pass filter from 10 to 350 Hz, using a fourth-order, zero-lag Butterworth filter, and then digitally processed using a centered root mean square algorithm with a 25-millisecond time constant (1,2). The 10 trials for each task were then ensemble averaged to obtain 1 representative trial for each subject and task.

A mean ± *SD* threshold buffer extracted the muscle activity onset times in milliseconds. Muscle activity onset time was defined as the time point before ground contact when the muscle activity first exceeded 2*SD*s above the baseline activity of the muscle for at least 25 milliseconds or longer (1,2,7,32). Baseline activity was collected in quiet stance for a period of 500 milliseconds before the commencement of the trial. A time interval buffer was set to extract the integrated amplitudes in volts per millisecond, collected over 150 milliseconds prelanding (preactivity) and 150 milliseconds post–ground contact (postactivity) of the drop landings and the first landing of the drop jumps. All amplitude data were then normalized to the peak integrated amplitude of the MVIC and reported as percentage of the MVIC (%MVIC). Peak ground reaction force was defined as the highest vertical peak force (in N) upon landing in the drop landing and the highest peak force in the initial landing phase of the drop jump. All ground reaction force data were then normalized to each individual's mass (N) and are reported in multiples of Body Weight. The time to reach peak vertical ground reaction force after ground contact (milliseconds) was also recorded.

Statistical Analyses

A 2 × 5 (task × muscle) repeated-measures analysis of variance (ANOVA) examined mean differences in muscle activity onset times between drop landings and drop jumps. A 2 × 2 × 5 (task × landing phase: prelanding and postlanding × muscle) repeated-measures ANOVA examined mean differences in the pre (before ground contact) and post (after ground contact) landing activation amplitudes of each muscle between the 2 tasks. To further explore significant interactions, simple main effect testing with Bonferroni corrections were used when needed. Separate paired samples t-tests examined differences in peak vertical ground reaction force and time to peak vertical ground reaction force between drop landings and drop jumps. All analyses were conducted using the SPSS 15.0 version for Windows software (Statistical package for Social Sciences, Chicago, IL, USA), with an alpha level of 0.05 for all tests.

RESULTS

A representative trial graphically depicting the dependent variables is presented in Figure 2.

Muscle Onsets

Muscle onsets differed by muscle and task ($p = 0.006$; Table 1, Figure 3). To understand this interaction, simple main effect tests were conducted which revealed that overall muscle activity onsets were earlier in drop landings than in drop jumps ($p = 0.004$) because of the lateral gastrocnemius muscle activating earlier ($p = 0.02$) (Table 1).

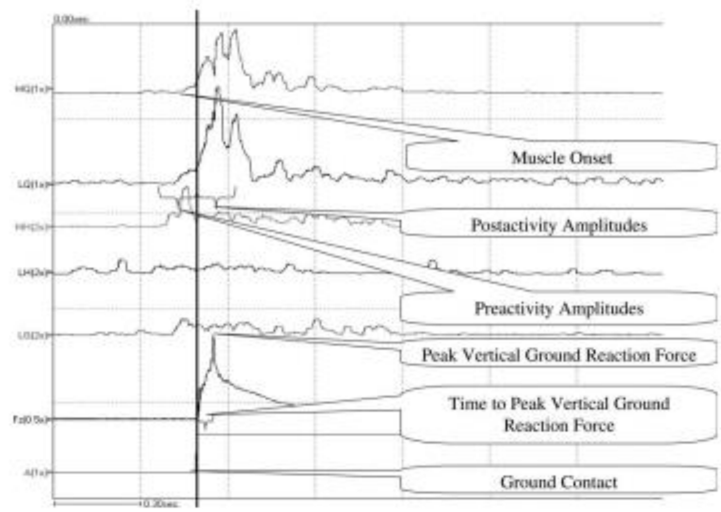

Figure 2. Representative trial showing variables of interest. MQ = medial quadriceps muscle, LQ = lateral quadricep muscle, MH = medial hamstrings muscle, LH = lateral hamstrings muscle, LG = lateral gastrocnemius muscle, F_z = vertical ground reaction force, A = event marker for ground contact.

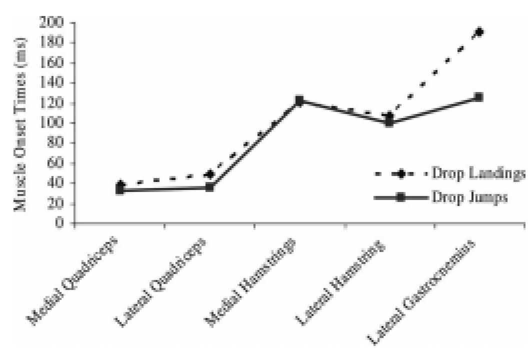

Figure 3. Muscle activity onsets (milliseconds) between drop landings and drop jumps.

Table 1. Muscle onset times (milliseconds; mean ± *SD*) before ground contact during double-leg drop landings and drop jumps.

Muscle	Drop landings	Drop jumps	Average
Medial quadriceps	38.3 ± 20.0	32.9 ± 13.7	35.6 ± 16.8
Lateral quadriceps	48.7 ± 50.1	35.2 ± 20.8	42.0 ± 35.4
Medial hamstrings	120.5 ± 46.9	122.3 ± 47.0	121.4 ± 46.9*
Lateral hamstrings	106.7 ± 46.6	99.9 ± 57.1	103.3 ± 51.8*
Lateral gastrocnemius	190.3 ± 116.7†	125.1 ± 35.5	157.7 ± 76.1*
Totals	100.9 ± 56.0†	83.1 ± 34.8	92.0 ± 45.4

*Earlier than medial and lateral quadriceps.
†Earlier than drop jumps.

Muscle Amplitudes

Muscle activation differed by task, ground contact, and muscle (*p* = 0.047; 3-way interaction; Table 2). To interpret the 3-way interaction, 2 separate 2-way ANOVAs analyzing pre and postlanding phases separately followed by simple main effect testing with Bonferroni adjustments for multiple comparisons and pairwise comparisons.

Prelanding muscle amplitudes differed by task and muscle (*p* = 0.05). Pairwise comparisons of this interaction indicated that in drop jumps, subjects had lesser medial quadriceps (p = 0.02) and lateral gastrocnemius (*p* = 0.002) prelanding muscle activity than drop landings (Figure 4). In contrast, postlanding muscle activity was greater in the drop jumps (*p* = 0.006), with drop jumps resulting in higher lateral quadriceps (*p* = 0.001) and lateral gastrocnemius (*p* = 0.04) postlanding muscle activity than drop landings.

TABLE 2. Prelanding (preactivity) and postlanding (postactivity) integrated muscle amplitudes (%MVIC; mean ± *SD*) for the drop landings and drop jumps.*

	Drop landings			Drop jumps		
	Prelanding	Postlanding	Average	Prelanding	Postlanding	Average
Medial quadriceps	38.3 ± 44.4†	276.9 ± 271.1	157.6± 157.8	32.6 ± 36.6	283.4 ± 205.3	158.0 ± 121.0
Lateral quadriceps	27.0 ± 19.4	168.5 ± 101.9	97.8 ± 60.1	27.8 ± 21.3	228.6 ± 145.6	128.2 ± 83.4
Medial hamstrings	40.5 ± 26.8	58.9 ± 91.0	49.7 ± 58.9	40.3 ± 23.9	60.9 ± 87.2	50.6 ± 55.5
Lateral hamstrings	22.8 ± 21.0	50.0 ± 46.9	35.9 ± 34.0	24.0 ± 19.4	55.7 ± 54.2	39.8 ± 36.8
Lateral gastrocnemius	59.2 ± 41.2‡	58.2 ± 26.7	58.7 ± 33.4	53.6 ± 38.7	65.1 ± 27.1	59.3 ± 32.9
Total	37.4 ± 30.6	122.5 ± 107.1	79.9 ± 68.8	35.7 ± 28.0	138.7 ± 103.9	87.2 ± 65.9
Average preactivity amplitudes = 36.5 ± 29.3			Average postactivity amplitudes = 130.6 ± 105.5§			

*MVIC = maximal voluntary isometric contraction.
†Greater than preactivity medial quadriceps amplitudes in drop jumps.
‡Greater than preactivity lateral gastrocnemius amplitudes in drop jumps.
§Greater than average preactivity amplitudes.

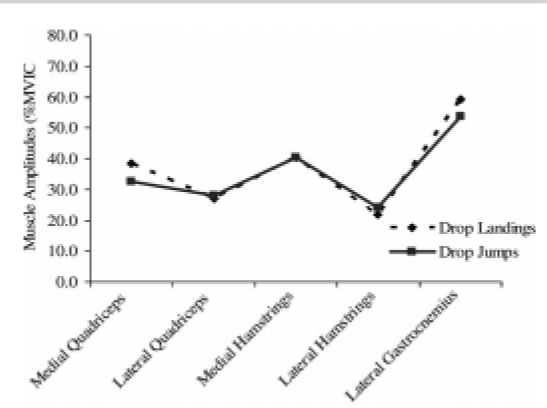

Figure 4. Prelanding muscle amplitudes (% maximum voluntary isometric contractions [MVIC]) between drop landings and drop jumps.

Kinetics

Peak vertical ground reaction forces were 1.3 times higher when performing the initial landing of drop jumps as compared to drop landings ($p = 0.04$; Figure 5). However, no difference existed in the time to reach peak forces across the tasks ($t_{14} = 0.52$, $p = 0.60$; Figure 6).

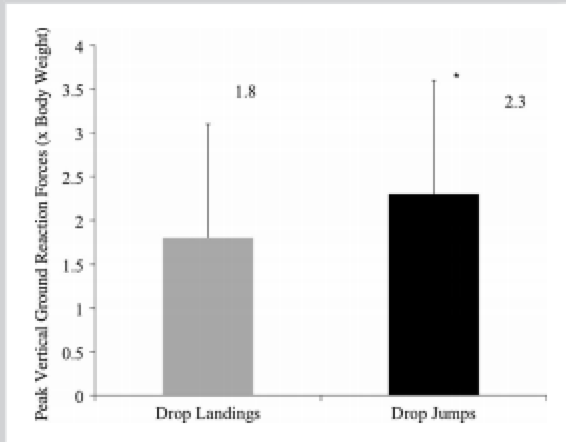

Figure 5. Peak vertical ground reaction forces between drop landings and drop jumps (× body weight). *Greater than drop landings.

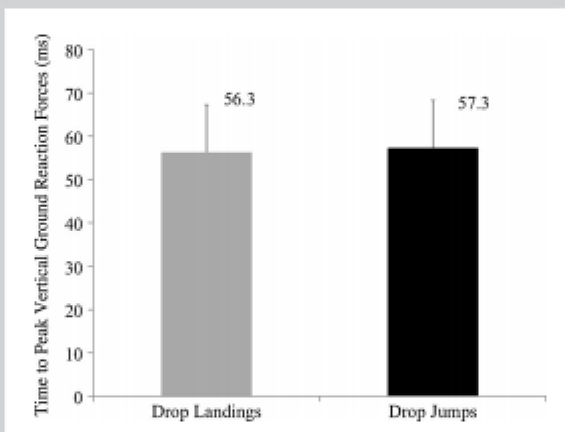

Figure 6. Times to peak vertical ground reaction forces between drop landings and drop jumps (milliseconds).

DISCUSSION

Our primary findings were that subjects had differing lower extremity muscle activation and kinetic patterns during landing when they were required to perform a subsequent movement after the initial landing (i.e., drop jumps) when compared to a single landing motion (i.e., drop landings). Specifically, when performing drop jumps, subjects demonstrated later and lesser gastrocnemius and medial quadriceps preactivity followed by increased postactivity in all muscles. We also observed higher peak vertical ground reaction forces in drop jumps but no differences in times to these peaks between tasks. These findings existed despite subjects landing from the same height, onto the same surface, and becoming familiar with both tasks.

Although both drop landings and drop jumps require individuals to land from a height, the final task outcomes differ (34). In drop landings, the goal is to decelerate body momentum, absorb impact forces, stabilize the body, and prevent harmful and excessive joint rotations (10,18). In drop jumps, there is an additional goal of performing a subsequent vertical jump after this initial landing. (3,18,35) Thus, when getting ready for a subsequent task upon landing in drop jumps, the timing and magnitude of the antigravity muscle activation appears to be modulated to be closer to the time of ground contact. This strategy may allow subjects to reduce the amortization coupling time and maximize the subsequent propulsive phase by efficiently using the stretch-shortening cycle in the drop jumps. (3,24) In contrast, the stretch-shortening mechanism is not as important in drop landings, where shock absorption in the single terminal landing is the final task outcome.

Because of the additional jump in drop jumps, they are more demanding than drop landings. The drop landings did not have this further movement. Muscle activity requirements should have thus been higher in the drop jumps. In support, we noted that postlanding all muscles activated at higher levels in the drop jumps than in the drop landings.

It was also interesting to note that although differences existed between tasks in the antigravity muscles (gastrocnemius and quadriceps), hamstring muscle onsets or amplitudes did not differ. This finding is understandable when considering the role of the hamstrings. The hamstrings are knee flexors and are important during the initial landing (required in both tasks) to allow safe shock absorption (15,31). In drop landings, after this shock absorption function is completed, the hamstrings do not have a further significant role. Similarly in the drop jumps, the subsequent jump requires knee extension for which the hamstrings (knee flexors) do not have a further significant role. Thus, despite the differing overall functional end results of the 2 tasks, the role of the hamstrings was the same in both tasks, resulting in no differences observed in the hamstring muscles across both tasks.

Subjects had higher peak vertical ground reaction forces in drop jumps than in drop landings. However, no differences existed in the times required post–ground contact to reach these peaks. Thus, the loading rate in drop jumps was greater than in drop landing. Prior research suggests that higher ground reaction forces are related to greater resistance to joint rotations through higher levels of muscle activation (26,30). This suggestion is consistent with our findings of higher total muscular activation postlanding in drop jumps. Overall, all these mechanisms would lead to a stiffer knee joint during the initial landing to efficiently use the stretch-shortening cycle in drop jumps (4,36).

We acknowledge that our results are limited to observations in healthy female subjects. Further comparisons are needed across men, different athletic sports, physically active, and pathologic populations to allow for generalization of our findings. Given that the body can modulate impact force absorption during landings by adjusting both muscle activation levels and length–tension relationships (22,34), joint kinematics should also be examined in future work. Also, because we did not examine muscle activity of all hip and ankle muscles and complete 3D biomechanics of the lower extremity during the tasks, limited assumptions can be made about hip and ankle muscle activity and kinetics from the current results. Concurrently examining lower body kinematics and kinetics with muscle activity will allow for comprehensive analyses of task dependent landing strategies.

Overall, landing neuromuscular and kinetic activity during an isolated landing event (i.e., drop landing) differs from a landing when a subsequent movement after the initial landing is required after the initial landing (e.g., drop jump). Our findings add to previous literature by noting that in addition to expected time of impact and the landing surface, whether a subsequent activity follows a landing or not also influences prelanding and postlanding muscle activity and kinetics. Thus, interpretations from landing-only research models may not be valid if they are directly extrapolated to interpretations made from landing-followed-by-activity research models (e.g., drop jumps).

Practical Applications

Researchers, coaches, and athletic trainers should (a) recognize that having to perform a subsequent movement after landing alters lower extremity muscle activity and kinetics during landing, (b) not generalize results from studies where landing is the final outcome with studies where landing is followed by some activity, and (c) incorporate landing exercises based on sport-specific demands, for example, emphasize drop landings in gymnasts for dismounts, but emphasize drop jumps in basketball players to improve rebound height in basketball players.

ACKNOWLEDGMENTS

This study was supported in part by the Susan Stout Research Grant at the University of North Carolina at Greensboro, USA.

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