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The Quantification, Autoregulation and Reliability of the Stomp as an Osteogenic Exercise

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Abstract

Performing jump-landings may not be suitable for some individuals when programming for bone health. This study quantified a stomp exercise to determine its magnitude (body weight's [BW's]) and rate (body weights per second [BW·s-1]) of strain among premenopausal women. Twenty healthy premenopausal women [Mean ±SD: 41.7±5.6y; 68.2±10.6kg; 165±5.5cm; 27.5±8.7% body fat] performed stomps on left and right legs at different rate of perceived exertions (RPE's) (5 and 8) within the same session. The stomp RPE5 resultant magnitudes (3.08 and 2.89, BW's) and rates of strain (199 and 180, BW·s-1) for right and left legs (respectively), performed on a Kistler force plate, were similar to previously determined osteogenic thresholds (>3BW's and >43 BW·s-1 respectively). The stomp performed at RPE8, significantly ($p < 0.001$) exceeded stomps performed at RPE5 (4.58 and 4.42, BW's and 344 and 333, BW·s-1). The within-session reliability was good to excellent (0.68 to 0.89) for stomps performed at RPE5 and moderate to excellent (0.56 to 0.90) for stomps performed at RPE8. The stomp exercise achieves osteogenic thresholds thought pre-requisite for bone growth in premenopausal women and can be safely and reliably auto regulated by individuals for use in bone health programs where jump-landings may be contraindicated.

Keywords: Biomechanics; Bone; Ground reaction Forces; Impact exercise

Introduction

Osteoporosis is a skeletal disorder characterised by low bone density and compromised bone strength [1,2], as well as qualitative changes in the microarchitecture of the bone [3]. Overall bone strength is determined by bone size, bone morphology and properties of the Bone Mineral Density (BMD), such as collagen traits and micro damage [4,5]. The result of low bone density and compromised bone strength is an increased risk of osteoporotic fractures. Common areas for osteoporotic fractures to occur are at the femoral neck, vertebral column and distal radius [6]. However, there is still an increased risk and possibility for fractures to occur at other sites as a result of low bone density [7]. The World Health Organisations (1994) operational definition of osteoporosis is based on the estimation of bone mineral density, which is measure by dual-energy x-ray absorptiometry (DEXA). This is considered the gold standard measurement for BMD [8]. In 2018, it was reported that approximately 52 million people had been diagnosed with osteoporosis or osteopenia in the United States alone [9]. This number was expected to rise to 61 million by the year 2020. Globally, osteoporosis is accountable for over 50% of fractures in women and 20% of fractures in men [10].

Osteoporosis can negatively affect a person's quality of life, as well as have a large economic burden [11,12]. As the elderly population increases, it is expected that the economic burden will continue to grow. During the year of 2016, Canada was estimated to spend $4.6 billion dollars on osteoporosis [13]. Different populations have different risks of getting osteoporosis, with women being at greater risk than men. In 2017, nearly two-thirds of Australians over the age of 50 suffered from low bone mass, however only 30% of those were males. According to Osteoporosis New Zealand (2020), at least one in three women and one in five men will suffer from an osteoporotic fracture during their lifetime [14]. It is estimated that a 50-year-old white female has a 15 - 20% lifetime risk of hip fracture and a 50% risk of any osteoporotic fracture [3,15]. Researchers have focused on the effects of exercise such as bilateral vertical jumps, on bone mineral density, largely focusing on women [16-19]. One study has investigated bilateral jumps with a reactive jump landing [20,21].

Bone tissue is a structural material that has the ability to adapts its form and microstructure to changing environmental loading conditions [22]. Turner (1998) [23] has identified three fundamental rules that determine bone adaptation; 1) bone adaptation is driven by dynamic rather than static loading, 2) only a short duration of mechanical loading is required to initiate an adaptive response; and 3) bone cells will adjust to a mechanical loading environment, making them less responsive to routine loading signals. Research has investigated the threshold of strain required to achieve skeletal adaptation, with Frost hypothesising that mechanical forces exceeding this remodelling threshold would therefore stimulate bone formation, as well as increase overall bone strength and mass [24-26].

Bassey and colleagues (1998) demonstrated that peak vertical landing forces of 3 BW’s and peak loading rates of 43 BW·s-1 achieved during a countermovement jump landing, resulted in significant increases (↑2.8%) in Bone Mineral Density (BMD) at the femoral neck [18]. Other studies that have seen improvements in femoral neck BMD in premenopausal women, used a range of different jumping protocols, (3 - 7 days per week), lasted in duration of 4 - 18 months [16,18,27,28] and used loading magnitudes between 2 - 6 BW.

To the authors knowledge, only jump landings have been quantified and investigated. Some researchers have focused on the effects of instructions being given during these jumps [21,29], while others have focused on different landing mechanics [21,30,31]. These jumps and hops that have been investigated may be technically difficult and challenging for certain populations. Therefore, studies are needed to investigate other exercise alternatives, that may be more suitable for various populations to stimulate bone development at clinically relevant sites. Moreover, no studies have investigated whether osteogenic exercises can be reliably auto regulated to influence the loading response (i.e. magnitude (BW) and rate of strain (BW·s-1). Such information could help individuals safely periodize osteogenic exercises and slowly progress over time using the principle of progressive overload. Previous research has investigated using a Rate of Perceived Exertion (RPE) as a method of volume autoregulation within a periodized program [32], determining that volume and intensity can effectively be auto regulated using RPE.

Given the technical difficulty associated with jumping and jump landings for some populations, it is important to quantify other potential osteogenic exercises to determine their suitability in osteogenic programs which may improve bone health. Therefore, this study sought to; a) determine whether the stomp exercise can be auto regulated and reach osteogenic thresholds previously determined by Bassey and colleagues (1998), in premenopausal women; and b) determine the reliability of the magnitude and rate of strain variables of the stomp performed at different RPE intensities [18]. It was hypothesised that stomps would achieve previously established osteogenic thresholds and the high RPE (i.e. 8) would produce significantly greater magnitudes and rates of strain compared to stomps performed at a moderate RPE (i.e. 5).

Methods

Approach to The Problem

Exercise has been utilised as a preventative strategy for improving bone density in premenopausal women [21]. Researchers have quantified a series of jumping and hopping exercises to determine whether they exceed thresholds thought to stimulate bone (3BW and 43 BW·s-1) [18,21]. The aim of this research was to quantify a stomp exercise performed at different RPE intensities and determine if the stomp can be reliably auto regulated. A cross-sectional descriptive design was used for this research. The stomp exercises were performed on left and right legs on a Kistler (Kistler Instruments, Victoria, Australia) force plate (length 1200mm x width 600mm x height 100mm). Ground Reaction Forces (GRF) were recorded during one testing session. Such a design was similar to that used to investigate whether bilateral vertical jumps with reactive jump landings achieve osteogenic thresholds with and without instruction in premenopausal women [21].

Participants

Twenty healthy premenopausal women took part in this study. A summary of their descriptive characteristics is presented in Table 1. Participants were provided with a participant information sheet and completed an informed consent form. This sample size and demographic is comparable to other studies that have used a similar design [18,21]. Inclusion criteria for this research was that participants must have a regular menstrual cycle, indicating premenopausal status (32 - 50y). A participant was excluded if any medical problems were reported, such as injury, arthritis, osteoporosis, or balance issues that impacted their ability to perform the stomp exercise. These medical problems were identified on a pre-exercise questionnaire. The methods and procedures used in this study were approved by the Institutional Review Board Committee (R14/17).

	Participants (n = 20)
Demographics	
Age (y)	41.7 ± 5.6
Height (cm)	165.0 ± 7.6
Body mass (kg)	68.2 ± 10.6
BMI	25.0 ± 3.5
Body fat (%)	27.5 ± 5.5
Maximal countermovement jump	
Jump height (cm)	36.4 ± 6.0

Table 1: Descriptive characteristics of participants (mean ± SD).

Testing protocol

Participants were required to attend a familiarisation session before they completed the testing session. During this familiarisation session, participants filled in a pre-screening questionnaire containing information about injuries or medical issues that may exclude them from the study. Height was measured using a portable stadiometer, and body mass and composition were measured using a Hologic DEXA Discovery fan beam machine (Marlborough, Massachusetts, USA). This machine has been shown to have excellent validity [33]. A Vertec yardstick (Swift Performance Equipment, Wacol, Australia), was used to collect maximal vertical jump height for each participant. This data was taken at the end of the warmup. This data was used to determine baseline jumping and lower body power abilities [21,34]. Before jumping commencement, the participants reach height was determined by reaching as high as possible (allowing scapular elevation) and the researcher adjusted the Vertec height accordingly. The participant was then encouraged to jump and tough the highest vane possible on the Vertec device. The participants were given three attempts.

Participants were given a demonstration of the stomp exercise. They were then asked to practice the stomp on the force plate (3 practice submaximal stomps on each leg). All stomps were performed in bare feet (see Figure 1) in order to standardise the testing between all participants. It has previously been suggested that the natural elastic components of the body are able to provide greater protection to loading forces in comparison to footwear [21,35]. Prior to performing the stomps during the testing session, each participant provided a light 5 - minute standardised warmup on the Watt bike (Wattbike Trainer, Nottingham, United Kingdom), as well as 10 submaximal countermovement jumps, before the Vertec testing. Participants were asked to stand on the force plate and perform two stomps on each leg for each RPE condition (i.e. RPE5 and RPE8). The stomps at RPE5 were performed first followed by stomps at RPE8. This order was used to ensure for participant safety and adequate progression of the stomp. Participants rested for thirty seconds between each stomp. RPE was self-determined by each participant on how they perceived a 50% effort stomp and an 80% effort stomp. All data is presented as an average of the two stomps (mean ± SD).

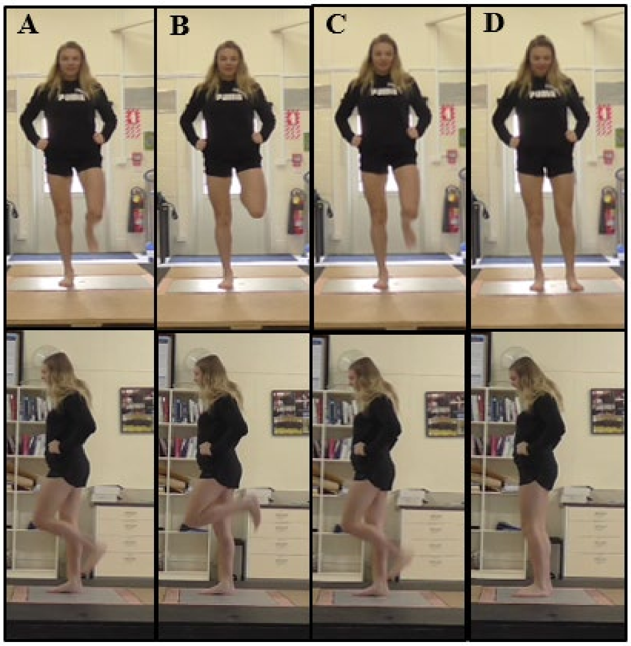

Figure 1: Anterior (top row) and lateral (bottom row) view of the stomp movement being performed. A) mid-point of preparation, B) start of execution, C) mid-point of execution, D) end of execution.

Data Analysis

All force-time data was collected at 1000HZ and filtered using a second order low-pass Butterworth filter (cut off frequency 20 Hz) with zero lag. The force-time data was calculated in Microsoft Excel 2013, and presented as peak values (i.e. N, BW and BW·s^{-1}). Peak resultant forces were calculated as √(x^2+y^2+z^(2)) and used to determine the rate of force development (N·s^{-1} * 100/ body mass, N; body weight per second, BW·s^{-1}) over 10 ms taken from the steepest part of the slope between the start of the stomp and the peak stomp force [17]. A pictorial representation of the force profiles (RPE 5 and RPE 8) of the stomps (normalised for time using ensemble averaging in Microsoft Excel 2013) utilised in this study are presented in Figure 2.

Statistical Analyses

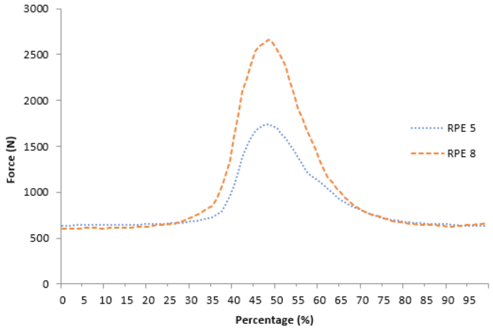

Figure 2: A Typical Vertical Force Profile (normalised for time and smoothed with a 2pt moving average) of the Stomp performed at RPE5 and RPE8. RPE = Rate of perceived exertion.

Stem and leaf plots were used to ascertain whether there were any outliers in the data for each variable. After extreme outliers were removed, descriptive statistics were calculated and reported as means and standard deviations. A repeated measures ANOVA with sidak pairwise comparisons were used to determine if statistical differences existed between stomps performed on left and right legs, and for each rate of perceived exertion (i.e. RPE 5 and RPE 8). Classifications of effect size (small = 0.20 to 0.50, moderate = 0.51 to 0.80 and large = >0.80) [36], were calculated to determine the magnitude of the differences between each stomp RPE condition. Within session reliability of stomp measures (i.e. between each left and right leg trial within each perceived condition) was evaluated by Intraclass Correlation Coefficients (ICC) using a two-way random effects model, absolute agreement, and average measures ICC. ICC's were classified as follows; 'poor' (≤0.40), 'moderate' (0.41 – 0.60), 'good' (0.61 – 0.80), or 'excellent' (≥ 0.81) [37,38]. 95% confidence intervals (95% CI) were calculated for all reliability measures. Internal consistency was assessed using Cronbach Alpha. All data analyses were conducted using SPSS 25.0 for Windows (SPSS Inc., Chicago, IL, USA). Significance was set at $P < 0.05$.

Results

The magnitude and rate of strain for the right leg RPE 5 (3.08 BW and 199.37 BW·s-1) and left leg RPE 5 (2.89 BW and 179.87 BW·s^{-1}) are similar to the magnitude of strain (>3BW's) and exceed the rate of strain (43 BW·s-1) previously determined for osteogenic thresholds [18]. The magnitude and rate of strain for the right leg RPE 8 and left leg RPE 8 were 4.42 BW's and 332.75 BW·s-1, and 4.58 and 343.67 BW·s-1 (respectively). The RPE 8 condition significantly exceeded ($P < 0.001$) the RPE 5 condition for magnitude of strain (BW) (↑58% and ↑44%; ES= 1.32 and 1.25) and rate of strain (BW·s-1) (↑91% and ↑67%; ES= 1.41 and 1.40) for right and left legs (respectively). No significant differences were found between right and left leg for each RPE condition (i.e. 5R and 5L). A summary of the ground reaction force data (presented as N, BW and BW·s-1) is presented in Table 2.

Variables	RPE 5		RPE 8	
	Right Leg	Left Leg	Right Leg	Left Leg
Peak Vertical Force (N)	1911 ± 469*t	1853 ± 512*t	2826 ± 713	2930 ± 842
Peak Resultant Force (N)	1984 ± 488*t	1911 ± 527*t	2934 ± 717	3026 ± 839
Peak Vertical Force (BW)	2.97 ± 0.80*t	2.81 ± 0.90*t	4.26 ± 1.26	4.44 ± 1.52
Peak Resultant Force (BW)	3.08 ± 0.82*t	2.89 ± 0.92*t	4.42 ± 1.26	4.58 ± 1.51
Peak Rate of Force Development (N)	1297 ± 463*t	1175 ± 529*t	2195 ± 734	2256 ± 823
Peak Rate of Force Development (BW·s-1)	199.37 ± 78.71*t	179.87 ± 87.11*t	332.75 ± 125.13	343.67 ± 144.39
Key: *significantly different (*P* <0.001) to RPE right leg 8; t significantly different (*P* <0.001) to RPE left leg 8.				

Table 2: Ground reaction forces associated with the stomp at RPE 5 and RPE 8.

The within session reliability of a right and left leg stomp at RPE 5 and was calculated using ICC's. The results are presented in Table 3. Excellent reliability was shown for the stomp on the right leg and good to excellent reliability was shown for the left leg stomp.

Within session reliability	**ICC (SinMea)**	**95% CI**	**ICC (AvgMea)**	**95% CI**	**CA**	**Qualitative Inference**
Stomp right leg RPE 5						
Peak Vertical Force (N)	.77^{s}	.50 to .91	.87^{s}	.67 to .95	.87	Excellent
Peak Resultant Force (N)	.77^{s}	.49 to .91	.87^{s}	.65 to .95	.87	Excellent
Peak Vertical Force (BW)	.81^{s}	.55 to .92	.89^{s}	.71 to .96	.88	Excellent
Peak Resultant Force (BW)	.80^{s}	.53 to .91	.89^{s}	.70 to .96	.88	Excellent
Peak Rate of Force (N)	.75^{s}	.45 to .90	.86^{s}	.62 to .95	.86	Excellent
Peak Rate of Force (BW·s^{-1})	.77^{s}	.49 to .91	.87^{s}	.66 to .95	.87	Excellent
Stomp left leg RPE 5						
Peak Vertical Force (N)	.56^{s}	.16 to .81	.72^{s}	.28 to .89	.73	Good
Peak Resultant Force (N)	.53^{s}	.12 to .79	.68^{s}	.21 to .88	.71	Good
Peak Vertical Force (BW)	.68^{s}	.34 to .87	.81^{s}	.50 to .93	.82	Excellent
Peak Resultant Force (BW)	.65^{s}	.29 to .85	.79^{s}	.45 to .92	.80	Good
Peak Rate of Force (N)	.51^{s}	.10 to .78	.68^{s}	.18 to .88	.69	Good
Peak Rate of Force (BW·s^{-1})	.59^{s}	.20 to .82	.74^{s}	.34 to .90	.75	Good
Key: ICC Intraclass correlation coefficient; SinMea Single measures; AvgMea Average measures; s $P < 0.05$; CA Chronbach's Alpha.						

Table 3: Within session reliability of a right and left leg stomp at RPE 5.

The within session reliability of a right and left leg stomp at RPE 8 was calculated using ICC's. The results are presented in Table 4. Moderate to good reliability was shown for the stomp on the right leg, and excellent reliability was shown for the left leg stomp.

Within session reliability	**ICC (SinMea)**	**95% CI**	**ICC (AvgMea)**	**95% CI**	**CA**	**Qualitative Inference**
Stomp right leg RPE 8						
Peak Vertical Force (N)	.44^{s}	-.01 to .73	.61^{s}	-.02 to .85	.60	Good
Peak Resultant Force (N)	.39^{s}	-.07 to .71	.56^{s}	-.17 to .83	.55	Moderate

Peak Vertical Force (BW)	.53^{s}	.12 to .79	.70^{s}	.21 to .88	.68	Good
Peak Resultant Force (BW)	.49^{s}	.06 to .77	.66^{s}	.12 to .87	.65	Good
Peak Rate of Force (N)	.42^{s}	-.04 to .72	.59^{s}	-.08 to .84	.58	Moderate
Peak Rate of Force (BW·s^{-1})	.50^{s}	.07 to .77	.66^{s}	.12 to .87	.65	Moderate
Stomp left leg RPE 8						
Peak Vertical Force (N)	.77^{s}	.50 to .90	.87^{s}	.66 to .95	.86	Excellent
Peak Resultant Force (N)	.75^{s}	.47 to .89	.86^{s}	.64 to .94	.85	Excellent
Peak Vertical Force (BW)	.81^{s}	.58 to .92	.90^{s}	.74 to .96	.89	Excellent
Peak Resultant Force (BW)	.80^{s}	.56 to .92	.89^{s}	.72 to .96	.88	Excellent
Peak Rate of Force (N)	.75^{s}	.46 to .89	.86^{s}	.63 to .94	.85	Excellent
Peak Rate of Force (BW·s^{-1})	.79^{s}	.54 to .91	.88^{s}	.70 to .95	.88	Excellent
Key: ICC Intraclass correlation coefficient; SinMea Single measures; AvgMea Average measures; s P <0.05; CA Chronbach's Alpha.						

Table 4: Within session reliability of a right and left leg stomp at RPE 8.

Discussion

Previous studies have focused purely on jump landings and their effect on bone health in premenopausal women [21,30,31]. However technical difficulty associated with jumping and jump landings, may not be suitable osteogenic exercises for all populations. This study quantified and determined the reliability of ground reaction forces associated with an autoregulated stomp exercise in premenopausal women at different RPE intensities (5 and 8). The results support the hypotheses generated for this study with stomps performed at a moderate intensity (RPE 5) being similar to and exceeding the previously determined osteogenic thresholds (3 BW's; 43 BW·s-1, respectively) shown to improve bone health at clinically relevant sites for premenopausal women [18]. Stomps performed at higher intensities (RPE8) achieved significantly greater rates and magnitudes of strain in comparison to stomps performed at a moderate intensity (RPE5). Within session reliability measures were good to excellent for stomps performed at RPE5 and for the left leg RPE 8 intensity. Moderate to good reliability was observed for the left leg RPE8 condition.

In this study, stomps performed at a lower intensity (RPE5) produced peak vertical forces of 2.97 (right) and 2.81 BW's (left) which is similar to the >3BW of landing forces previously observed in the countermovement vertical jump in this population [18]. Bassey and colleagues (1998) investigated the effects of a vertical jumping exercise regime on BMD in pre- and postmenopausal women [18]. The exercise consisted of 50 vertical jumps 6 days/week, resulting in a significant increase of 2.8% in femoral neck BMD for the premenopausal women, after 5 months of completing the exercise. However, there was no significant change in the postmenopausal women, therefore suggesting that premenopausal status is a more desirable time to develop BMD gains. This is due to oestrogen deficiency in postmenopausal women, as oestrogen plays a major role in the bone remodelling process [39,40].

Stomps performed at the RPE8 intensity in the current study produced peak resultant forces (PVF) of 4.26 (right) and 4.44 BW's (left), which greatly exceeded the previously determined osteogenic threshold (3 BW's) [18]. Ground reaction forces were measured in three axes and then used to calculate peak resultant forces for all stomp conditions. The steepest 10ms was used to represent peak rate of force development (PRFD). The same process was used by Bassey and colleagues (1998) [18]. PRFD under both RPE5 and RPE8 conditions (respectively) in the current study were substantially higher (199.37 and 179.87 BW·s-1; 332.75

and 343.67 BW·s-1) for right and left legs (respectively) than the previously determined value of 43 BW·s-1 [18]. Such values are similar to or greater than those previously reported [18,20,21]. Clissold and colleagues (2020; 2018), investigated whether bilateral vertical jumps and multidirectional jumps with reactive jump landings achieved osteogenic thresholds in premenopausal women [20,21]. The magnitudes of strain (4.59 to 5.59 BW's) achieved are similar to those achieved with the stomp at RPE8. The rates of strain (264 to 359 BW·s-1) achieved for bilateral vertical jumps were relatively higher than those achieved by the stomp RPE5. However, stomps performed at an RPE8 achieved similar rates of strain (332 to 343 BW·s-1). Such findings from the current study indicate that the stomp can indeed be autoregulated and potentially be utilized as a way of progressive overload in osteogenic programs.

Previous researchers have identified that key mechanisms for providing the greatest influence for stimulating bone formation are, peak vertical force (magnitude of strain) and peak rate of force development (rate of strain) [41]. It has been suggested that if peak rate of force development is sufficiently high, bone adaptation may be stimulated without using high peak vertical force [21,25,42]. Therefore, although the stomp performed at a lower intensity (RPE5) did not exceed peak vertical force thresholds (>3 BW's), it clearly exceeds peak rate of force development thresholds (43 BW·s-1) and may still stimulate the bone [41-43].

Reliability refers to the reproducibility of values of a test in repeated trials on the same individuals [44]. ICC's were used in this study to measure the within session reliability. Excellent reliability was shown for the right leg stomp at RPE5 and the left leg stomp at RPE8. Good to excellent reliability was shown for the left leg stomp RPE5 with moderate to good reliability being observed for the right leg stomp RPE8. To the authors knowledge, this is the first study to determine whether a stomp exercise can be reliably auto regulated for magnitude and rate of strain using an RPE scale. Helms and colleagues (2018) sought to determine whether RPE could be used as a method of volume autoregulation, with results showing that it is possible to use RPE to auto regulate training volume [32]. The results of the current study show that the stomp exercise can be reliably auto regulated by participants using an RPE scale. The results from this study demonstrate that the stomp exercise can be used in bone health programs and in combination with other exercises that have been shown to reach these thresholds [21], to create programmes targeted to premenopausal women with the goal of increasing their bone mineral density and preventing osteoporosis. Exercise prescription guidelines for the prevention and management of osteoporosis, recommended healthy adults (Low to moderate risk), to perform moderate to high-impact weight-bearing activities (>2 to >4 BW; 3-5 sets 10-20 repetitions, 1-2 minutes' rest between sets), four to seven days each week [1].

Conclusion

Our results demonstrate that the stomp exercise performed at RPE5 and RPE8 can be reliably auto regulated, and reach and exceed osteogenic thresholds previously shown to increase bone mass in premenopausal women. Previously only bilateral and unilateral jumps have been quantified; however, these require a certain technical aspect and may not be appropriate or easily performed by high-risk populations. The stomp can therefore provide a safe and effective exercise to perform that will stimulate bone. In addition, individuals can auto regulate the stomp using an RPE scale as a means of progressive overload.

Further research should focus on training studies to determine exactly how effective osteogenic exercises such as the stomp are for improving bone health amongst various populations (e.g. age, life stage, and sex). There is a paucity of research that has quantified impact exercises that don't involve a jump and flight phase. In susceptible populations, the risk of performing jumping exercises may outweigh the potential benefits. Therefore, it would be of value to have the option of performing exercises that may help minimise risk, while still reaching osteogenic thresholds. To the authors knowledge, there is no research that has quantified upper body exercises. Given the fact that radius fractures are common it is important to also quantify upper body exercises for their suitability in osteogenic programs [45].

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