THE ROLE OF WALKING AND RUNNING VELOCITY ON OSTEOGENIC POTENTIAL

William P. Ebben, Steve M. Neahous, Jennifer M. Endisch, and Karisa D. Laskowski

Department of Health, Exercise Science & Sport Management, University of Wisconsin-Parkside, Kenosha, WI, USA

This study assessed the ground reaction forces (GRF) associated with walking and running at a variety of speeds and compared these kinetic values to the landing after a maximum counter-movement jump in order to understand the osteogenic potential for these activities. Twenty-four women walked and ran over a force platform at slow, medium, and fast walking and running speeds, which were assessed using Doppler radar. Landing vertical peak GRF and rate of force development (RFD) were analyzed for all movements using a force platform. In almost all cases, higher walking or running speeds resulted in statistically significant increases in GRF and RFD. Based on the findings of this study, moderate to fast sprints should be prescribed in the training programs for those who seek to maximize their bone health.

KEY WORDS: sprinting, bone, kinetic, osteogenesis

INTRODUCTION: Exercise has been shown to be osteogenic (Deere et al., 2012; Gomez-Cabello et al., 2012; Guadalupe-Grau et al., 2009). However, questions remain about the details of the exercise stimulus and its potential osteogenic benefits.

Exercise modes such as depth jumps from a height equal to a subject's counter-movement jump height, loaded jumps, and five repetition maximum back squats have been shown to have more osteogenic potential than walking or running (Ebben et al., 2010). High impact exercise such as jumping and resistance training seem to demonstrate the greatest benefits for bone health (Deere et al., 2012; Gomez-Cabello et al., 2012; Guadalupe-Grau et al., 2009). Since walking provides only a modest increase in impact loading, above bodyweight, this mode of exercise is believed to be less effective in preventing osteoporosis (Gomez-Cabello et al., 2012).

The evidence regarding the osteogenic potential of walking is inconclusive. Some evidence shows that walking improves (Habibzadeh, 2010), has no effect on (Habibzadeh et al., 2010), or even decreases (Humphries et al., 2000) measures of bone health such as bone mineral density. Some have speculated that the nature of the walking stimulus, such as the volume, as assessed by the number of steps per day, and ground reaction force magnitude, may be important (Worthen et al., 2005). Other characteristics of walking, such as the velocity, may influence its ostengenic potential. Additionally, higher velocities modes of locomotion, such as running, may be more effective as an osteogenic stimulus.

High impact exercise modes have been shown to produce higher rates of force development and peak ground reaction force compared to relatively slow walking and running (Ebben et al., 2010). However, no study has assessed the acute kinetic differences in walking and running at a variety of velocities, and how these forms of exercises compare to exercise modes that are known to be effective, such as landings after jumping. Therefore, the purpose of this study was to quantify select kinetic characteristics of walking and running at a variety of velocities, and compare these values to the landing after a counter-movement jump, in order to further understand their osteogenic potential.

METHODS: Twenty-four women (mean ± SD; age = 20.58 ± 1.69 yr; height = 172.26 ± 8.33 cm; body mass 71.69 ± 7.75 kg) served as participants. The study was approved by the institution's internal review board. Participants were involved in one testing session. This session included a general warm-up, a dynamic warm-up, an activity specific warm-up, and the test exercises.

The general warm-up included 3 minutes of low intensity exercise on a cycle ergometer. The dynamic warm-up included 5 slow bodyweight squats, 10 yard forward walking lunge, 10 yard backward walking lunge, 10 yard walking hamstring stretch, 10 yard walking quadriceps stretch, 20 yard skip, and 5 counter-movement jumps of increasing intensity. The activity specific warm-up will include one repetition each of slow, moderate, and fast walking for 10 meters, slow, moderate, and fast running from 20 meters, 20 meter run and cut at a 45 degree angle, 20 meter run and cut with a side shuffle, accelerate into a 20 m sprint from a standing start and decelerate from a 20 meter sprint. During the activity specific warm up, participants were taught the technique for each activity and the velocity of these movements were assessed with Doppler microwave radar (Stalker II, Applied Concepts Incorporated, Plan TX) so they could become familiar with the range of velocity to be assessed during the study. Participants also perform 5 repetitions of vertical jump and reach progressing from 50 to 100 percent of their self perceived intensity.

The test exercises included the performance of 2 repetitions each of the following test exercises in a randomized order. These exercises included slow (SW), moderate (MW), and fast (FW) walking for 10 meters, and slow (SR), moderate (MR) and fast (FR) running for 20 meters, and the counter-movement jump. For each test condition other than the counter-movement jump, participant's velocity was assessed and controlled via Doppler microwave radar with data-logging capability (Harasin, et al., 2006). Participants were provided feedback for any trial in which the velocity was outside the required range for the specific test condition. In those instances, participants rested and re-performed the task attempting to be within the specified velocity range. The range of velocities for the test exercises included walking 0.6 to 1.6 m/s and running 1.7 to 5 m/s. Maximal bilateral counter-movement jumps were included for comparison since exercises such as this are known to offer osteongenic potential or benefit (Deere, et al., 2012; Ebben, et al., 2010; Gomez-Cabello, et al., 2012; Guadalupe-Grau, et al., 2009). Participants rested for 15 seconds between the slow, moderate and fast walking trials. Participants rested for 60 seconds between slow, moderate and fast running trials and the maximal counter-movement jump.

Peak ground reaction forces and the rate of ground reaction force development were assessed for all test exercises via a force platform (BP6001200, Advanced Mechanical Technologies Incorporated, Watertown, MA, USA) which subjects contacted during the unilateral foot-stance phase of their stride for each walking and running condition, near the end of their 10 meter walk or 20 meter run, and for the bilateral counter-movement jump. The force platform was calibrated with known loads to the voltage recorded prior to the testing session. Kinetic data were collected at 1000 Hz, real time displayed and saved with the use of computer software (BioAnalysis 3.1, Advanced Mechanical Technologies, Inc., Watertown, MA, USA) for later analysis. All values were averaged for two trials for each test exercise.

Dependent variables were selected in order to evaluate the test exercises for their osteogenic potential, consistent with previously used methods (Ebben et al., 2010). The rate of force development (RFD) and vertical ground reaction force (GRF) were calculated for the unilateral foot strike of walking and running test exercise and for the bilateral landing of the counter-movement jump. Kinetic data for the countermovement jump were divided by two in order to approximate the unilateral portion of this bilateral event, to allow comparison to the unilateral values from the walking and running test exercise. All kinetic variables were calculated from the force time records of each test exercise consistent with methods previously used (Ebben at al., 2010; Jensen & Ebben, 2007; Moir, 2008). The RFD was defined as the first peak of GRF minus the initial GRF upon landing divided by the time to the first peak of GRF minus the time of initial ground reaction force and normalized to one second (Jensen & Ebben, 2007). Peak GRF was defined as the highest GRF value attained during the landing phase of each test exercise (Jensen & Ebben, 2007).

The statistical analyses were undertaken with SPSS 20.0. An one-way ANOVA with repeated measures for exercise condition was used to evaluate the differences in locomotion velocity as well as the main effects for exercise condition for GRF and RFD. Bonferonni adjusted pairwise comparisons were used to identify the specific differences between these exercise conditions. The trial-to-trial reliability of each dependent variable was assessed for each plyometric exercise using average measures intraclass correlation coefficient (ICC). In addition, a repeated measures ANOVA was used for each parameter to confirm that there was no significant difference ($p > 0.05$) between three trials of each exercise condition. Assumptions for linearity of statistics were tested and met. An *a priori* alpha level of $p \le 0.05$ was used with post hoc power and effect size represented by d and η_p^2, respectively.

RESULTS: The analysis of locomotion velocity revealed significant main effects for exercise condition ($p \le 0.001$, $\eta_p^2 = 0.98$, $d = 1.00$). Results are shown in Table 1. The analysis of GRF revealed significant main effects for exercise condition ($p \le 0.001$, $\eta_p^2 = 0.83$, $d = 1.00$). Analysis of RFD also showed significant main effects for exercise condition ($p \le 0.001$, $\eta_p^2 = 0.78$, $d = 1.00$). Results of Bonferroni adjusted pairwise comparisons for each dependent variable and locomotion velocity are presented in Tables 1 and 2. Intraclass correlation coefficients assessing the trial to trial reliability ranged from 0.68 to 0.99, with most ICC's over 0.80, for the exercise conditions and dependent variables.

Table 1
Mean ground reaction force (GRF) in Newtons and standard deviation (SD), body weight coefficient (xBW), and mean horizontal velocity (VEL) in m-sec and standard deviation (SD) for each exercise condition.

	BW	SW	MW	FW	CMJ/2	SR	MR	FR
GRF	701.85	761.13	871.44	1057.89	1247.25	1643.38	2061.68	2834.29
SD	75.87	109.20	138.97	200.16	370.73	258.50	506.99	645.47
xBW	1.0	1.08	1.24	1.51	1.78	2.34	2.93	4.03
VEL	NA	1.00	1.61	2.15	NA	2.43	2.86	4.16
SD	NA	0.09	0.22	0.10	NA	0.22	0.21	0.17

BW=body weight; SW=slow walk; MW=moderate walk; FW=fast walk; SR=slow run; MR=moderate run; FR=fast run; CMJ/2 = ½ the bilateral countermovement jump
All exercise conditions are significantly different ($p \le 0.01$)

Table 2
Mean rate of force development (RFD) and standard deviation (SD) in N/s^{1}

	SW	MW	FW	SR	CMJ/2	MR	FR
RFD	3432.05	7090.46	13767.35	19852.91	20209.83	61157.81	128744.48
SD	2903.54	7341.36	10405.65	10120.26	13098.00	39235.86	47208.12

BW=body weight; SW=slow walk; MW=moderate walk; FW=fast walk; SR=slow run; MR=moderate run; FR=fast run; CMJ/2=½ the bilateral countermovement jump
All exercise conditions are statistically different ($p \le 0.05$) except for SR and CMJ/2.

DISCUSSION: This is the first study to assess the role of walking and running velocity on kinetic parameters of osteogenic potential and to compare these values to known osteogenic exercise such as jumping. This study demonstrates that higher walking and running velocity results in higher GRF and RFD. The GRF values obtained during all running conditions were higher than the values produced during the counter-movement jump. The RFD values obtained during the MR and FR were higher than those associated with the counter-movement jump.

Increased GRF were present between all conditions with the exception that slow walking was not statistically different than static body weight alone. Thus, slow walking may not provide enough stimulus to produce an osteogenic benefit as has been suggested (Deere et al., 2012; Ebben et al., 2010; Gomez-Cabello et al., 2012; Gaudalupe-Grau et al., 2009) and confirms that low intensity walking does not produce GRF higher than body weight alone which may explain why low intensity walking does not increase bone density (Humphries et al., 2000). The current study shows that waking at higher velocities produces modest increases in GRF above body weight as has been suggested.(Gomez-Cabello et al., 2012). While higher walking velocities produced larger GRF's, which ranged from 1.24 to 1.51 times body weight, it is unknown if these values arise to the level of being osteogenic. However, higher running velocities resulted in GRF in a range from 2.34 to 4.03 times body weight.

All running conditions produced GRF that were greater than those produced during the counter-movement jump. The counter-movement jump, as well as depth jump landings from a height equal to the counter-movement jump, are believed to be among the highest acute osteogenic stimuli (Ebben et al., 2010), and jumping has been shown to increase markers of bone health and strength such as bone mineral density (Deere et al., 2012; Gaudalupe-Grau et al., 2009). In fact, GRF values during the FR condition of the present study exceed the mean GRF values shown for a variety of plyometric exercises (Ebben, et al., 2011), and resistance training exercises, such as the back squat (Ebben et al., 2010). In the present study, the FR condition can best be characterized as moderate sprinting. Thus, based on GRF values, sprinting is a better osterogenic stimulus than jumping.

Similar to the GRF response, the RFD also increased as locomotion velocity increased. Slow running produced RFD values that were 5.8 times greater than slow walking. Fast running produced RFD values that were 37.5 times greater than slow walking. Moderate running and FR also produced higher RFD values than the counter-movement jump. In fact, MR and FR RFD values were approximately three to six times greater than the values obtained during the maximum counter-movement jump in this study. This study also shows that MR and FR each produced mean RFD that were higher than the mean RFD of a variety of plyometric exercises (Ebben et al., 2010; Ebben at al., 2011) and the back squat exercise (Ebben et al., 2010).

CONCLUSION: Moderate to fast running produced unilateral GRF and RFD that were significantly higher than the values obtained during walking and jumping. Sprints should be prescribed in the training programs for those who are interested in attempting to maximize their bone health.

REFERENCES:

Deere K., Sayers, A. Rittweger, J & Tobias, J.H. (2012). Habitual levels of high, but not moderate or low, impact activity are positively related to hip BMD and geometry: Results from a population based study of adolescent. *Journal of Bone & Mineral Research*. 27, 1887-1898.

Ebben, W.P., Feldmann, C.R., Garceau, L.R. & Petushek E.J. (2011). Kinetic quantification of plyometric intensity. *Journal of Strength and Conditioning Research,* 25, 3288-3298.

Ebben, W.P., Fauth, M.L., Kaufmann C.E. & Petushek E.J. (2010). Magnitude and rate of mechanical loading of a variety of exercise modes. *Journal of Strength and Conditioning Research.* 24, 213-217.

Gomez-Cabello, A, Ara, I, Gonzalez-Aguero, A., Casajus, J.A. & Vicente-Rodriguez, G. (2012). Effects of training on bone mass in older adults: A systematic review. *Sports Medicine.* 42, 301-326.

Guadalupe-Grau, A., Fuentes, T., Guerra, B., & Calbet, J. (2009). Exercise and bone mass in adults. *Sports Medicine,* 39, 439-469.

Habibzedah, N. (2010). Preventing osteoporosis among underweight and obese sedentary young women. *Baltic Journal of Health and Physical Activity*. 2, 97-104.

Habibzedah, N., Rahami-Nia, F., & Daneshamandi, H. (2010). *International Journal of Fitness.* 6, 53-60.

Harasin, D., Dizdar, D., & Markovic, G. (2006). High reliability of tests of maximum throwing performance. *Journal of Human Movement Studies*, 51, 63–76.

Humphries, B., Newton, R.U., Bronks, R. Marshall, S., McBride, J., Triplett-McBride, T., Haekkinen, K., Kraemer, W.J. & Humphries, N. (2000). Effect of exercise intensity on bone density, strength, and calcium turnover in older women. *Medicine and Science in Sports and Medicine*, 32, 1043-1050.

Jensen, R.L., & Ebben, W.P. (2007). Quantifying plyometric intensity via rate of force development, knee joint and ground reaction forces. *Journal of Strength and Conditioning Research,* 21, 763-767.

Moir, G. (2008). Three different methods of calculating vertical jump from force platform data in men and women. *Measurements in Physical Education and Exercise Science,* 12, 207-218.

Worthen, L.C., Kim, M.C., Kautz, S. A., Lew, H.L., & Kiratli, J. B. (2005). Key characteristics of walking correlate with bone density in individuals with chronic stroke. *Journal of Rehabilitation Research*, 42, 761-769.