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Biomechanics of Skateboarding: Kinetics of the Ollie

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Seven top amateur or professional skateboarders (BW = 713 N ± 83 N) performed Ollie maneuvers onto and off an elevated wooden platform (45.7 cm high). We recorded ground reaction force (GRF) data for three Ollie Up (OU) and Ollie Down (OD) trials per participant. The vertical GRF (VGRF) during the OU has a characteristic propulsive peak (M = 2.22 body weight [BW] ± 0.22) resulting from rapidly rotating the tail of the board into the ground to propel the skater and board up and forward. The anterior-posterior (A-P) GRF also shows a pronounced peak (M = 0.05 ± 0.01 BW) corresponding with this propulsive VGRF peak. The initial phase of landing in the OD shows an impact peak in VGRF rising during the first 30 to 80 ms to a mean of 4.74 ± 0.46 BW. These impact peaks are higher than expected given the relatively short drop of 45.7 cm and crouched body position. But we observed that our participants intentionally affected a firm landing to stabilize the landing position; and the Ollie off the platform raised the center of mass, also contributing to higher forces.

Key Words**:** impact, force, jump, sport

Skateboarding had over 11 million participants in the U.S. in 2003 (Anonymous, 2004a), putting the sport on a par with tennis, volleyball, and soccer in terms of participant levels (Anonymous, 2004b). Since 1993 the number of participants has more than doubled (Anonymous, 2004a). Given these large numbers of participants, many are also often injured. Published epidemiological studies characterize skateboarding as a generally safe activity but with a significant and increasing incidence of musculoskeletal injuries to the extremities (Kyle, Nance, Rutherford, & Winston, 2002; Osberg, Schneps, Di Scala, & Li, 1998).

Despite this high frequency of injury and the sport's large and growing number of participants, skateboarding is poorly represented in the scientific and clinical literature. Until the recent publication of two abstracts (Determan, Frederick, & Cox, 2004; Frederick, Determan, Whittlesley, & Hamill, 2003), early work by Hubbard (1979, 1980; Hubbard & Glass, 1979) describing the mechanics of stability and board control were the only peer-reviewed scientific accounts of skateboarding biomechanics. Clinicians and epidemiologists have done somewhat better.

A small number of papers by clinicians over more than 35 years have discussed the frequency and type of skateboarding injuries often in comparison to other sports (Jacobs & Keller, 1977; Kyle et al., 2002; Osberg et al., 1998; Shuman, 1967). Although these papers describe a wide array of musculoskeletal injuries with a disproportionately high incidence of ankle injuries, the clinical literature has been silent on the biomechanical factors that might be causing or exacerbating these musculoskeletal injuries. To rectify this paucity of published scientific research on skateboarding, we have begun a series of studies aimed at describing the biomechanical characteristics of the sport. These descriptive studies provide a necessary foundation for future research on the mechanisms of injury and their prevention.

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In this first study, we describe the biomechanics of the "Ollie" maneuver and landing from a jump performed by top-level skateboarders. Because many of the reported injuries in skateboarding occur during the landing phase, we think it is important to understand the dynamic load experienced by skateboarders during these core movements.

An Ollie is a common maneuver used by skateboarders to hop onto, off of, and over things. The maneuver is complex and precisely coordinated, but essentially is a jumping movement intended to bring both skater and skateboard together into a new position, vertically and horizontally. Because the skateboard is not tethered to the skater in any way, a precise sequence of movements is needed to keep the skater and board together.

To perform the Ollie, the skater rapidly rotates the board about the rear axle, causing the tip to pitch upward (see Figure 1a). This bounces the tail of the board off the ground, causing the board to rise. At the same time the skater jumps up and usually forward while using the lateral forefoot of the leading foot to control and direct the trajectory and spatial orientation of the board. The board and skater follow similar trajectories, and in the end the skater lands on top of the board. A more detailed description with illustrations can be found in Bermudez (2001). Skaters who are practiced in the subtleties of the Ollie can hop over obstacles of a meter or more, but we have chosen to study more modest challenges.

Our results provide a descriptive record of the kinetics of the Ollie maneuver as well as patterns of movement used in landing from a jump. These data on landing strategies show higher than expected impact forces on landing, suggesting the need for further investigations of the cushioning and pressure distribution characteristics of footwear for skateboarding, especially in the forefoot region.

Methods

Seven male top-amateur or professional skateboarders (mean body mass = 72.7 kg, *SD* = 8.51 kg; mean body weight = 713 N, *SD* = 83.0 N) visited the University of Massachusetts Biomechanics Laboratory to take part in this study. They ranged in age from 17 to 29 years (median age = 25 years). Approval for their participation in this investigation was obtained from the University of Massachusetts Institutional Review Board, and we obtained informed consent from each participant.

All skaters performed two movements: Ollie Up (OU), and Ollie Down (OD). The OU movement required the participant to roll, with both feet on the skateboard, onto the force plate, and then to Ollie up onto a long flat plywood platform 45.7 cm (18 in.) above floor level. The edge of the platform was located approximately 80 cm beyond the end of the force plate. This spacing between the trailing edge of the force plate and the leading edge of the wooden platform was adjusted slightly to accommodate individual skaters' movements and to ensure that the major movements of the Ollie were all completed on the force plate. Figure 1a shows a diagram of the basic Ollie movement used by the skaters to leap onto the platform in the OU maneuver.

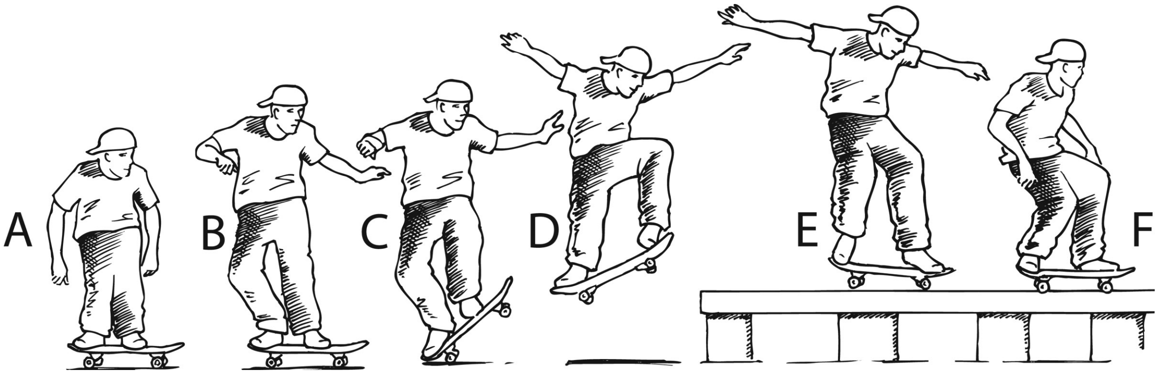

Figure 1a — Diagram of the Ollie technique. To perform the Ollie, the skater rapidly rotates the board about the rear axle, causing the tip to pitch upward (B–C). This bounces the tail of the board off the ground and causes the board to rise. At the same time the skater jumps up and usually forward while using the lateral forefoot of the leading foot to control and direct the trajectory and spatial orientation of the board (D). The board and skater follow similar trajectories, and in the end the skater lands on top of the board (E–F).

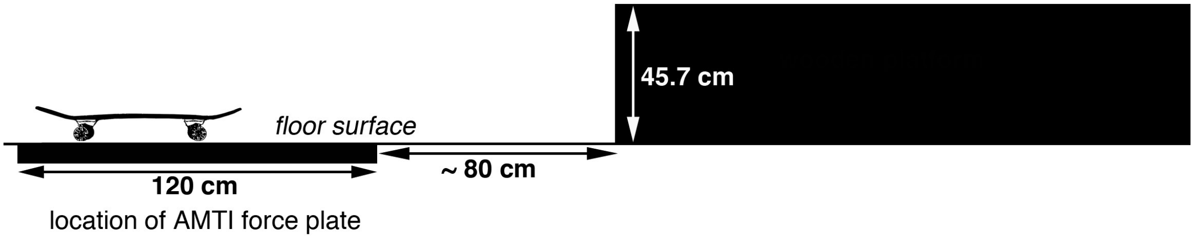

Figure 1b — Diagram of the experimental setup. The wooden platform to the right was raised 45.7 cm above the floor surface. The 120-cm long AMTI force plate was mounted flush with the floor with its farthest edge approx. 80 cm from the edge of the wooden platform. Skaters traveled from left to right for the Ollie Up (OU) maneuver and from right to left of the Ollie Down (OD) maneuver.

The OD maneuver involved rolling toward the edge of the platform (located 45.7 cm above the floor level) and, at the last moment, using an Ollie maneuver similar to the movements shown in Figure 1a (parts A-D) to hop off the wooden platform, subsequently landing on the floor-level force plate and then rolling forward off the force platform. Figure 1b shows a detailed diagram of the experimental setup. Relative to the orientation of the diagram in Figure 1b, the skaters traveled from left to right for the OU trials and from right to left for the OD trials.

A large AMTI model BP6001200 force plate (1.2 m long and 0.6 m wide) was used to measure ground reaction forces (Advanced Mechanical Technologies, Inc., Newton, MA). The frequency response of the mounted force platform was 380 Hz in the vertical plane and 383 Hz in the shear directions. Force data for all components were collected at 960 Hz and low-pass filtered using a fourth-order Butterworth filter with a 50-Hz cutoff frequency. Ground reaction force data were collected after a threshold of 20 N was reached.

In addition, in-shoe RSscan Footscan® insole-system pressure sensors were placed in both shoes to provide data on the distribution of forces under the plantar surface of each foot. The frequency response of the RSscan insole-system was at least 500 Hz as used in this experiment. The pressure data were captured at 500 Hz on a data-logger with a removable 4 MB SRAM PCMCIA card carried in a waist pack. After each trial, the pressure data were transferred from the PCMCIA card to a desktop computer for subsequent analysis using the RSscan software. We collected ground reaction force and pressure data for three trials of each movement (OU and OD) for each participant. Trials were rejected and repeated only if the participant was unable to complete the required maneuver within the defined space, or if the data were corrupted.

To minimize the chance of injury, the participants were allowed to use their own skateboards during the study. However, all were required to wear the same model of skateboarding shoe (Model: Etnies Sal 23), in their size, during the study. The shoes were of a basic cupsole style of construction with a thin layer of ethylene vinyl acetate (EVA) foam inserted into the cupsole. The polymeric foam layer was 8.5 mm thick in the heel area, tapering to 6 mm thick under the ball of the foot. The sole unit did not contain any special cushioning devices.

Results

During the Ollie Up, the resulting vertical ground reaction forces (VGRF) observed have a characteristic two-humped shape. Figures 2 and 3 contain the OU and OD data for all three trials for a single representative skater, Participant 4. The results for this skater show some of the typical results we observed. In Figure 2, the first VGRF peak, occurring after both wheels are on the force plate, is usually lower in magnitude (approx. 2 x BW) than the second peak. This is followed by a force minimum, or at least a cessation of the rise in force, that is reached in between the two peaks. This appears to be the result of an unweighting of the board as the center of mass is lowered just prior to the Ollie jump.

The second and usually higher magnitude peak is the result of the force rapidly applied by the back foot to the tail of the board as it is rotated about the rear axel and slammed into the ground. This force applied to the tail causes the board and skater to leave the ground. The magnitude of these second, propulsive, peaks has a mean of 1614.7 N ± 118.6

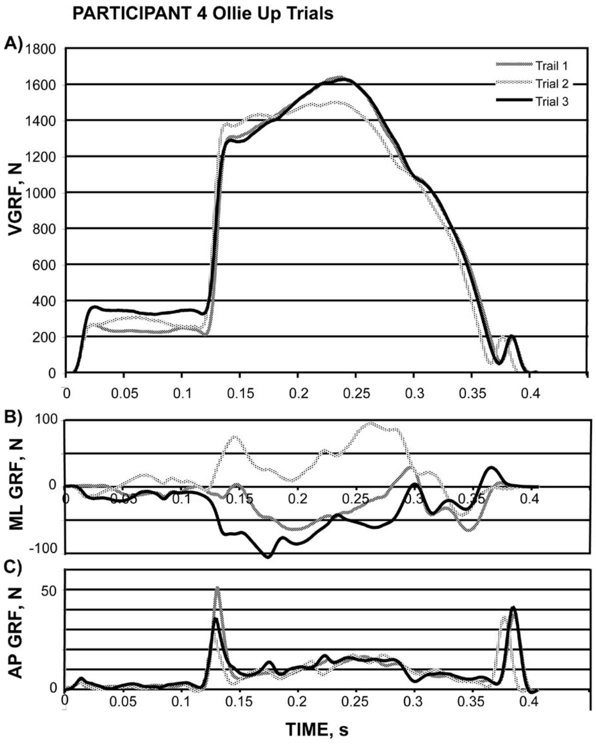

Figure 2 — (A) Three trials of vertical ground reaction force (GRF) data for one skater performing the Ollie Up (OU) maneuver. (B) Three trials of medial-lateral plane GRF data for one skater performing the OU maneuver. (C) Three trials of anterior-posterior plane GRF data for one skater performing the OU maneuver.

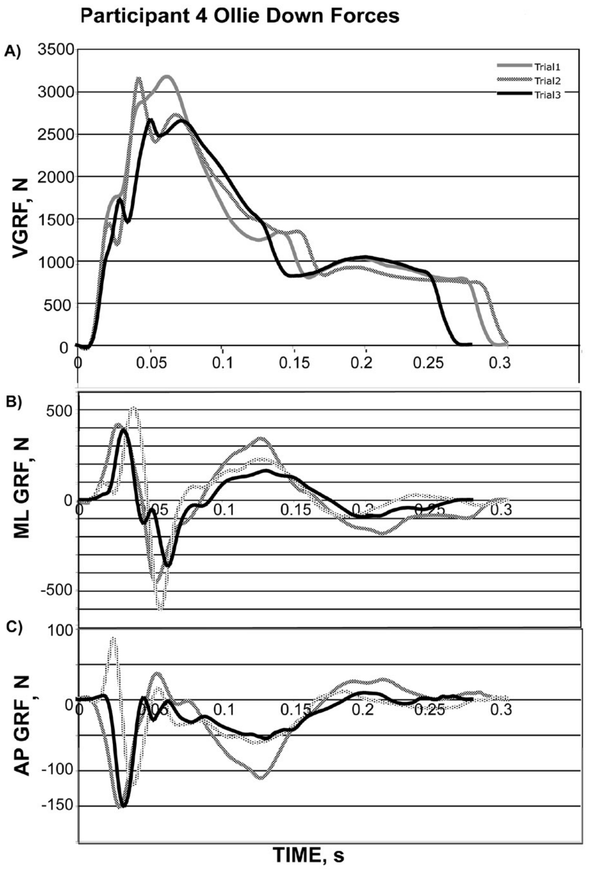

Figure 3 — (A) Three trials of vertical ground reaction force (GRF) data for one skater performing the Ollie Down (OD) maneuver. (B) Three trials of medial-lateral plane GRF data for one skater performing the OD maneuver. (C) Three trials of anterior-posterior plane GRF data for one skater performing the OD maneuver.

SD. Expressed as a proportion of body weight, the results for this propulsive peak VGRF are 2.254 BW ± 0.133 *SD*. See Table 1 for the peak force data for all skaters. The average GRF data for each participant is plotted in Figure 4 to give the reader an appreciation for the interindividual variation in the kinetics of the Ollie Up maneuver.

Because only the forefoot is in contact with the skateboard at this time, all of these forces are being applied by the ball of the foot and the toes. Our analysis of the in-shoe pressure data supports the observation that these forces are primarily being applied to the back foot and overwhelmingly to the first through third metatarsal heads and to the hallux. There is only minimal pressure applied by the leading foot during the Ollie Up.

During the OU, medial-lateral forces are more variable and do not show a consistent pattern (see Figure 2B). However, the anterior-posterior (A-P) shear forces are more regular (Figure 2C). Most prominent in the A-P force curve is a pronounced peak observed to correspond with the propulsive peak in VGRF. This is consistent with the rapid upward pitch in the board, produced by shifting the weight onto the back foot. This movement forces the tail of the board to forcefully impact the surface. It is off the tail of the board that the body and board are launched upward in the Ollie. The mean peak in this anterior shear force is 23.25 N ± 3.86 *SD* for all participants and all trials.

For the Ollie Down, the initial phase of landing consistently shows a rapidly rising impact curve reaching a peak magnitude in VGRF concomitant with the initial landing of the skater and board on the force plate. Shortly after that initial impact peak, VGRF drops as the ankles, knees, hips, and trunk

Table 1A Peak Ground Reaction Forces During the Ollie Up and Ollie Down Maneuvers in Newtons, Individual Means and Standard Deviations for Peak Ground Reaction Force (GRF) Data

Partici-pant		Ollie UP					Ollie DOWN					Body weight
		Vmax	MLmin	MLmax	APmin	APmax	Vmax	MLmin	MLmax	APmin	APmax	
1	*M*	1777.67	-83.27	19.80	-0.58	38.65	4,044.41	-665.35	735.21	-150.69	5.16	756.45
	SD	16.47	32.55	11.35	0.04	7.22	195.62	187.40	236.15	31.82	4.08	
2	*M*	1627.63	-46.92	18.92	-0.68	29.77	3,473.13	-768.26	650.50	-159.35	5.88	778.70
	SD	45.23	13.49	15.28	0.15	2.71	319.26	278.93	188.02	50.52	5.45	
3	*M*	1480.24	-3.40	106.73	-0.44	34.99	2,929.06	-560.75	444.08	-88.19	19.60	667.46
	SD	25.65	3.06	15.49	0.08	6.68	610.76	113.52	18.18	21.15	16.62	
4	*M*	1585.11	-71.46	50.57	-1.18	42.48	2,984.51	-473.81	431.42	-141.16	43.55	667.46
	SD	77.58	32.02	38.17	0.37	7.57	290.65	120.40	63.38	17.64	38.98	
5	*M*	1422.78	-42.97	76.06	-0.88	27.08	3229.27	-808.06	481.47	-130.28	3.65	600.72
	SD	5.78	15.38	11.50	0.18	3.32	381.13	64.52	30.08	34.99	2.64	
6	*M*	1595.99	-89.50	14.51	-1.68	31.29	3,285.69	-367.70	169.20	-98.04	3.37	676.89
	SD	67.15	12.63	10.17	0.67	2.69	488.13	90.28	84.04	42.41	0.96	
7	*M*	1492.95	-84.71	21.26	-1.76	51.39	3,595.34	-645.80	595.03	-184.23	40.06	843.66
	SD	56.47	12.04	3.64	0.30	2.15	458.88	236.05	228.04	68.97	46.45	
Total	*M*	1568.91	-60.32	43.98	-1.03	36.52	3363.06	-612.82	500.99	-135.99	17.33	713.05
	SD	117.62	31.14	35.61	0.53	8.42	384.24	157.19	184.66	33.85	17.66	83.00

Table 1B Peak Ground Reaction Forces During the Ollie Up and Ollie Down Maneuvers Normalized to Body Weights, Normalized Individual Means and Standard Deviations for Peak Ground Reaction Force (GRF) Data

Partici-pant		Ollie UP					Ollie DOWN					Body weight
		Vmax	MLmin	MLmax	APmin	APmax	Vmax	MLmin	MLmax	APmin	APmax	
1	*M*	2.35002	-0.11008	0.02617	-0.00077	0.05109	5.34656	-0.87957	0.97192	-0.19920	0.00682	756.45
	SD	0.02177	0.04303	0.01500	0.00005	0.00955	0.25860	0.24774	0.31218	0.04207	0.00539	
2	*M*	2.09019	-0.06025	0.02429	-0.00087	0.03823	4.46017	-0.98659	0.83536	-0.20464	0.00755	778.70
	SD	0.05808	0.01732	0.01962	0.00020	0.00349	0.40999	0.35820	0.24145	0.06487	0.00700	
3	*M*	2.21771	-0.00509	0.15990	-0.00066	0.05242	4.38837	-0.84012	0.66533	-0.13213	0.02937	667.46
	SD	0.03843	0.00459	0.02321	0.00012	0.01001	0.91504	0.17008	0.02724	0.03168	0.02491	
4	*M*	2.37484	-0.10706	0.07577	-0.00176	0.06365	4.47144	-0.70987	0.64636	-0.21149	0.06525	667.46
	SD	0.11623	0.04797	0.05719	0.00055	0.01134	0.43546	0.18038	0.09495	0.02643	0.05840	
5	*M*	2.36845	-0.07153	0.12661	-0.00146	0.04508	5.37567	-1.34515	0.80148	-0.21688	0.00608	600.72
	SD	0.00962	0.02561	0.01914	0.00030	0.00553	0.63446	0.10740	0.05007	0.05824	0.00439	
6	*M*	2.35783	-0.13222	0.02143	-0.00248	0.04623	4.85410	-0.54322	0.24997	-0.14484	0.00498	676.89
	SD	0.09920	0.01865	0.01503	0.00099	0.00398	0.72113	0.13338	0.12416	0.06266	0.00142	
7	*M*	1.76961	-0.10040	0.02520	-0.00209	0.06092	4.26159	-0.76548	0.70529	-0.21837	0.04749	843.66
	SD	0.06693	0.01427	0.00431	0.00036	0.00255	0.54392	0.27979	0.27030	0.08175	0.05506	
Total	*M*	2.21838	-0.08380	0.06563	-0.00144	0.05109	4.73684	-0.86714	0.69653	-0.18965	0.02393	713.05
	SD	0.22420	0.04233	0.05710	0.00071	0.00896	0.46330	0.25286	0.22698	0.03577	0.02426	83.00

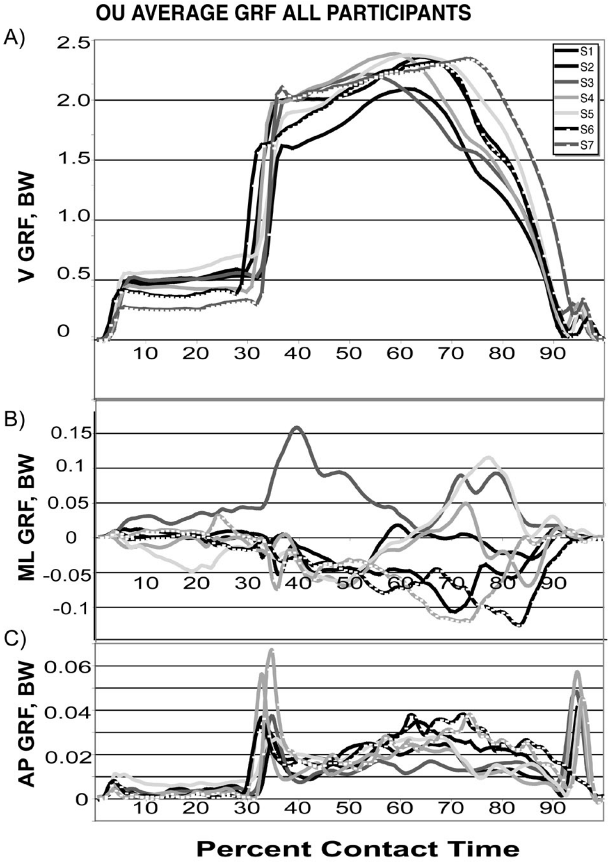

Figure 4 — Average ground reaction force (GRF) data for all skaters performing the Ollie Up (OU) maneuver. Units are expressed in body weights (BW) and in percent of total contact time. Each skater's curve represents the time-based average of his three trials: (A) vertical GRF data; (B) medial-lateral GRF data; (C) anterior-posterior GRF data.

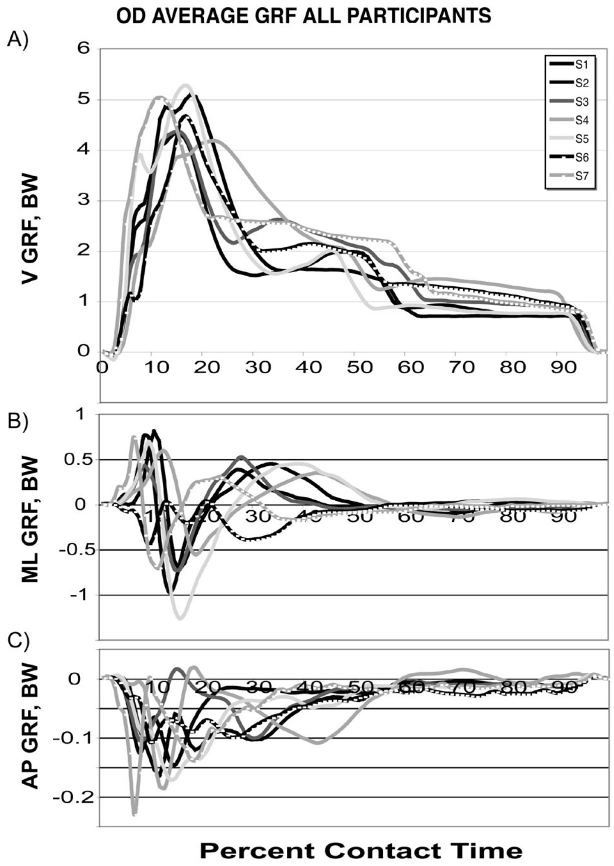

Figure 5 — Average ground reaction force (GRF) data for all skaters performing the Ollie Down (OD) maneuver. Units are expressed in body weights (BW) and in percent of total contact time. Each skater's curve represents the time-based average of his three trials: (A) vertical GRF data; (B) medial-lateral GRF data; (C) anterior-posterior GRF data.

flex as the skaters absorb the shock of landing. One secondary and one or two tertiary peaks, much lower in magnitude than the impact peak, are observed in most landings as the body oscillates while absorbing the landing forces. But it is the initial impact peaks that we are most interested in.

The OD VGRF impact peak rises to a magnitude ranging from about 4.0 to 5.0 times body weight and reaches this peak 40 to 50 ms after initial contact. The mean value for this impact peak for all participants including all trials is 3250.5 N ± 530 *SD* (4.519 BW ± 0.582 *SD*). At the time these impact forces are developing, our in-shoe pressure results show that most of the force is being borne by the forefoot region of the back foot. These impact peaks are of a higher magnitude than would be expected given the relatively short drop of 45.7 cm, especially given the crouched position of the skaters just prior to leaving the platform. However, in our discussion we will explain the cause of these higher impact forces.

The ML GRF and AP GRF results for the OD are quite variable both within and between skaters (see Figure 3B and C, and Figure 5B and C). This seems largely due to the result of the instability of the skaters shortly after landing.

As the skaters touch down, generally only the rear wheels make first contact followed by the back foot landing on the board, and then the front foot and front wheels landing. Upon first landing, the skater also may not be centered on the board in the medial lateral plane. The instability of these landings, both medial to lateral and fore to aft, requires the skater to make corrective movements to stabilize his position on the board. These stabilizing movements, which are different for each skater and each landing, create the observed variability in the shear forces that are visible in Figure 5B and C. The only regular feature of these forces we can report is that the sinusoidal shape of the curves seems characteristic of an oscillation, an expected result given the nature of stabilizing body movements.

Discussion

The peak VGRF results are lower than expected for the OU, given the fact that the board and the mass of the body must be raised by 45.7 cm. These propulsive peak values are similar in magnitude to those observed in runners who raise the center of mass to a much lesser extent in each step (Frederick & Hagy, 1986). This suggests that the mass center is raised by less than the height of the platform. This is consistent with our observation of the crouched position of the body at the time the board and body first land on the platform. In essence these skilled skateboarders seem capable of minimizing the force required to Ollie up onto the platform by choosing a relatively flat trajectory of the center of mass of board and skater.

The impact peaks observed during the landing in the OD are of a higher magnitude than would be expected, given the relatively short drop of 45.7 cm and the crouched position of the skaters on their skateboards on the platform. This position would have lowered the center of mass and should have also contributed to relatively lower impact forces than those observed in other studies of landing from a jump.

Stacoff and colleagues studied landing from a primarily vertical blocking jump in volleyball (Stacoff, Kaelin, & Stuessi, 1988). They observed a two-stage landing pattern with a forefoot landing on one foot producing VGRF in the range of 1 to 2.5 BW, followed immediately by a harder heel impact mostly ranging between 3 and 6 BW but with a median magnitude of about 4.5 BW. Given the fact that the participants in their study were consistently jumping higher than 45 cm, we would have expected to observe lower VGRF impact forces in our study compared to the volleyball landings. However, the results we observed showed impact forces consistently in the 4.5 to 5.0 BW range.

In a study of landing from a jump in basketball, Valiant and Cavanagh (1985) observed mean impact forces equivalent to 4.1 BW when the participants in their study landed toe-heel from a simulated rebound. These are lower magnitude impact forces than the mean 4.74 BW impact peak we report in this study, despite that fact that their basketball players were landing from a greater height.

In a study by McNitt-Gray (1993) of gymnasts landing from various heights to simulate the landing movements in various gymnastic events, the results were similar in magnitude to ours if we interpolate her results to our approximate drop heights. Using the slope of McNitt-Gray's data to predict peak forces for a drop from our drop height of 0.457 m, her data predict a mean peak force of 4.72 BW. This is very close to what we observed.

A closer examination of the pattern of movement of the participants in our study and those in McNitt-Gray's study may help explain these relatively high forces when compared with some sports. When our skaters landed on their skateboards on the force plate, they seemed to intentionally affect a firm, forceful landing to stabilize their position and balance. This appears similar to "spiking" a landing in gymnastics. The participants in McNitt-Gray's (1993) study were required to use this same landing technique and produced peak forces similar to what we observed.

We also observed that the skaters do not just roll off the end of the platform; instead, they Ollie off the end. In other words, they create a trajectory for the center of mass that actually rises after they leave the platform. This is done to put both the body and board in position for a controlled landing. If they were just to roll off the end, they would not have enough time to affect a stable landing and the skateboard would fall along a nose-down path, making it difficult for the skaters to land on the board. The Ollie gives them time and allows them to get the board into the right attitude for a proper landing.

This combination of raising the center of mass and actively applying force to the board on landing results in higher vertical ground reaction forces than we would expect just based on the 45.7-cm height of the drop. The fact that these forces are borne almost exclusively by the forefoot is also significant.

When landing from a jump in other sports, peak forces are usually reduced by affecting a toe-heel landing pattern. The forefoot strikes first and then the heel absorbs the remainder of the force as it drops to the surface, establishing foot contact over both the heel and forefoot regions. This toe-heel landing pattern is known to reduce the magnitude of peak forces (Stacoff et al., 1988; Valiant & Cavanagh, 1985). But in skateboarding, the heel is not in contact with the skateboard during these landings and, as our pressure data show, all the forces of impact are being borne primarily by the metatarsals and the hallux. Footwear manufacturers should take this into account in designing shoes for skateboarding.

The participants in our study were highly skilled, as evidenced by their professional or top-amateur standings in competitive skateboarding. Also, in terms of body mass they were not typical of other skateboarders. In a recent survey of 797 North American skateboarders conducted by our research group, we found that the average skateboarder was younger (mean of 15 years 8 months) and lower in body mass (mean of 56.7 kg) than the experienced and more mature skaters used in this study. We need to exercise caution in applying these findings to the general population of skateboarders. Nevertheless, the tasks we asked our skaters to perform were not extreme and are within the skill level of many more typical skateboarders. Furthermore, our data are scaled to body mass, making the data more applicable to discussions of the general skateboarder population.

The Ollie maneuver is ubiquitous in skateboarding and these forces are being experienced by skateboarders with great frequency. Footwear manufacturers need to better understand the high impact forces and pressures on the forefoot region of skateboarders' feet, especially given the relative skeletal immaturity of typical skaters (Chambers, 2003). We also recommend studies on the cushioning and pressure distribution characteristics of footwear for skateboarding, especially in the forefoot region, to determine whether their functional properties are consistent with the needs of the sport.

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