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The Chronic Effects of a Quantified Jump-Landing Program on Bone Health, Body Composition and Performance Parameters in Premenopausal Women

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Abstract

The primary purpose of this study was to determine the effects of a 12-month quantified jump-landing program at clinically relevant bone sites in premenopausal women. Secondary measures of interest included; lower body explosive power, muscle reactivity, balance performance parameters and body composition. A longitudinal controlled trial was implemented to determine the effect of utilizing previously quantified jumps and hops with specific cues provided for jump-landings. Participants; Fifty-seven women (age, 42.4 ± 5.50 y; body mass, 70.2 ± 11.5 kg; height, 165.4 ± 0.10 cm; body fat, 31.5 ± 6.20%) were assigned to a jump (JL) or control (CON) group. The JL performed periodized jumping-landing exercises up to five times per week for 12-months. Linear mixed model regression analysis was used to determine if differences existed between the JL and CON. Significant group main effects (P<0.01) in favour of the JL (↑0.41 - ↑3.72%) were observed for bone mineral density and bone mineral content at the femoral neck, total hip and lumbar spine. Significant group main effects (P<0.01) for cross-sectional area, cortical thickness and section modulus at the femoral narrow neck were also in favour of the JL (↑2.78 - ↑3.84%). For ground contact time, improvements in the JL over the CON between baseline and 12-months were apparent (↑21.9% *vs.* ↓8.86%) with significant group and time effects (P<0.01) being observed. A longitudinal quantified periodized jump-landing program performed 2-3 mins/day; 4-5 times a week is osteogenically effective in improving bone strength at clinically relevant lower body sites associated with osteoporosis in premenopausal women.

Keywords: Exercise; Osteoporosis; Fracture prevention; Biomechanics; DXA

Introduction

Osteoporosis has been described as a silent epidemic responsible for fractures in 50% of women and 20% of men worldwide [1,2]. In the United States approximately 52 million women and men have osteoporosis or osteopenia (low bone mass) and it is predicted to increase to more than 61 million by 2020 if additional efforts are not made to address this disease [3]. It is well accepted that women have less total bone mass than men and experience rapid bone loss during menopause. Generally women experience bone losses of approximately 1% per year after the fourth decade of life, however annual losses of 3 - 5% bone mineral density (BMD) can be experienced during early post-menopause [4]. The National Osteoporosis Foundation of America estimate up to 20% of BMD can be lost in the 5 - 7 years after menopause, with lifetime bone losses estimated to be 30 - 40% of peak bone mass [4,5].

The measurement of ground reaction forces (GRF's), represented as body weight's (BW's) have been used to estimate the influence of loading on bone [6-9], and researchers have suggested that to achieve an adaptive bone response an exercise regime should satisfy the following criteria: a) be of sufficient magnitude and rate of strain; b) present its strain in a range of diverse and unusual distribution patterns; c) provide a limited number of loading cycles at each distribution; d) be of short duration; and e) provide adequate recovery periods. However, research has predominantly focused on "high risk" postmenopausal women and as a consequence exercise regimes for minimizing bone loss in adults are generic and lack specific recommendations for women before they experience accelerated bone losses during and post menopause [10,11].

Jumping and hopping exercises have been researched for their role in enhancing bone mass in young people and for minimizing age-related bone loss in females [6,12-17]. Exercises, with emphasis on the jump-landing, may be of special interest given their role in increasing peak bone mass in premenopausal women and minimizing age-related bone loss [13,18-20]. Authors of meta-analyses concluded [18,19] that jump-landing programs that; utilized brief jumping protocols (10-100 jumps/day, 3 - 7 days/week), are 4 - 18 months duration, and present loading magnitudes of between 2 - 6 BW, can result in significant gains in femoral neck BMD of 0.5 - 3% in premenopausal women during a time when normal bone loss is 0.5% - 1% per year [18,21].

Recently researchers investigated the vertical and resultant GRF's associated with bilateral vertical jumps, countermovement and drop jumps combined with a reactive jump (defined as 'jumping immediately after an initial jump-landing') as a potential osteogenic

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stimuli for premenopausal women [22]. The authors reported peak vertical landing forces (4.6 - 5.5 BW) which were substantially higher (1.2 to 1.8 times greater) than the values previously reported for the same jump-landings performed by a similar populations [13,20,23]. The use of repeated jumps requires the participant to flex minimally upon landing and push off quickly thereafter, thus preventing a 'soft' landing and the absorption of impact energy by the leg musculature [24-26].

Recent exercise prescription guidelines for the prevention and management of osteoporosis have been published by Exercise and Sports Science Australia (ESSA), according to level of risk of fragility fracture [27]. Individuals classified as 'low risk' (T score < -1.0), are recommended to perform moderate to high-impact weight-bearing activities (50 jumps per session), defined as greater than two body weights (BW) (moderate impact), to greater than four body weights (high impact) of ground reaction forces, four to seven times each week. Although the position statement identifies the types of jumps to be performed, it lacks specific detail in terms of jump-landing technique, program design, and monitoring of the daily and weekly loading. Therefore a program to safely optimize the impact stimulus required to promote bone formation needs to provide specific cues for jump-landings and adhere to best practice musculoskeletal program design [28-31].

Although the effects of jumping exercises on bone health in premenopausal women have been documented by several research groups, many diverse protocols are used in exercise and BMD research, making it challenging to compare outcomes. In addition, the focus on jump-landing technique and utilizing a reactive jump component within a 12-month periodized training program has not been previously presented. Given the limitation identified, the primary outcome this study sought to determine was whether the jump group (JL) would achieve and exceed gains in bone mass, and improved aspects of bone geometry at the femoral narrow neck (cortical thickness, cross-sectional area, section modulus). We were also interested in secondary measures associated with the reduction of falls risk, including; lower body explosive power, muscle reactivity and body composition. Due to the scope of the study, several hypotheses were generated; i) Bone mineral density and bone mineral content will increase at the femoral neck, total hip and lumbar spine in the JL and age-predicted BMD losses (≤1%) will occur in the control group (CON); ii) Bone geometry variables will increase at the femoral neck in the JL and decrease in the CON; iii) Improvements in functional performance parameters (i.e. lower body explosive power and muscle reactivity), will be observed in the JL only; and, iv) The JL will achieve improvements in body composition (i.e. increased fat free mass and decreased fat mass and body fat percentage), with no improvements in the CON.

Methods

A longitudinal controlled trial was implemented for a period of 12-months to determine the effects of a quantified jump-landing program on measurements of bone health in premenopausal women. Eighty premenopausal women (30 - 51 years) were assigned to either the JL or CON. Participants utilized an online registration form in which they could indicate a preference for treatment, control or either. Fifty percent (n = 40) chose either and were randomized into the JL or CON group. The remaining participants were allocated based on their ability to participate in the daily jump-landing program (in their own homes), and attend jump-landing group classes regularly. Such methodology was deemed necessary as previously published longitudinal exercise studies involving premenopausal women have reported high dropout rates 38% to 50% [23,32,33]. Studies with an insufficient sample size may not have sufficient statistical power to detect meaningful effects and may produce unreliable answers to important research questions [34]. The current study design sought to improve the adherence to the jump-landing training program [33] and to determine the true meaningful effect of the mechanical stimulus associated with the jump landings. Although it was not possible to blind the intervention providers due to their specific expertise in the field of this research, blinding was applied for the process of data entry and analysis.

Participants in the CON were asked to maintain their normal activity level and to attend 3-monthly testing sessions. No significant differences for any physiological measures were observed between the CON and JL group at baseline. All testing was performed at baseline, 3, 6, 9 and 12-month intervals in a Sports Science laboratory at a local Institute of Technology. All participants provided written informed consent after being briefed on the potential risks associated with this research. The methods and procedures used in this study were approved by the New Zealand Health and Disability Ethics Committees (17/NTB/155), and registered with the Australian New Zealand Clinical Trials Registry (ACTRN12617001145392p).

Participants

Eighty healthy premenopausal women (30 - 51 years), from the Bay of Plenty community, New Zealand (including; Toi Ohomai Institute of Technology and Sport Bay of Plenty), volunteered to participate in this study in response to intra and inter- institution advertisement. This sample size is comparable to other studies which have used a similar design and length of study [13,35,36]. A flow diagram depicting the recruitment and retention of participants during the study is presented in Figure 1. Of the eighty participants, eight did not meet the inclusion criteria due to regular participation in sport or exercise involving high impact activities (n = 8). A further fifteen women were removed from the study due to either; becoming pregnant (n = 4), sustaining an unrelated injury (n = 6), leaving the region (n = 3), or withdrawing for personal reasons (n = 2). The results from this study are based on the data obtained by the remaining 57 participants (Table 1).

All participants were considered healthy as determined by a Physical Activity Readiness Questionnaire (PAR-Q) and inclusion criteria required participants to be between 30 and 51 years of age, which was used in conjunction with a regular menstrual cycle (9 - 12 menstrual cycles in the previous 12 months) to determine premenopausal status. Although menstrual cycle was not formally monitored, no participants reported any change in menstrual status throughout the study. Participants were excluded if any medical problems were reported, that compromised their participation or performance in this study: including having a recent or current musculoskeletal injury; osteoporosis, osteoarthritis; and, any condition of impaired balance or coordination. Osteoporosis was defined by World Health Organization Z-score criteria (2.5 standard

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

	Jump (n = 32)	Control (n = 25)
Demographics		
Age (y)	43.0 ± 5.30	41.5 ± 5.80
Height (cm)	165 ± 0.10	165 ± 0.10
Body mass (kg)	70.8 ± 11.0	68.9 ± 12.6
BMI (kg·m^{-2})	25.9 ± 3.70	25.4 ± 4.20
Nutritional Status		
Calcium intake (mg) €	867 ± 368	838 ± 260
Protein (g) €	97.4 ± 33.3	95.2 ± 27.4
Bone Mineral Density (g·cm²)		
Femoral neck*	0.877 ± 0.15	0.839 ± 0.10
Total hip*	1.008 ± 0.14	0.979 ± 0.09
Lumbar spine (L1 - L4) *	1.104 ± 0.14	1.059 ± 0.09
Body Composition		
Fat free mass (kg) *	48.0 ± 5.90	47.0 ± 6.85
Fat mass (kg)*	23.1 ± 7.32	22.0 ± 7.20
Body fat (%) *	31.9 ± 6.50	31.3 ± 5.80
Performance Tests		
Jump height (Vertec, cm)	35.2 ± 7.70	35.4 ± 5.40
Ground contact time (ms)	0.309 ± 0.10	0.261 ± 0.11

Data expressed as mean ± SD. *DXA; € Determined using 3-day food diary and Foodworks software analysis. No significant differences were observed between the JL and CON at baseline.

deviations below the age-matched mean), using baseline DXA scan data [37]. Participants were also excluded if currently (or in the past 12 months), engaged in regular physical activity involving impact exercise (i.e. playing sports such as tennis, squash and netball), and if taking corticosteroids. In addition, pregnant women were excluded from the study due to contraindications related to DXA testing.

Testing procedures

During the first session, less than one month after recruitment, both JL and CON groups were subjected to the same testing protocol (DXA, balance, muscle reactivity and maximal vertical jump) at the same time of day. A 3-day food diary (including 2-week days and 1 weekend day), was used to assess dietary status at baseline. Dietary assessment software Foodworks Professional 8 (Xyris Software, Australia), was used to determine average estimated energy intake (KJ/day), protein and calcium intake (mg/day), from food, fluids and supplements. An information sheet was provided to all study participants describing the role of calcium for bone health and to promote the recommended dietary intake (RDI) of 1000mg [38]. In addition, participants in both groups completed a 7-day activity diary to determine participation in regular high-impact physical activity and eligibility to participate in this study.

Anthropometry and bone mineral density: Participants had their height measured (wall-mounted stadiometer to the nearest 0.1cm) prior to having BMD assessed (g·cm^2) at the proximal femur (femoral neck and total hip) and lumbar spine (L1 - L4) using Dual energy x-ray absorptiometry (DXA) utilizing specialized hip structural analysis (HSA) software (Hologic Discovery QDR Series Bone Densitometer, Bedford, Massachusetts). However, as BMD represents an important but not exclusive dimension of bone strength (describes 50 - 70% of the strength of bone) [37,39,40], geometric properties (cross-sectional area, cortical bone thickness and sectional modulus; a geometric index of bone bending strength), were measured at the hip.

Body mass and composition (total tissue mass, lean muscle mass, fat mass) was also measured using DXA, as this technology is one of the methods considered as "Gold Standard" for this measurement [41,42]. Precision and calibration were carried out in accordance with manufacturer instructions. Participants were instructed to standardize clothing (workout clothing without metal), and nutrition (maintain hydration and not be fasted), for each scanning session. Significant correlations ($p < 0.001$) were observed for all measures and reliability was excellent for all bone mineral density (ICC's = 0.99 - 1.00; CV's = 0.31% - 1.25%), bone mineral content (ICC's = 0.98 - 1.0; CV's = 0.43% - 1.53%), hip structural analysis of the narrow neck (cortical thickness, cross-sectional area and section modulus) (ICC's = 0.99 - 1.0; CV's = 1.45% - 1.56%) and body composition measures (ICC's = 1.0; CV = 0.52% - 1.23%).

Performance testing: For each testing session, participants performed a ten-minute standardized warm up prior to testing that consisted of easy cycling on a stationary Wattbike (Wattbike Trainer, Nottingham, United Kingdom) followed by dynamic stretching and bodyweight mobilization exercises. Testing commenced five minutes after the warm up. All instructions, and order of performing tests was standardized for every participant. All testing for this study was undertaken at a similar time of day with participants instructed to maintain their normal dietary intake before and after each testing session. Participants completed an activity questionnaire between testing sessions to monitor physical activity and ensure that inter-session physiological status was similar. We did not control for nutrition, or hydration levels but participants were told not to make any changes in the above during the testing period.

Muscle reactivity: Participants were instructed to step off a 20 cm step and land with both feet together on a contact mat (Swift Performance Equipment, Queensland, Australia), and jump again as quickly as possible (i.e. to think of the mat as a 'hot plate'). Each participant performed two practice jumps, followed by two jumps, where ground contact time (ms) was collected. Each jump was separated by a 30- second rest interval. The best (shortest) ground contact time of the two jumps was used for analysis.

Leg extensor power: The Vertec Yardstick (Swift Performance Equipment, Queensland, Australia), a portable device used to measure vertical jump height, was used to determine jumping ability and as a surrogate measure for tracking change in lower body explosive power [43,44]. Before jump commencement the participants reach height was determined, then they were encouraged to use a countermovement arm swing to jump and touch the highest vane of the Vertec device. Each participant performed three maximal vertical jumps, with each jump separated by a 30-second rest interval. The maximum jump height was used for analysis.

Introduction to the 'Jump-landing program'

A 4-week phase of strength and conditioning (neural adaptation program) was implemented prior to the introduction of the jump-landing program to adequately prepare JL participants for the impact intensities prescribed [31]. Participants were required to attend weekly group exercise sessions (jump-landing classes) and perform the jump-landing program in a group environment. These were instructional sessions for participants to demonstrate proper technique for each of the jumps in the jump-landing program. This requirement was expected to positively affect compliance to the program by creating a 'club like environment as well as providing regular opportunities to monitor participants jumping proficiency [45].

The jump-landing program: Participants were introduced to the bilateral vertical and multidirectional jumps [22, 46] combined with a reactive jump which had previously been quantified and shown to easily exceed osteogenic thresholds which achieved BMD gains premenopausal women [22]. The unilateral jumps were implemented six months into the jump-landing program, and were demonstrated and practiced before they were introduced. For bilateral jumps, participants were instructed to land as if the ground was a "hot plate" (first jump-landing; reactive jump), and to immediately jump again for maximal height before landing again (second jump-landing; post-reactive jump). For unilateral jumps, participants were asked to land stiffly and to minimize knee flexion. Participants in the CON were asked to maintain their normal activity level.

The jump-landing program was designed to progressively increase in magnitude and rate of strain, number of ground contacts (32 - 42 per day), frequency (2 - 5 sessions per week), and technical difficulty (i.e. bilateral to unilateral) over the 12-month period (see supplementary content). Therefore it was necessary to utilize data obtained from previously quantified jump-landings to determine the order these exercises should be introduced into the osteogenic jump-landing program [22]. A stress stimulus rating was developed based on previously determined jump-landing force variables for each of the jumps utilized in the 12-month periodized program. The minimum adherence threshold determined for performing the jump-landing program was set at an average of 3-times each week over the 12-month program.

Each jump was separated by a 5-second interval, with 30-seconds rest inserted between each set (4 -5) of jumps, as adequate recovery between loading cycles has been shown to maintain the mechano-sensitivity of bone and optimize the osteogenic response [47,48]. All jumps in this study were performed barefooted as researchers have suggested the natural elastic components of the body provide a greater protective effect than artificial footwear against excessive load during voluntary exercise [6,12].

Website and social media: The JL were emailed their exercise programs and were provided additional resources via a 'Bone health study' website. Compliance to the exercise regime during the intervention period was monitored via a 'Jump-tracker' feature on the website, which was filled in weekly and uploaded to a group spreadsheet that was accessed online. Regular feedback was provided using weekly infographics, emails, phone calls and text messages (eTXT), with participants encouraged to contact the researcher any time about any concerns or issues they might have. The use of social media platform 'Facebook' was also utilized to allow social interaction among participants to promote greater 'buy in' and thus adherence to the training study over the 12-month period.

Statistical analyses

A restricted maximum likelihood linear mixed model (LMM) with fixed effects was performed to investigate the effect of the variables 'group' (JL and CON) and 'time' for all clinically relevant dependant variables. This method could accommodate for correlated data, unequal variances and missing data points encountered in the longitudinal dataset. Basic analytic assumptions were met: data were of normal and equal variance. The Sidak confidence interval adjustment was used to compare all main effects. Significance was accepted at the $p \leq 0.05$ level. Percentage changes and modified effect sizes (ES = mean change/standard deviation of the sample scores) using ratios of 0.10 - 0.19, 0.20 - 0.29, ≥ 0.30 indicating small, moderate and large changes, respectively, were calculated to determine the magnitude of change of bone from baseline to 12-months. The modified effect size classification was calculated based on significant improvements (ES = 0.15 to 0.26) on BMD previously reported in this population [13,33,49]. Cohen's classifications of effect size (0.2 to 0.5, 0.51 to 0.8 and >0.8) [50] were calculated to determine the magnitude of the change differences for all other variables (body composition and performance parameters) between the two groups. The smallest worthwhile change (%) for each dependant variable was calculated (SWC = ES * Standard Deviation). Coefficients of variation (CV) were also calculated (CV = SD/mean * 100) for each dependant variable. All statistical analyses were carried out using SPSS 25.0 for Windows (SPSS Inc., Chicago, IL, USA) and Microsoft Excel (version 9.0; Microsoft, Seattle, WA).

Results

All JL participants performed the jump-landing program an average of 3-times each week over 12-months, as determined using a self-reported online jump tracker. The required minimum adherence for participating in the JL program was 3-times each week, which equated to 80% adherence to the JL program. Although all JL participants met this inclusion criteria for analysis in this study, eight participants were removed due to participation in additional high impact physical activity, as determined by 3-monthly activity questionnaires. Data obtained from these questionnaires reported no injury or adverse effects relating to performance of the jump-landing program (Figure 1).

Total Body BMD and BMC

No significant main effects were observed for total body BMD, however a small increase occurred in the JL (↑2.34%; E = 0.17) compared to a trivial loss in the CON (↓0.12%; ES = -0.01). Both groups reported a loss in total body BMC, with a moderate bone loss occurring in the CON (↓2.49%; ES = -0.26) compared to a trivial loss in the JL (↓0.82%; ES = -0.05) (Table 2).

Femoral Neck

Significant group effects in favour of the JL for femoral neck BMD (↑3.44% versus ↓0.19; df =263, F = 11.08, p = 0.001), BMC (↑2.61% versus ↓0.11; df 252, F = 6.65, p = 0.011), femoral narrow neck cross-sectional area (CSA) (↑2.78% versus ↓0.64; df =247, F = 6.65, p = 0.004) and cortical thickness (↑3.84% versus ↑0.84; df =261, F = 9.77, p = 0.002) were observed. Small to moderate positive changes (based on modified ES classifications) were observed for all femoral neck variables between baseline and 12-months (ES = 0.13 to 0.20) for the

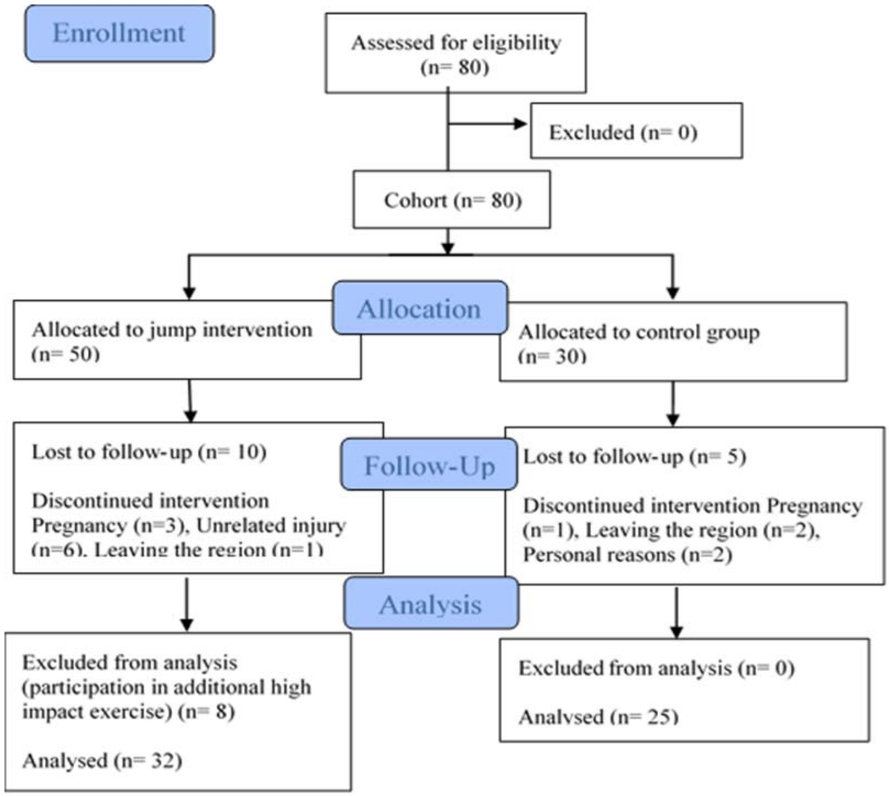

Figure 1: A flow diagram depicting the recruitment and retention of participants during the study.

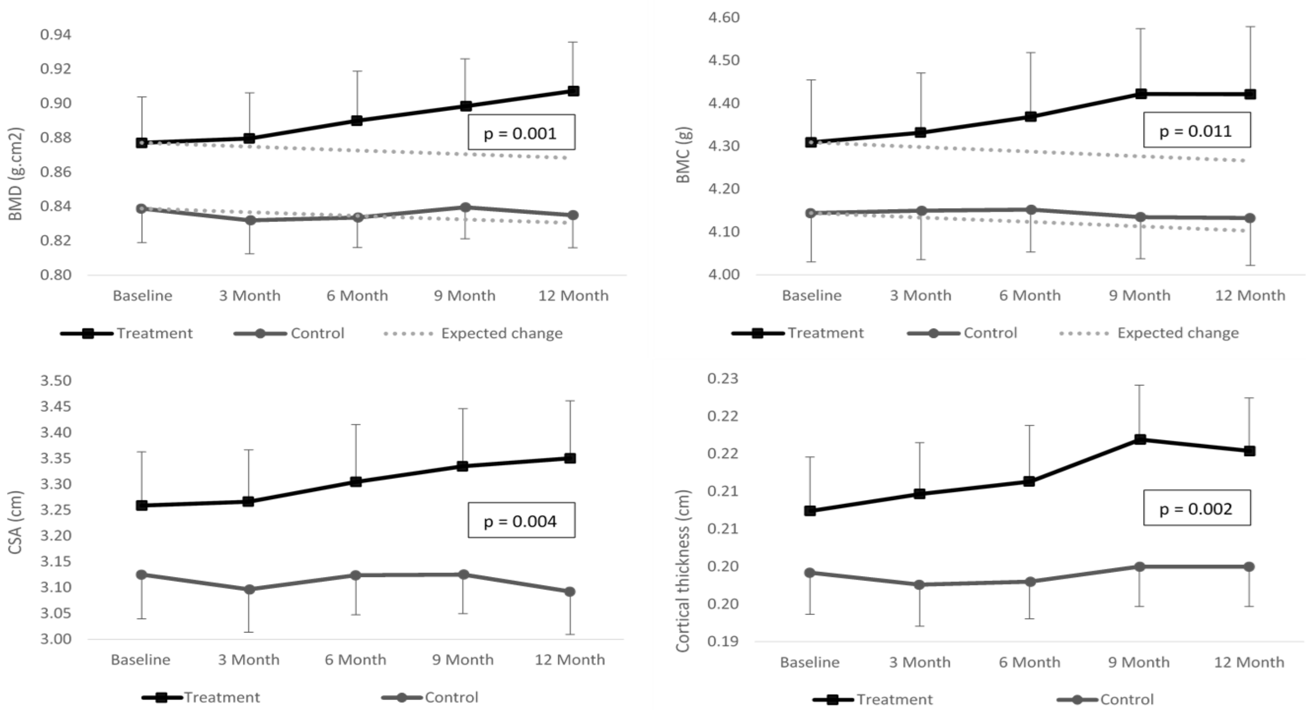

Figure 2: The jump and control group average time course of change for femoral neck bone mineral density (top left), bone mineral content (top right), and femoral narrow neck cross sectional area (bottom left) and cortical thickness (bottom right) across the 12-month study duration. P values depict significant group main effects.

Table 2: Within group changes and effect sizes in bone from baseline to 12-months.

	Jump (n = 32)					Control (n =25)				
	Baseline	12 months	Percentage Change (%)	SWC (%)	ES	Baseline	12 months	Percentage Change (%)	SWC (%)	ES
Total body										
Bone mineral density (g·cm^2)	1.01 ± 0.14 (0.96 - 1.06)	1.03 ± 0.14 (0.98 - 1.08)	2.34	0.19	0.17^t	0.98 ± 0.09 (0.94 - 1.02)	0.98 ± 0.09 (0.94 - 1.02)	-0.12	0.19	-0.01
Bone mineral content (g)	2344 ± 369 (2216 - 2472)	2324 ± 348 (2203 - 2445)	-0.82	0.14	-0.05	2323 ± 225 (2235 - 2411)	2265 ± 227 (2176 - 2354)	-2.49	0.16	-0.26*
Femoral neck										
Bone mineral density (g·cm^2)	0.88 ± 0.15 (0.83 - 0.93)	0.91 ± 0.15 (0.86 - 0.96)	3.44	0.19	0.20*	0.84 ± 0.15 (0.78 -0.90)	0.84 ± 0.10 (0.80 -0.88)	-0.15	0.34	-0.01
Bone mineral content (g)	4.31 ± 0.84 (4.02 - 4.60)	4.42 ± 0.83 (4.13 - 4.71)	2.61	0.36	0.13^t	4.14 ± 0.59 (3.91 -4.37)	4.13 ± 0.55 (3.91 4.35)	-0.11	0.4	-0.01
Cross-sectional area (cm^2)	3.26 ± 0.60 (3.05 - 3.47)	3.35 ± 0.60 (3.14 -3.56)	2.78	0.19	0.15^t	3.11 ± 0.44 (2.94 - 3.28)	3.09 ± 0.42 (2.93 3.25)	-0.64	0.33	-0.05
Cortical thickness (cm)	0.21 ± 0.04 (0.20 - 0.22)	0.22 ± 0.04 (0.21 - 0.23)	3.84	0.45	0.20*	0.20 ± 0.03 (0.19 -0.21)	0.20 ± 0.03 (0.19 -0.21)	0.84	0.55	0.06
Section modulus, Z (cm^3)	1.54 ± 0.32 (1.43 - 1.65)	1.59 ± 0.33 (1.48 - 1.70)	3.2	0.51	0.15^t	1.47 ± 0.26 (1.37 - 1.57)	1.46 ± 0.26 (1.36 -1.56)	-0.4	0.49	-0.07
Total hip										
Bone mineral density (g·cm^2)	1.01 ± 0.14 (0.96 - 1.06)	1.03 ± 0.14 (0.98 -1.08)	2.3	0.19	0.17^t	0.98 ± 0.09 (0.94 -1.02)	0.98 ± 0.09 (0.94 - 1.02)	-0.12	0.19	-0.01
Bone mineral content (g)	34.2 ± 6.23 (32.0 -36.4)	35.5 ± 7.01 (33.1 -37.9)	3.72	0.45	0.19^t	33.0 ± 4.77 (31.1 - 34.9)	33.4 ± 4.73 (31.6 -35.3)	1.26	0.36	0.09
Lumbar spine (L1-L4)										
Bone mineral density (g·cm^2)	1.11 ± 0.12 (1.07 - 1.15)	1.11 ± 0.13 (0.98 -1.24)	0.41	0.26	0.04	1.05 ± 0.09 (1.01 - 1.09)	1.05 ± 0.09 (1.01 - 1.09)	-0.15	0.33	-0.02
Bone mineral content (g)	67.2 ± 14.2 (62.3 - 72.1)	69.3 ± 13.5 (53.7 -80.7)	3.13	0.37	0.15^t	63.8 ± 8.34 (60.5 -67.1)	64.1 ± 8.31 (60.8 -67.4)	0.45	0.41	0.03

Within group baseline and 12-month data expressed and mean ± SD with percentage changes and effect sizes for each variable. ES: Effect Size, t small ES; * moderate ES, SWC: Smallest Worthwhile Change (SWC = ES 0.1 * Standard Deviation). Values in brackets denote 95% Confidence Intervals.

Table 3: Within group changes and effects in body composition and performance parameters from baseline to 12-months.

	Jump (n=32)					Control (n=25)				
	Baseline	12-months	Percentage Change (%)	SWC (%)	ES	Baseline	12-months	Percentage Change (%)	SWC (%)	ES
Body Composition										
Fat free mass (kg)#	48.1 ± 5.9 (46.1 -50.1)	50.7 ± 6.2 (48.6 - 52.9)	5.44	0.72	0.43^t	47.0 ± 6.9 (44.3 - 49.7)	49.2 ± 7.0 (46.5 - 51.9)	4.63	0.72	0.32^t
Fat mass (kg)#	22.9 ± 7.3 (20.4 -25.4)	19.5 ± 6.4 (17.3 - 21.7)	-15	-2.2	0.50*	22.9 ± 7.3 (20.0 - 25.8)	20.1 ± 6.8 (17.4 - 22.8)	-8.86	-2.18	-0.40^t
Body fat (%)#	31.7 ± 6.6 (29.4 -34.0)	27.4 ± 6.1 (25.3 - 29.5)	-13.8	-1.79	0.68*	31.3 ± 5.8 (29.0 -33.6)	28.3 ± 5.8 (26.0 -30.6)	-9.56	-1.82	-0.52*
Vertec										
Vertical Jump (cm)	34.9 ± 7.4 (32.3 -37.5)	37.5 ± 6.4 (35.3 - 39.7)	7.54	3.35	0.38^t	35.4 ± 5.4 (33.3 - 37.5)	35.3 ± 7.1 (32.5 - 38.1)	-0.24	3.11	-0.01
Contact Mat										
Ground contact time (ms)	0.31 ± 0.10 (0.28 -0.34)	0.24 ± 0.05 (0.22 -0.26)	-21.9	-5.62	0.91^	0.27 ± 0.10 (0.23 - 0.31)	0.30 ± 0.09 (0.26 -0.34)	8.86	-5.41	0.26^t

Within group baseline and 12-month data expressed as mean ± SD with percentage changes and effect sizes over the 12 months presented for each variable. ##DXA, ES: Effect Size, t small ES; * moderate ES, ^ large ES, SWC: Smallest Worthwhile Change (SWC = ES 0.2 * Standard Deviation). Values in brackets denote 95% Confidence Intervals.

JL (Figure 2).

A significant group effect in favour of the JL for section modulus (a geometric index of bone bending strength at the femoral narrow neck) (↑3.22% *vs.* ↓0.43, df =265, F = 7.15, p = 0.008) was observed. The effect size between baseline and 12-months demonstrated a small worthwhile change (ES = 0.15) in section modulus (Figure 3).

Total Hip BMD and BMC

A significant group effect in favour of the JL for total hip BMD (↑2.34% *vs.* ↓0.12%; df =257, F = 7.20, p = 0.008) and total BMC (↑3.72% *vs.* ↑1.26; df =257, F = 4.96, p = 0.027) was observed. Small to moderate increases were observed for the JL for total hip BMD and BMC baseline and 12-months (ES = 0.17 - 0.19) (Figure 4).

Total Lumbar Spine BMD and BMC (L1 - L4)

A significant group effect in favour of the JL for total lumbar BMD (↑0.41% *vs.* ↓0.15%; df = 253, F = 13.21, p < 0.001) and total lumbar BMC (↑3.13% *vs.* ↑0.45%; df =236, F = 7.57, p = 0.006) were observed. Small worthwhile increases (ES = 0.15) in total lumbar BMC were observed for the JL between baseline and 12-months (Figure 5).

Body composition

A significant time effect (df = 263, f = 3.077, p = 0.017) was observed for fat percentage with moderate losses being observed in both the JL (↓13.8%; ES = -0.68) and CON (↓9.56%; ES = -0.52) over the study duration. While small increases in fat free mass (↑5.44% and ↑4.63%, ES = 0.43 and 0.32) and small to moderate reductions in fat mass (↓15.0% and ↓8.86%; ES = -0.50 and -0.40) were identified between baseline and 12-months for both the JL and CON (respectively), no significant main effects were observed over the 12-months (Table 3).

Performance parameters

A significant group X time interaction (df =244, F = 3.27, p =

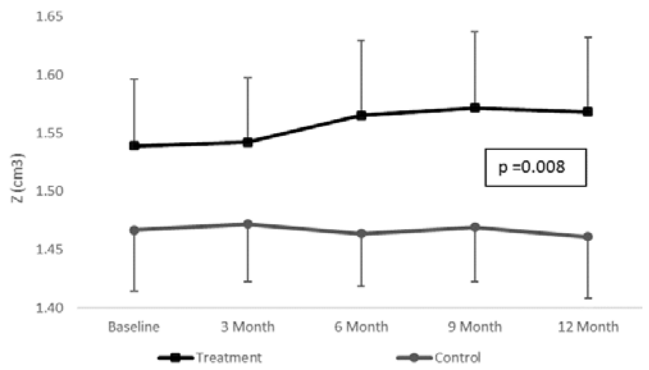

Figure 3: The jump and control group average time course of change for section modulus at the femoral narrow neck (Z cm^3) across the 12-month study duration. P value depicts significant group main effect.

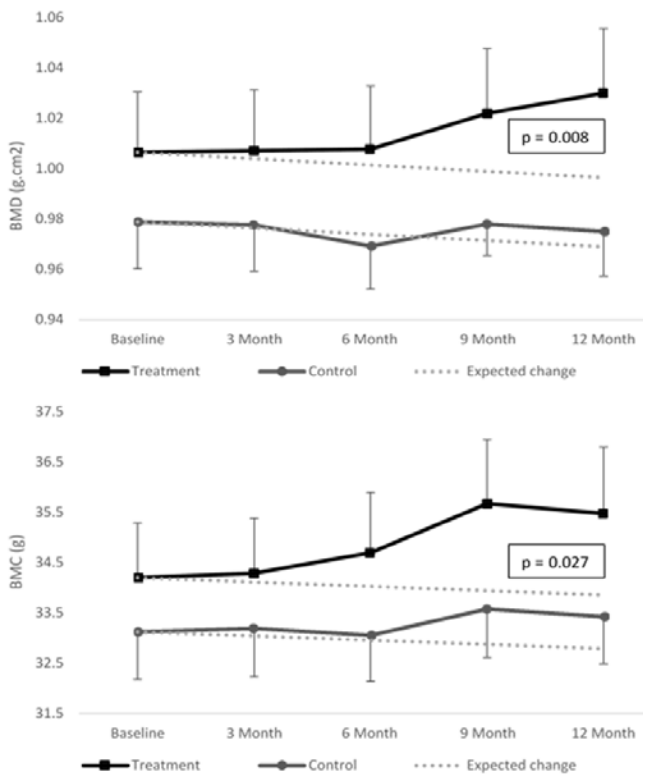

Figure 4: The jump and control group average time course of change for section modulus at the femoral narrow neck (Z cm^3) across the 12-month study duration. P value depicts significant group main effect.

0.012) and a significant effect for time (df =244, F = 2.92, p = 0.022) was observed for ground contact time. Significant group effects in favour of the JL were also observed (↓21.9% *vs.* ↑8.86%; df 244, F = 6.10, p = 0.014), representing large reductions (ES = -0.91) in ground contact time achieved over the 12-month study. No significant effects were observed in the vertical jump, however group effects that approached significance were in favour of the JL (↑7.54% *vs.* ↓0.24%, df =244, F = 3.22, p = 0.074) (Figure 6).

Discussion

This study is unique in its presentation of a quantified periodized,

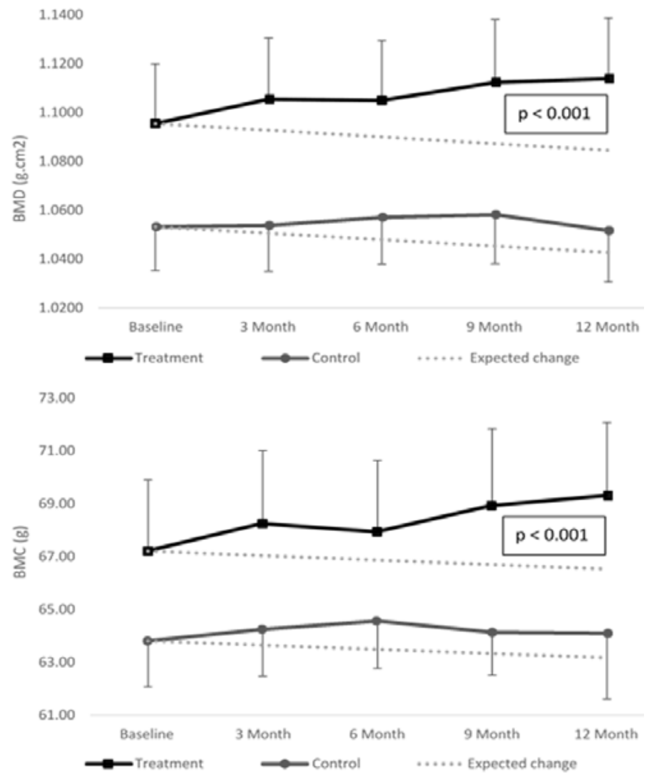

Figure 5: The jump and control group average time course of change for total lumbar spine (L1-L4) bone mineral density (top) and bone mineral content (bottom), across the 12-month study duration. P values depict significant group main effects.

jump-landing program on parameters of bone strength and overall fracture resistance for premenopausal women over a 12-month period. The main findings of the current study support the initial hypotheses and demonstrate that a quantified jump landing program performed over 12-months can; (i) Improve bone health (compared to the CON) with significant (p < 0.05) worthwhile improvements being observed in lumbar spine BMD and BMC (↑0.41 to ↑3.13%; ES = 0.04 and 0.15, respectively), and femoral neck BMD and BMC (↑3.44% and ↑2.61%; ES = 0.20 and 0.13, respectively) measures; (ii) Achieve significant (p < 0.01) improvements in bone geometry variables at the femoral neck (↑2.78 - ↑3.84%; ES = 0.15 – 0.2) in the JL with losses (↓0.64 - ↓0.84%; ES = -0.05 - -0.07) being observed in the CON, except a trivial increase for cortical thickness (↑0.84; ES = 0.06); (iii) Improve jump performance parameters with significant increases (p < 0.05) in muscle reactivity (↓21.9%; ES = -0.91) and non-significant increases in vertical jump performance (↑7.54%; ES = 0.38), for the JL, in contrast to the performance decrements observed in the CON (↑8.86% and ↓0.24%; respectively); (iv) Improve body composition changes, however contrary to the initial hypothesis a significant time effect (p = 0.017) was observed for body fat percentage with moderate fat losses observed in both the JL (↓13.8%; ES = -0.68) and CON (↓9.56%; ES = -0.52).

In the current study, we observed significant (p < 0.01) BMD gains at the femoral neck (↑3.44%) and the total hip (↑2.34%) for the JL, compared to the CON, where a reduction in BMD was observed (↓0.11% to ↓0.15%). Our findings have important clinical

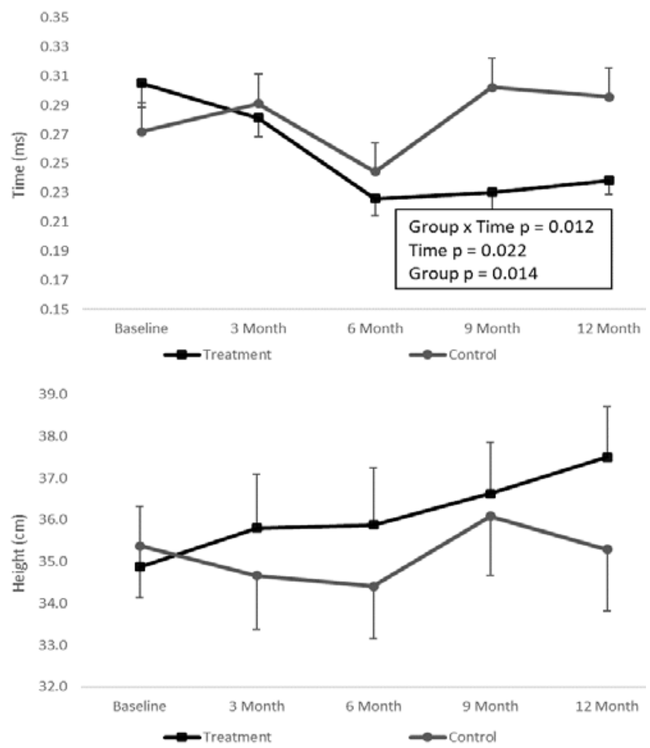

Figure 6: The jump and control group average time course of change for ground contact time (top) and vertical jump height (bottom), across the 12-month study duration. P values depict significant interactions and main effects.

implications with reference to the 1% per year expected bone loss at this site for women between 40 and 50 years old [4]. The significant ($p < 0.05$) gains also observed for BMC for femoral neck and total hip (↑2.61% and ↑3.72%, respectively) in our JL suggest that the increase of bone mass at the femoral neck site are an 'actual' gain and not just a reallocation of existing hip bone mineral. In comparison, the CON experienced small losses in BMC at the femoral neck (↓0.11%), suggestive that the stimulus provided by the jump-landings was effective in targeting the hip region, and specifically the femoral neck.

Researchers have suggested that jump-landings would not provide an effective stimulus for individuals aiming to improve bone strength at the spine, and recommend upper body resistance exercises as a better option [33]. We however observed significant ($p < 0.001$) gains in BMD (↑0.41%) at the lumbar spine (L1 - L4) for our JL, with BMD losses occurring in the CON (↓0.15%). Our JL also amassed significantly ($p < 0.01$) greater BMC than the CON at the lumbar spine (L1 - L4) (↑3.13% *vs.* ↑0.45%, respectively). Such results demonstrate that the lower body focused jump-landings utilized in this study were able to provide the required stimulus for positive bone adaptation at this additional clinically relevant site.

In this study, the JL achieved significant ($p < 0.01$) increases in bone geometry variables at the narrow neck (narrowest section of the femoral neck) including; cross-sectional area (CSA) (↑2.78% *vs.* ↓0.64), cortical thickness (↑3.84% *vs.* ↑0.84) and section modulus (a measure of bone stiffness closely related to the bending and torsional strength of bone) (↑3.22% *vs.* ↓0.43), when compared with the CON. Interestingly, studies showing large increases in BMD and BMC resulting from pharmacologic therapy result in very small increases in fracture resistance [51]. In comparison, mechanical loading as determined using animal studies achieved smaller gains in BMD and BMC, which translated to very large increases in bone strength and resistance to fracture (64 - 94%) [9].

Researchers have suggested that targeting exercises that reduce the likelihood of falling by improving muscle strength, balance, mobility & posture should also be included in an osteoporosis prevention programme [10,52]. Our JL improved their maximal jumping ability (↑7.54%), in contrast to the CON who experienced a reduction in lower body explosive power (↓0.24%). Similarly, improvements ($p < 0.05$) were observed in the JL for lower body muscle reactivity (determined by reduced ground contact time when performing a drop jump) when compared with the CON (↑21.9% *vs.* ↓8.86%, respectively). The reduction in ground contact time observed in the JL participants may be attributed to stretch shortening cycle adaptations induced from performing the reactive jump and thereby the stretch shortening cycle [26,53].

All participants in the current study experienced favourable body composition changes, with moderate body fat percentage losses observed in both the JL (↓13.8%; ES = -0.68) and CON (↓9.56%; ES = -0.52). In addition, JL and CON participants experienced small increases in fat free mass (↑5.44% and ↑4.63%, respectively), over the 12-month study period. Previous research has associated lean mass with linear increases in hip bone strength (BMD and CSA) in postmenopausal women [54,55], and in premenopausal women (BMD and section modulus) [56], suggesting that gravitational loading, muscle-contractions and associated hormonal factors may be responsible for the positive relationship between skeletal muscle and bone. In addition, a recent study investigating the relationship between body composition and osteoporosis including premenopausal women (n = 10, 884) concluded that individuals with low strength and low muscle mass were two times more likely to have osteopenia or osteoporosis [57].

Our original hypothesis posed that gains in muscle and losses in body fat would only be observed in the JL, and therefore our results possibly obscure the training effect we expected from the jump-landing program. However, activity questionnaires completed at each testing session (3-monthly intervals), showed that physical activity levels (walking, cycling and resistance training) had increased substantially from baseline for the CON and may explain the changes observed. We concluded that sharing DXA body composition results with the participants (both JL and CON) during the study period, whilst potentially helpful in improving study adherence, was a limitation to the study design with participants stating this increased their motivation to make positive lifestyle changes. Interestingly, although improvements in body composition were observed for the CON, their increased participation in non-weight bearing exercise did not translate into gains in BMD. In addition, the initial assignment of some participants to either group (JL or CON) based on their choice, may be need to be considered when interpreting the findings from this study. This limitation is acknowledged by using a controlled trial experimental design, as the primary focus was to determine the "true effect" of the mechanical stimulus provided by the jump-landing programme, which required long-term adherence.

To the author's knowledge, this is the first study to assess the effect of a 12-month periodized and quantified osteogenic exercise programme using low repetition, rapid-onset, high-intensity jumps offering unusually distributed strains, and utilizing a repeated jump-landing technique. This study has shown that a brief (2 - 3 minute) quantified osteogenic jump-landing program performed at least 3 times a week can not only maintain bone health but can reverse the trend of expected age-related bone loss at these clinically relevant sites [22]. Thus, it can be concluded that such preventative interventions which are cost-effective and easily implemented in the home setting represent a "window of opportunity" for premenopausal women to prevent or delay the time before the fracture threshold is surpassed in the postmenopausal years. In addition to improving overall bone health during a life-stage normally associated with progressive bone losses, the regular performance of jump-landings with a reactive component may also contribute to a reduced falls risk by improving muscle strength and reactive muscle qualities.

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