THE INFLUENCE OF DROP HEIGHT ON GROUND REACTION FORCES IN MOUNTAIN BIKING

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This study examined ground reaction forces (GRFs) when landing from a drop-off in mountain biking. Eight male mountain bikers participated in this study. Participants rode up onto and across an adjustable wooden platform, performing three drop maneuvers at each vertical height of 29 cm, 48 cm, and 67 cm, simulating drop-offs in mountain biking. Peak vertical GRFs when landing from each drop was measured using 3 force platforms in the landing area. When examining the rear and front tire individually, peak vertical GRFs were significantly higher for the rear tire at each drop height. Additionally, significant increases in summed peak vertical GRFs occurred from the low to middle and middle to high drop-off. Therefore, this may support implications that mountain biking includes osteogenic stimuli that is beneficial to bone health.

KEYWORDS: force platform, downhill, freestyle, off-road cycling

INTRODUCTION: The sport of downhill mountain biking has seen a recent surge in research. Topics examined include the physiological demand (Burr, Drury, Ivey, & Warburton, 2012), performance characteristics (Chidley, MacGregor, Martin, Arthur, & Macdonald, 2014), activity profiles (Hurst et al., 2013), upper body muscle activation (Hurst et al., 2012) and power output (Hurst & Atkins, 2006). Downhill mountain biking trails commonly contain both man-made and natural jumps and vertical drop-offs (Burr et al., 2012; Hurst et al., 2012). When landing from such features, impact forces are absorbed through both the suspension system and the rider. Ground reaction forces (GRFs) experienced while cycling have been an area of interest in research. Road cycling, specifically, has been an area of concern in relation to osteopenia due to its non-weight bearing nature. Although highly trained and physically fit, road cyclists have been shown to be at higher risk for developing osteoporosis with advancing age (Nichols, Palmer, & Levy, 2003). However, it has been proposed that as much as 70 – 90% of a mountain biker's body weight may be applied on the pedals while standing and coasting or traveling downhill (Rowe, Hull, & Wang, 1998; Wang & Hull, 1997). With the addition of bumps, jumps, and drop-offs, downhill mountain bikers may experience a higher weight bearing stimulus than a road cyclist, which may benefit bone mineral density (BMD). Therefore, the purpose of this study was to investigate differences in GRF's while landing from three different drop heights.

METHODS: Eight male mountain bikers participated in this study. Mean age, height, and weight were 23.3 ± 1.5 years, 180.3 ± 6.8 cm, and 76.6 ± 6.3 kg respectively. All participants had significant prior experience in performing the drop maneuver examined in this study. A 43 cm high wooden platform was constructed to simulate a drop-off in mountain biking. Concrete blocks, measuring 19 cm high, were used to elevate the platform. Three different drop heights were examined. The low, medium, and high drop-offs measured a vertical distance of 29 cm, 48 cm, and 67 cm above the force platforms, respectively. Three force platform were positioned in the landing area, in a straight line on the floor. The back tire landed on 2 force platforms (OR6-7-2000; AMTI, Watertown, MA) closest to the wooden platform while the front tire landed another force platform (AccuPower; AMTI, Watertown, MA) in front of the others. These were adjusted throughout testing to ensure that the tires were landing directly on their respective force platforms. GRF data were collected at 1,000 Hz for the rear tire, 400 Hz for the front tire and saved with the use of computer software (BioSoft 1.0; AMTI) for later analysis. The GRFs for each drop were recorded and averaged for each rider.
All participants used the same 19" frame Specialized Stumpjumper FSR Comp mountain bike (Specialized, USA) with 29" tires. The bike included a Fox Float CTD Evolution Series 29 fork (Fox, USA) with 130 mm of air sprung travel and a Fox Float CTD Evolution rear shock (Fox, USA) with auto-sag and 130 mm of travel. Both the fork and shock were kept in the 'trail'

setting. Both tires were kept at an inflation pressure of 193053 pascal (28 PSI) throughout testing.

Participants warmed up by completing 10 minutes of self-selected pace cycling on a cycle ergometer. Next, participants completed a self-selected number of drop-offs at each height to become familiarized with the bike and the platform. Participants were instructed to ride at a speed they found acceptable for the drop height, and attempt to land flat on the force platforms. Each participant completed three drop maneuvers at each height, from lowest to highest.

Descriptive data were determined using the SPSS statistical software package (SPSS Inc., version 21, Chicago, IL). Means and standard deviations were calculated for GRFs of each tire and drop height. A repeated measures ANOVA was used to analyze the difference in data between the 3 drop heights. A paired-samples t test was used to examine differences in forces occurring at each tire at each drop height. Statistical significance was set at $p < 0.05$.

RESULTS: Means and standard deviations are presented in Table 1 for the summed peak vertical GRFs that occurred at each drop height. Table 2 presents the peak vertical GRFs that occurred for the rear tire and front tire, individually. Significant increases in summed peak vertical GRFs occurred from the low to middle and middle to high drop off ($p < 0.05$). When examining the rear and front tire, peak vertical GRFs were significantly higher for the rear wheel at each drop height ($p < 0.05$). There was no significant interaction ($p > 0.05$).

Table 1. Mean ± SD sum peak vertical forces (N) that occurred at each drop height.

	Low [a]	Middle [b]	High
Sum Forces	5442.343 ± 247.970	6799.632 ± 240.112	7877.567 ± 368.333

[a] Significantly different from Middle and High conditions.
[b] Significantly different from Low and High conditions

Table 2. Mean ± SD peak vertical forces (N) that occurred at the rear and front tire, individually, at each height.

	Low *	Middle *	High *
Rear	3358.254 ± 665.518	3867.732 ± 775.489	4424.670 ± 918.062
Front	2084.089 ± 356.141	2931.900 ± 282.789	3452.896 ± 354.785

* Significantly different between rear and front tires.

DISCUSSION: Dropping from a variety of heights is commonly experienced in downhill and freestyle mountain biking. Therefore, this study analyzed the GRFs that occurred when landing on a level surface from a vertical drop height of 29 cm, 48 cm, and 67 cm. Significant increases in summed GRFs were observed as the drop height increased. When examining the combined average weight of the riders and the mountain bike, 884.8 N, summed peak GRFs were 6.1, 7.6, and 8.9 times higher when landing at the low, medium, and high drop heights, respectively. However, it is unknown how much of these forces were absorbed through the bike or the rider. Downhill mountain biking races involve a time trial format in which the rider must complete the trail as fast as possible. When experiencing a vertical drop, riders will typically maintain speed, stand up, move their center of gravity behind the saddle of the bike, and pull up on the handle bars to elevate the front tire. If this was not done, riders would risk being thrown forward over the handle bars. As this study has shown, peak GRFs were significantly higher for the rear wheel at each drop height. Additionally, riders will usually attempt to land level with the riding surface to maintain speed. As one can imagine, if a rider landed from a drop with the rear tire striking significantly earlier than the front tire, this may cause a rocking effect of the riders body, quickly shifting the weight of the rider forward and risking a crash.

GRFs have been examined during the sport of cyclocross (Tolly, Chumanov, & Brooks, 2014). Cyclocross is similar to mountain biking in terms of terrain but, in addition, requires the rider to perform weight-bearing activity. Specifically, the rider is required to repeatedly dismount, carry or push the bike while running and jumping over an obstacle and/or uphill, and then remount; this is unique to cyclocross as mountain bikers often are able to ride over barriers they encounter. Tolly et al. (2014) showed that cyclocross provides athletes with brief bouts of weight-bearing activity that generate GRF similar in magnitude to running and hopping. Similar to mountain biking, cyclocross involves more intense weight-bearing components interspersed with periods of relative rest, which may be more beneficial to bone health than seated road cycling.

Warner, Shaw, and Dalsky (2002) compared the BMD of elite male cross-country cyclists, elite road cyclists, and a recreationally active control group. When adjusted for body weight and controlled for age, BMD was significantly higher at all sites in the mountain cyclists compared with the road cyclists and controls. They theorized that typical mountain biking at an elite level requires the athlete to conquer different ground surfaces (rocks, gravel, sand, packed dirt, logs, drop-offs, etc.) at varying speeds and inclines that could represent osteogenic stimuli through loading forces at varying intensities and frequencies. Also, the arms and legs are considered significant vibration isolators in dynamic system models of mountain biking, which is not the case for road cycling (Wang & Hull, 1997). As the current study has shown, significant GRFs occur when landing from different drop heights in mountain biking, and may be beneficial to bone health.

CONCLUSION: In conclusion, the current study showed that significant increases in GRFs occurred when mountain bikers landed from increasing drop heights. This may support implications that mountain biking includes osteogenic stimuli that is beneficial to BMD. However, future studies should examine forces that occur at the foot and hand in order to distinguish how much force the rider absorbs compared to the bike. Additionally, future studies could examine forces when landing on a down slope, such as the landing of a jump.

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