Targeting bone and fat with novel exercise for peripubertal boys:

The CAPO Kids trial

**Short title:** Exercise, bone and fat in boys

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ABSTRACT

To test the effect of a brief, novel bone- and fat-targeted exercise program on bone, muscle and fat in healthy pre and peripubertal boys. We conducted a 10-min, 3/wk capoeira and jumping exercise intervention for 9 months with year 5 and 6 school boys. Anthropometrics, maturity, heart rate, blood pressure, maximal vertical jump, aerobic capacity and calcaneal broadband ultrasound attenuation and stiffness index (BUA and SI; Achilles, GE) were assessed. Bone, lean and fat tissue (DXA; XR800, Norland), and parameters of bone geometry (pQCT, XCT3000, Stratec) were measured from a subsample of 36 boys.

Of 188 boys (10.6±0.5 yr) who consented, 172 completed all testing; 104 exercisers (EX) and 68 controls (CON). 30 EX and 6 CON participants underwent DXA and pQCT measures. EX improved BUA (+4.3% vs. +2.1%, \( p=0.035 \)), waist circumference (+2.8% vs. +6.2%, \( p=0.001 \)), heart rate (-5.3% vs. +1.5%, \( p=0.005 \)), maximal vertical jump (+12.2% vs. -0.3%, \( p=0.001 \)) and estimated maximal oxygen consumption (+9.1% vs. +1.2%, \( p=0.001 \)) compared to CON. Three 10-min sessions of capoeira and jumping per week improved calcaneal bone and metabolic health of pre and peripubertal boys over the course of a school year with little disruption to the academic schedule.

**Key words**: bone; lean mass; obesity; pediatric; exercise; physical activity.
INTRODUCTION

It is well recognized that childhood and adolescence represent critical periods for bone growth (50). It is also known that excess body fat accumulated in youth typically tracks into adulthood, leading to increased risk of chronic metabolic diseases (9, 39). In light of the important positive influence of exercise on both bone and fat tissue (33), childhood is considered something of a “window of opportunity” to apply physical activity to enhance bone and prevent the accumulation of excess fat to secure lifelong health benefits (8, 15).

Currently however, worldwide, most children do not meet Australia’s Physical Activity and Sedentary Behaviour Guidelines for healthy levels of physical activity in youth nor the American College of Sports Medicine Physical Activity Guidelines (2, 36). The situation likely contributes to the increased prevalence of overweight children, and an associated increased risk of developing metabolic diseases and sustaining fractures in youth and later life (5, 44). Increasing physical activity levels of children not currently meeting the guidelines is an obvious but challenging solution to a growing public health crisis.

Opportunity and inclination are the primary obstacles to widespread adoption of increased childhood physical activity, and important targets for encouraging greater engagement, thus appealing activities that are easily incorporated into the school routine should be identified.

Brief, rapid, high impact, weight bearing exercise is the most osteogenic (11, 12). By contrast, sustained low impact aerobic exercise is typically recommended to reduce or prevent overweight, and resistance training most effectively improves lean mass. The disparity between exercise recommendations for the skeletal and metabolic systems has created challenges for holistic exercise prescription. However, only a small degree of creativity is required to develop activities that incorporate elements of each form of training, and novel programs can be particularly appealing to children. Nevertheless, to date, no
researchers have attempted combination exercise interventions specifically to target bone and fat for kids. Although women are at greatest risk of osteoporosis (21), there is also a strong relationship between bone mineral density and risk of fracture in men. Moreover, men suffer a higher risk of mortality after hip fractures than women (4). Although it has not yet been fully established if fractures in old age can be prevented by enhancing bone in youth, there is evidence to suggest it may be the case (13, 49). Thus, increasing levels of exercise of growing boys would be a strategy to reduce the burden of morbidity and mortality of male osteoporosis in the aging population (12, 24).

The aim of the current study then, was to test the efficacy of a brief, novel and enjoyable bone- and fat-targeted exercise program on parameters of bone, muscle and fat in healthy pre and peripubertal boys over the course of a school year. We hypothesized that the exercise group would experience greater improvements in parameters of bone, muscle and fat than age-matched controls.

METHODS

Participants

One hundred and eighty-nine boys enrolled in years 5 and 6 at two local primary schools (Gold Coast, Queensland, Australia) were initially included in the study. Students were excluded if they: were taking medications known to affect bone, muscle or metabolism; had limb injuries or been immobilized in the previous six months; or had any condition not compatible with a 10-minute bout of moderate to vigorous physical activity. Ethical approval was obtained from Griffith University Human Research Ethics Committee (PES/25/11/HREC). As both schools chose to incorporate the CAPO Kids activities
(exercises and/or testing) into their curriculum (irrespective of our study), all students
performed the specific activities delivered at each school. We requested consent from the
children to include their data from the testing activities in our analysis and all children did so.
Parents were requested to decline to consent if they did not wish their child’s data to be
included in the study analysis. The parents of only a single student from the control school
declined to consent.

Experimental design

A nine-month, cluster controlled trial was designed to address our hypotheses. The two
participating schools were randomly assigned to control (CON) or exercise (EX) sites by a
coin toss. The EX school adopted a 10-minute exercise intervention as part of its daily class
schedule on three consecutive days each week and sessions took place every week of the
school year with the exception of scheduled holidays. The aim of the intervention activities
was to target multiple physiological systems to improve indices of cardiovascular and
metabolic health, body composition and physical performance, with minimal disruption to the
daily class schedule. Testing took place at baseline (T0, Feb/2012) and follow-up (T9,
Dec/2012).

School-based exercise intervention

The intervention program was fundamentally based on capoeira, a Brazilian sport that
contains mixed elements of martial arts and dance. Capoeira movements were supplemented
with a combination of medium to high impact manoeuvres intended to load the upper and
lower limbs. Each exercise bout was led by a single instructor (RN), and comprised 10
minutes of continuous high intensity movements. All exercise sessions were held during
school hours, before lunch break for Year 5 participants (n = 57) and after lunch break for
Year 6 (n = 50). Each session was led by a single investigator (RN). Up to three classroom
teachers were present to provide general supervision. Activities in each session varied from day to day, however each was composed of several high impact movements, such as repetitive jumps and hops (with maximal effort) combined with *capoeira*-specific movements (with an emphasis on high speed execution) (Table 1). Initially (first two months), a typical session was composed of learning how to perform the *ginga*, followed by around 60 jumps, 20 kicks and 15 cartwheel and handstand practice. Repetition and intensity was progressively increased over the course of the year, such that a typical session in the final stages would entail a warm up with the *ginga*, followed by an average of 120 jumps, 30 kicks and 20 to 30 inverted movements such as handstands or cartwheels. Children were occasionally given small prizes such as sports balls and game vouchers to reward participation and performance.

**Control group activities**

Control school participants took part in baseline and follow up testing under the guise of an educational activity to learn about measures of health. Otherwise, CON boys participated in their usual school activities across the course of the year, unaware of the exercise activities carried out at the intervention school or the overall purpose of the study. The control school was well-matched to the intervention school in terms of student demographics, school fees, school hours, teacher-student ratio, and usual physical education regime.

**Data collection**

Anthropometrics, physical performance measures, and measures of bone, muscle and fat were performed at baseline (T0) and follow up (T9). The majority of measures were taken during physical education (PE) classes (i.e. anthropometrics, metabolic and physical performance measures, and calcaneal ultrasound measures), and a small subset of participants attended the Griffith University’s Bone Densitometry Research Laboratory for dual-energy x-ray absorptiometry (DXA) and peripheral quantitative computed tomography (pQCT) measures.
Anthropometrics

Height and sitting height were measured using a portable stadiometer (HART Sport and Leisure, Brisbane, Queensland, Australia) and a 50 cm flat stool, while body weight was measured in kg using digital scales (Soehnle, Hamburg, Switzerland). Waist circumference was measured using an anthropometric tape measure (Lufkin Executive Thinline, Apex, USA). The tape was positioned at the mid-point between the margin of the lowest pair of ribs and the iliac crest, taken at the end of gentle expiration (51). Neither weight, nor waist circumference were divulged to participants at the time of testing.

Maturity assessment

Years from the age of peak height velocity (YAPHV) were estimated using the algorithm developed by Mirwald and colleagues (31) to provide a marker of biological maturity. The algorithm incorporates sex, age, height, sitting height and weight in order to predict the timing of peak height velocity based on regression data from a large pediatric longitudinal trial.

Performance measures

Maximal vertical jump height was used as an index of lower limb muscle power using a Yardstick device (Swift Performance Equipment, Brisbane, Queensland, Australia). The height of a standing reach was recorded with the participant standing with feet shoulder-width apart, shoulders level, and preferred arm raised with extended elbow, wrist and fingers. After a practice attempt, five jumps for maximal height were performed in countermovement fashion without arm swing to touch the highest possible peg on the Yardstick. Maximal vertical jump height was determined as the difference between the height of a standing reach and the best total jump height.
Aerobic capacity was determined using a 20-metre shuttle-run test, from which maximal oxygen consumption (VO₂ max) was estimated using the algorithm:

\[ VO₂ \text{ max} = 31.025 + (3.238 \times velocity) - (3.248 \times age) + (0.1536 \times age \times velocity) \]

As described by Léger (16), participants ran between two points marked on the ground 20 meters apart. A pre-recorded audible tone sounded at progressively shorter intervals to determine lap speed. Once the participant was unable to meet the required speed on successive laps, the number of his/her level was recorded and the associated velocity was entered into the algorithm along with age to estimate VO₂ max (ml/kg/min).

**Cardiovascular measures**

Resting heart rate (beats/min) and resting blood pressure (mmHg) were measured using standard procedures. A single investigator (RN) measured heart rate from the radial pulse after the participant had rested for 15 minutes in the supine position. Systolic and diastolic brachial blood pressures were measured from the left arm of each participant while in the seated position. A stethoscope, sphygmomanometer and inflatable cuff were used to detect the first and fifth Korotkoff sounds per usual practice (52).

**Lifestyle measures**

Physical activity participation and dietary calcium intake were estimated using validated questionnaires. The bone-specific physical activity questionnaire (BPAQ) was used to quantify bone-relevant physical activity participation (46). Participants were asked to record all regular physical activities they have participated in during their life and to indicate the years when participation took place. Participants additionally recorded the type and frequency of all current physical activities (i.e. previous 12 months). Total BPAQ score was calculated by using current and past BPAQ scores, which were calculated from questionnaire responses with an on-line calculator (http://www.fithdysign.com/BPAQ/). Intraclass
correlation coefficients (ICC) for intra- and interoperator reliability for the BPAQ have previously been reported as 0.93, 0.97 and 0.97, and 0.86, 0.93 and 0.92, respectively for current, previous and total BPAQ-derived physical activity scores (48).

Daily dietary calcium intake was estimated using the Australian Child and Adolescent Eating Survey food frequency questionnaire (ACAES) (45). The questionnaire is composed of 120 items relating to diet, and 15 additional questions about age, vitamin use and sedentary behaviour. Participants were asked to complete the questionnaire during class time, based on food intake in the previous three days. The self-administered questionnaire is validated for Australian children from nine to sixteen years old. Completed questionnaires were computer analysed remotely per the questionnaire guidelines.

**Bone and body composition measures**

Quantitative ultrasonometry (Lunar Achilles™ Insight, GE) was employed to determine broadband ultrasound attenuation (BUA) (dB/MHz) and stiffness index (SI) (%) of the calcaneus. Least significance change (LSC) for BUA and SI from a subsample (n=10) of repeated QUS measures (with repositioning) was calculated to account for measurement error. BUA LSC was 6.27 dB/MHz and SI LSC was 2.77%.

The subgroup that participated in testing at the bone densitometry research laboratory were examined by DXA (XR800, Norland Medical Systems, USA) to estimate bone mineral content (BMC) and density (BMD) of the whole body (WB), lumbar spine (LS) and non-dominant hip (femoral neck, FN; and trochanter, TR). Estimates of lean and fat tissue mass were also determined from whole body scans. Additional parameters of bone strength were calculated from BMD measures, including material stiffness (E), bone structural strength (IBS), and cross-sectional moment of inertia (CSMI), as previously described (41). pQCT (XCT-3000, Stratec Medizintechnik GmbH, Pforzheim, Germany) was used to determine
bone strength measures of the non-dominant tibia (at 4 and 38% sites) and radius (at 4 and 66% sites), including: total content, total density, total area, trabecular content, trabecular density, trabecular area, total and trabecular bone strength index (BSI) at 4% sites, and cortical content, cortical density, cortical area, cortical thickness, cross-sectional area (CSA), periosteal and endosteal perimeters at the proximal (38 and 66% sites).

Statistical analyses

Between-group differences at baseline were examined using one-way ANOVA, while intervention effects were determined using two-way ANOVA controlling for weight, maturity, baseline values, physical activity and calcium consumption. Both per protocol and intention to treat (ITT) analyses were conducted.

In order to ensure adequate statistical power, an *a priori* power analysis was undertaken based on the bone measure with the largest precision error (i.e. BUA) using previously observed between-group effects (49). Accordingly, we required a total of 142 participants to observe a mean difference between groups of 4 dB/MHz with a standard deviation of 12 dB/MHz, assuming 80% power with an alpha level of 0.05. All statistical analyses were performed with SPSS version 21.0 for Windows (IBM, Chicago, IL, USA).

RESULTS

Participants

From 189 eligible participants, consent was obtained for 188 boys (109 EX and 79 CON). The majority (96%) of the participants were Caucasian while the remainder were Asian. Of those, 183 completed baseline testing (T0) and 172 participated in follow up testing (T9). Two boys from EX did not attend baseline testing, and three did not attend follow up, resulting in 104 boys included in EX for analysis. One CON participant’s parent did not
consent to use of their child’s data in our analysis. An additional three CON boys did not attend baseline testing and eight did not attend follow up testing, leaving 68 boys in CON for analysis (Figure 1). As results of per protocol (data not shown) and intention to treat analyses were essentially the same, we elected to report ITT findings unless otherwise indicated. Overall, data from 172 boys were included in the ITT analysis, representing 91% of the original consenting cohort.

At baseline, both groups exhibited similar characteristics for the majority of measures. EX exhibited slightly lower scores than CON however, for total BPAQ score (19.4 ± 13.6 vs. 25.4 ± 21.3, \( p = 0.039 \)); resting blood pressure (76.1 ± 7.1 vs. 77.9 ± 7.2 mmHg, \( p = 0.001 \)); and estimated VO\(_2\) max (28.65 ± 6.84 vs. 33.35 ± 7.11 ml/kg/min, \( p = 0.001 \)). EX exhibited similar scores for BUA (97.2 ± 9.8 vs. 93.9 ± 10.8 dB/MHz, \( p = 0.088 \)) and YAPHV (-2.9 ± 0.8 years vs. -2.7 ± 0.6 years, \( p = 0.065 \)) (Table 2). Any differences were managed by controlling for baseline values in the analysis of treatment effects.

Age, calcium and other physical and performance variables at baseline were not different. In the subgroup (EX: 30; CON: 6), no differences were found in DXA and pQCT variables at baseline.

Change in physical and performance outcomes

Following the nine-month intervention, EX exhibited more favourable change than CON in waist circumference (+2.8% vs. +6.2%, \( p = 0.001 \); 95% CI 1.7 to 3.9% vs. 4.6 to 9.0%), resting heart rate (-5.3% vs. +1.5%, \( p = 0.002 \); 95% CI -6.7 to -3.8% vs. -4.6 to 7.6%), vertical jump (+12.2% vs. -0.3%, \( p < 0.001 \); 95% CI 9.3 to 18.4% vs. -2.7 to 4.1%), and estimated VO\(_2\) max (+9.1% vs. +1.2%, \( p < 0.001 \); 95% CI 6.4 to 13.2% vs. -0.7 to 5.2%) (Table 2). After controlling for baseline values, YAPHV and weight, those findings
remained the same. There were no significant between-group differences in change for any other physical or performance parameters.

**Change in bone outcomes**

A significant between-group difference in change was observed for bone parameters (Table 2 and 3). Specifically, EX improved calcaneal BUA more than CON based on ITT analyses (+4.3% vs. +2.1%, \( p = 0.001 \); 95% CI 2.4 to 7.1% vs. 0.6 to 4.1%) and per protocol analyses \( (p = 0.035) \).

From the subgroup of participants who underwent bone densitometric measures, only LS E improved more for EX than CON (+14.2% vs. +1.5%, \( p = 0.039 \); 95% CI 10.4 to 20.4% vs. -4.9 to 7.6%). Although not statistically significant, a trend for reductions in fat in the EX group compared to CON (-3.5% vs. +7.7%, \( p = 0.074 \); 95% CI -7.8 to 1.8% vs. -3.5 – 18.1%) was observed. There were no between-group differences in any pQCT-derived tibial parameters. At the radius, however, periosteal circumference at the 66% site increased more for EX than CON (+9.2% vs. +4.8%, \( p = 0.030 \); 95% CI 8.5 to 15.1% vs. -1.3 to 18.1%) and a trend for greater improvements for EX than CON in cortical area at the 66% site was evident (+12.4% vs. +7.7%, \( p = 0.083 \); 95% CI 6.0 to 19.7% vs. -8.9 to 14.5%). No other significant between-group differences were observed in changes in bone geometry, volumetric density or strength parameters from pQCT.

**Compliance**

Mean intervention compliance was 90% with absence from school accounting for all missed sessions. Student relocation and absence from school on follow-up testing days contributed to an overall loss to follow-up of 8.5%. Only one relatively minor adverse event took place when an intervention participant inadvertently made contact with another participant during a
handstand maneuver. Other than the discomfort experienced at the time of the incident, there was no ongoing pain or injury.

**DISCUSSION**

The current intervention trial was designed to be a brief, engaging, school-based exercise intervention to improve parameters of musculoskeletal and cardiovascular health in pre and early pubertal boys, without notably disrupting a primary school schedule. The intervention improved a number of parameters of bone health and important metabolic characteristics.

**Intervention effects on bone**

We based our intervention activity on previous reports that 10 to 12 minutes of weight bearing impact exercises are sufficient to stimulate bone responses in children (7, 25, 27, 32, 33, 49). Our findings are in accord with reports that 10-minute bouts of moderately high impact exercise can improve bone health specifically in pre and peripubertal boys (20, 26, 27). The 2% between-group difference observed in calcaneal BUA also aligns with a previous observation that 8-months of 10-minute jumping twice per week improves BUA of adolescent boys (49).

An observed 12.7% increase in lumbar spine stiffness, and 4.4% improvement in periosteal circumference at the radius are also suggestive of meaningful exercise-related change at clinically relevant sites, however we note that only a sub-sample of the study cohort was able to attend the bone densitometry research laboratory for on-site testing and so power was very low for those analyses. Our lack of ability to detect broader findings in other DXA- and pQCT-derived outcomes may similarly reflect constraints of statistical power. By contrast, our ability to measure calcaneal BUA from the entire sample, owing to the portable nature of the QUS device, provided adequate power to detect significant effects of the exercise
intervention on BUA. While some investigators have reported that a 10-minute jumping
program applied three times per week for 7 months improved FN BMC and LS BMC and
BMD in prepubertal children (boys and girls combined) (7), others have reported a only
limited effect of exercise on BMD in pediatric cohorts. For instance, 20 months of 10-minute
high impact exercises improved FN BMC but no other bone parameter of prepubertal boys
(27), and a twice weekly jumping intervention improved only FN area of male adolescents
after 8 months (49).

The upper extremity loading included in the current intervention is novel. Traditionally
bone-targeted exercise interventions overlook the upper extremity in lieu of weight bearing
activities designed to load the sites of greatest clinical relevance to osteoporosis – the spine
and hip. However, some evidence exists to suggest that children with low bone mass are
more susceptible to upper extremity fractures, and since bone response to mechanical loading
is site-specific, upper extremity loading may be clinically beneficial in youth (5, 10).

Furthermore, distal radial fractures are the source of considerable morbidity and cost in older
individuals with osteoporosis (40). Our findings that the CAPO Kids intervention improved
periosteal circumference of the radius and tended to improve radius cortical area is therefore
noteworthy. It is possible that the non-weight-bearing skeleton is more sensitive to weight
bearing loading than regular weight-bearing bones (35). By contrast, we did not detect
exercise-induced changes in pQCT-derived parameters of bone geometry at the tibia.

Similarly, others have reported that twelve weeks of 25 daily jumps from a box did not
improve any pQCT tibia measurements of children and adolescents aged 3 to 18 (combined
boys and girls) (14). However, others have reported that a 16 month jumping program
(3min/day of counter-movement jumping, three times per day) increased tibial BSI of pre
and early pubertal boys (23). In light of the prolonged period required for bone to respond
and adapt to mechanical interventions, it is reasonable to assume the former study (12 weeks)
(14) was of inadequate duration to detect an effect on parameters of tibial geometry if there
was one. Our intervention was of adequate duration, but likely underpowered for most pQCT
outcomes.

**High-impact intervention and lean mass**

Although high-impact exercise interventions are typically designed specifically to stimulate
bone responses, fat and lean mass are frequently also measured (6, 12, 19, 22, 27, 30, 49). Those trials have reported a variety of effects of high-impact exercise on lean and fat mass; likely a function of differences between interventions. Notably, previous bone-targeted exercise interventions have effected either no change (22, 29, 30), or only small improvements in the lean mass of pediatric cohorts (33), and our findings are no different.

As an 8-month, twice-weekly jumping program for adolescents increased lean mass of boys by 4.9%, we suggest the lack of effect is related to maturation (47). There is considerable evidence in other literature to suggest that even targeted muscle training will not markedly increase lean mass in prepubertal children (28, 38). Those comments notwithstanding, on occasion lean mass improvements have been observed in prepubertal children. For instance, a 20-month high-impact circuit intervention (12 min, three times per week) improved lean mass of prepubertal boys by 4.2% (27).

Although change in bone and muscle mass are not always observed following exercise intervention, cross-sectional data indicates that muscle mass is the most important predictor of bone size in boys (3, 18, 42). While an association of bone mass and muscle mass is suggestive that the latter may be beneficial to the former, it is not possible to assume causality when there are common genetic determinants of both lean tissues.

**High-impact intervention and fat mass**
A recent observation that bone-targeted exercise interventions likely reduce fat in pediatric
cohorts (33) is supported by the current findings. Waist circumference, which is a good
predictor of visceral abdominal adiposity, is closely associated with obesity (17, 34). The
increase in waist circumference we observed in both groups was to be expected in our
growing pediatric cohort, however, our observation that the control group increased waist
circumference more than the exercise group over the course of a year suggests that the
intervention effectively minimised the accumulation of abdominal adipose tissue. In
addition, our observation that in the subgroup, the control group gained nearly 8% body fat
while the exercise group lost 3.5% (NS), supports the potential positive effect of our exercise
intervention on adiposity.

**High-impact exercise and performance**

The current intervention activities improved estimated VO₂ max (from the 20 m shuttle run)
and maximum jump height. It is commonly held that aerobic and continuous exercises are
the best activities to improve VO₂ max and resting heart rate (37), however our data show
brief high-impact exercise is also effective. Given the emphasis on high-velocity execution
of movements in our intervention (including jumps), it is perhaps not surprising that
maximum jump height improved in the exercise group. Although we did not perform motion
analyses, it is reasonable to assume that components of co-ordination and neuromuscular
adaptations may have contributed to jump performance in addition to muscle strength.

**Limitations**

The low number of participants in the subsample who were able to attend testing at the Bone
Densitometry Research Laboratory reduced our ability to detect between-group differences in
DXA- and pQCT-derived bone measures. We acknowledge the consequent potential for
sampling bias, and therefore present those DXA and pQCT findings as preliminary. We pre-
emptively included BUA as our primary bone outcome measure in light of the fact that it could be measured in-school using a portable QUS device. We therefore were able to obtain from all participants an index of bone strength, that is comparable to DXA and pQCT in its ability to monitor bone densitometric change in children (1, 43), to achieve sufficient statistical power to examine our primary outcome measure. The intervention school had a slightly larger student cohort than the control school, which we acknowledge may also have created a sampling bias.

CONCLUSION

Osteoporosis and metabolic diseases benefit from exercise intervention and early application is likely to be especially beneficial. Opportunity and inclination are the primary obstacles to widespread adoption of increased childhood physical activity, such that enjoyment and in-school programs are important engagement strategies. Our novel, enjoyable exercise intervention was easily incorporated into the primary school setting and improved indices of calcaneal bone and metabolic health in pre and early pubertal boys. Given the provocative preliminary findings at the radius, there is a compelling need for additional pQCT studies in larger cohorts of children that examine the effects of this unique exercise regimen on bone health at the distal forearm.
REFERENCES


19. Linden C, Ahlborg HG, Besjakov J, Gardsell P, Karlsson MK. A school curriculum-based exercise program increases bone mineral accrual and bone size in prepubertal girls:


### TABLE 1: DESCRIPTIONS OF INTERVENTION ACTIVITIES

<table>
<thead>
<tr>
<th>Activity</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jumps</td>
<td>Two-leg take off, followed by a two-leg landing;</td>
</tr>
<tr>
<td>Hops</td>
<td>Single-leg take off, followed by a single-leg landing on the same side;</td>
</tr>
<tr>
<td>Tuck-jumps</td>
<td>Double-leg jump, with hips and knees flexed during flight, bringing the knees into close proximity to the chest, and arms momentarily holding the knees when they reach the chest;</td>
</tr>
<tr>
<td>Jump-squats</td>
<td>Double-leg jump, where the start and final position is with hips and knees flexed to approximately 90 degrees;</td>
</tr>
<tr>
<td>Star jumps</td>
<td>With feet together, jumping and positioning legs apart, at the same time the arms go up touching the hands above the head, and returning to the initial position, continuously;</td>
</tr>
<tr>
<td>Jump-lunges</td>
<td>Taking a large step forward so that the knee is flexed to 90 degrees as a start position, jumping while swapping legs, returning to start position with the opposite leg;</td>
</tr>
<tr>
<td><strong>Ginga</strong></td>
<td>Feet positioned shoulder-width apart, and then one foot is placed behind on the ball of the foot. The back foot returns to the initial position, and the other is placed back, imagining that a triangle is being drawn on the floor with the feet;</td>
</tr>
<tr>
<td>Handstands</td>
<td>From <strong>ginga</strong>, the hands are placed on the ground shoulder-width apart and the legs up, together, open or even with one leg forwards;</td>
</tr>
<tr>
<td>Cartwheels</td>
<td>Traditional movement, but performed slowly and with arms and legs slightly flexed;</td>
</tr>
<tr>
<td><strong>Bêncão</strong> with jumps</td>
<td>Starts from the <strong>ginga</strong> position. A straight forward push kick is performed, with the ankle dorsi-flexed before returning to the base position.</td>
</tr>
</tbody>
</table>
TABLE 2: BASELINE AND NINE-MONTH MEASURES (± SD) WITH PERCENT CHANGE AND 95% CONFIDENCE INTERVAL IN PHYSICAL AND LIFESTYLE CHARACTERISTICS (N = 172).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Control (n = 68)</th>
<th>Intervention (n = 104)</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Baseline</td>
<td>Follow up</td>
<td>%</td>
<td>95% CI</td>
<td>Baseline</td>
<td>Follow up</td>
</tr>
<tr>
<td>Age (years)</td>
<td>10.7 (0.6)</td>
<td>11.4 (0.6)</td>
<td>6.5 (6.4 – 6.6)</td>
<td>10.5 (0.5)</td>
<td>11.3 (0.5)</td>
<td>7.6 (7.4 – 7.8)</td>
</tr>
<tr>
<td>YAPHV (years)</td>
<td>-2.7 (0.6)†</td>
<td>-2.2 (0.6)</td>
<td>-18.5 (-22.3 – -16.4)</td>
<td>-2.9 (0.5)†</td>
<td>-2.3 (0.6)</td>
<td>-20.7 (-23.4 – -19.3)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>39.6 (9.2)</td>
<td>42.9 (9.8)</td>
<td>8.5 (6.6 – 11.5)</td>
<td>38.7 (8.8)</td>
<td>41.7 (10.2)</td>
<td>7.8 (5.7 – 10.6)</td>
</tr>
<tr>
<td>Standing height (m)</td>
<td>1.437 (0.062)</td>
<td>1.477 (0.067)</td>
<td>2.8 (2.3 – 3.2)</td>
<td>1.441 (0.0)</td>
<td>1.478 (0.078)</td>
<td>2.6 (2.3 – 2.8)</td>
</tr>
<tr>
<td>Sitting height (m)</td>
<td>0.742 (0.032)</td>
<td>0.756 (0.031)</td>
<td>1.9 (1.5 – 2.5)</td>
<td>0.735 (0.032)</td>
<td>0.758 (0.036)</td>
<td>3.1 (2.6 – 3.4)</td>
</tr>
<tr>
<td>Waist circumference (cm)</td>
<td>67.7 (10.8)</td>
<td>71.9 (10.5)</td>
<td>6.8 (4.6 – 9.0)</td>
<td>67.0 (9.0)</td>
<td>68.8 (9.1)</td>
<td>2.8 (1.7 – 3.9)</td>
</tr>
<tr>
<td>Resting heart rate (beats/min)</td>
<td>69 (2)</td>
<td>70 (2)</td>
<td>1.5 (-4.6 – 7.6)</td>
<td>71 (6)</td>
<td>67 (6)</td>
<td>-5.3 (-6.7 – -3.8)</td>
</tr>
<tr>
<td>Blood pressure (mmHg)</td>
<td>78 (7)†</td>
<td>76 (6)</td>
<td>-2.3 (-4.1 – -0.4)</td>
<td>74 (10)†</td>
<td>72 (9)</td>
<td>-3.2 (-4.5 – -1.0)</td>
</tr>
<tr>
<td>Vertical jump (cm)</td>
<td>31 (5)</td>
<td>31 (5)</td>
<td>-0.3 (-2.7 – -4.1)</td>
<td>30 (5)</td>
<td>34 (5)</td>
<td>12.2 (9.3 – 18.4)</td>
</tr>
<tr>
<td>Estimated VO₂ max (ml/kg/min)</td>
<td>33 (7)†</td>
<td>34 (6)**</td>
<td>1.2 (-0.7 – 5.2)</td>
<td>29 (7)†</td>
<td>31 (7)**</td>
<td>9.1 (6.4 – 13.2)</td>
</tr>
<tr>
<td>BUA (dB/MHz)</td>
<td>97.2 (9.3)†</td>
<td>99.1 (8.6)</td>
<td>2.1 (0.6 – 4.1)</td>
<td>93.9 (9.9)†</td>
<td>97.7 (9.6)</td>
<td>4.3 (2.4 – 7.1)</td>
</tr>
<tr>
<td>SI (%)</td>
<td>79.2 (8.4)</td>
<td>83.1 (9.1)</td>
<td>4.9 (3.2 – 7.2)</td>
<td>79.1 (9.0)</td>
<td>84.6 (9.2)</td>
<td>7.2 (5.4 – 9.8)</td>
</tr>
</tbody>
</table>

**Abbreviations:** CI = Confidence interval; YAPHV = Years from age of peak height velocity; BUA = Broadband ultrasound attenuation; SI = Stiffness index; VO₂ max = maximal oxygen consumption. P values represent between-group comparisons of percent change.

* = p≤0.05; † = p≤0.05, Difference between groups at baseline; ** = p≤0.05, Difference between groups at follow up.
## TABLE 3: BASELINE AND NINE-MONTH MEASURES (± SD) WITH PERCENT CHANGE AND 95% CONFIDENCE INTERVAL IN DXA MEASURES (N = 36).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Control (n = 6)</th>
<th>Intervention (n = 30)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Baseline</td>
<td>Follow up</td>
</tr>
<tr>
<td>Lean mass (Kg)</td>
<td>29.7 (7.1)</td>
<td>32.2 (9.6)</td>
</tr>
<tr>
<td>Fat mass (Kg)</td>
<td>17.3 (10.6)</td>
<td>18.7 (12.3)</td>
</tr>
<tr>
<td>WB BMC (g)</td>
<td>1769.25 (423.77)</td>
<td>1943.00 (543.97)</td>
</tr>
<tr>
<td>WB BMD (g)</td>
<td>0.765 (0.083)</td>
<td>0.806 (0.103)</td>
</tr>
<tr>
<td>LS BMC (g)</td>
<td>22.7 (6.2)</td>
<td>25.0 (9.2)</td>
</tr>
<tr>
<td>LS BMD (g/cm²)</td>
<td>0.674 (0.123)</td>
<td>0.705 (0.150)</td>
</tr>
<tr>
<td>LS E (MPa)</td>
<td>19.98 (11.53)</td>
<td>20.28 (4.8)</td>
</tr>
<tr>
<td>FN BMC (g)</td>
<td>3.499 (0.759)</td>
<td>3.741 (0.952)</td>
</tr>
<tr>
<td>FN BMD (g/cm²)</td>
<td>0.803 (0.116)</td>
<td>0.843 (0.134)</td>
</tr>
</tbody>
</table>

**Abbreviations:** CI = Confidence interval; BMC = bone mineral content; BMD = bone mineral density; FN = femoral neck; LS = lumbar spine; WB = whole body; E = material stiffness – Young’s modulus. P values represent between-group comparison of percent change. * = p≤0.05.
### TABLE 4: BASELINE AND NINE-MONTH MEASURES (± SD) WITH PERCENT CHANGE AND 95% CONFIDENCE INTERVAL IN TIBIA AND RADIUS PQCT MEASURES (N = 36).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Control (n = 6)</th>
<th>Intervention (n = 30)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Baseline</td>
<td>Follow up</td>
</tr>
<tr>
<td>Tibial total content 38% (mg)</td>
<td>240.65 (36.80)</td>
<td>259.24 (61.18)</td>
</tr>
<tr>
<td>Tibial trabecular content 38% (mg)</td>
<td>165.78 (27.46)</td>
<td>169.87 (48.07)</td>
</tr>
<tr>
<td>Tibial cortical content 38% (mg)</td>
<td>231.21 (46.97)</td>
<td>266.58 (84.87)</td>
</tr>
<tr>
<td>Tibial cortical area 38% (mm²)</td>
<td>225.44 (67.1)</td>
<td>238.75 (63.08)</td>
</tr>
<tr>
<td>Tibial periosteal circumference 38% (mm)</td>
<td>63.11 (7.81)</td>
<td>66.67 (8.69)</td>
</tr>
<tr>
<td>Tibial endosteal circumference 38% (mm)</td>
<td>31.56 (4.59)</td>
<td>32.54 (4.37)</td>
</tr>
<tr>
<td>Radial total content 66% (mg)</td>
<td>49.33 (7.89)</td>
<td>53.64 (9.06)</td>
</tr>
<tr>
<td>Radial trabecular content 66% (mg)</td>
<td>29.45 (7.45)</td>
<td>35.56 (9.9)</td>
</tr>
<tr>
<td>Radial cortical content 66% (mg)</td>
<td>48.49 (13.21)</td>
<td>49.49 (5.76)</td>
</tr>
<tr>
<td>Radial cortical area 66% (mm²)</td>
<td>53.00 (6.87)</td>
<td>55.08 (3.71)</td>
</tr>
<tr>
<td>Radial periosteal circumference 66% (mm)</td>
<td>36.20 (2.39)</td>
<td>37.93 (1.46)</td>
</tr>
<tr>
<td>Radial endosteal circumference 66% (mm)</td>
<td>24.51 (2.30)</td>
<td>25.47 (3.31)</td>
</tr>
</tbody>
</table>

**Abbreviations:** CI = Confidence interval. P values represent between-group comparison of percent change. * = p≤0.05.
Fig. 1. CONSORT diagram of participant flow.

Fig. 2. Nine-month change (%) in calcaneal BUA, waist circumference, maximal vertical jump, resting heart rate and estimated VO₂ max for CON (black) and EX (grey).

BUA = Broadband ultrasound attenuation; VO₂ max = maximal oxygen consumption.

Error bars indicate ±SEM.