DO IN-LINE DANCE, PROGRESSIVELY LOADED SQUATS AND FOOT STOMPING AFFECT THE PARAMETERS OF FRACTURE RISK IN POSTMENOPAUSAL WOMEN?

by

Catherine Mary Young, B Phry, M Sports Physiotherapy
School of Physiotherapy and Exercise Science, Faculty of Health, Griffith University


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This work has not previously been submitted for a degree or diploma in any university. To the best of my knowledge and belief, the thesis contains no material previously published or written by another person except where due reference is made in the thesis itself.

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Acknowledgements

The author wishes to acknowledge the expertise, and the firm yet friendly guidance provided to her by her principal supervisor Dr Belinda Beck.

Belinda, your continuous encouragement smoothed the path, maintained the perspective, and made this particular journey a very pleasant one. Thank you.
Abstract

Introduction: The incidence of hip fracture is increasing and the associated costs to individuals and the community needs to be vigorously addressed. This study was a randomized controlled intervention designed to examine the effects of a simple-to-do, easy-to-implement exercise programme on the elements of hip fracture risk which are known to be amenable to exercise therapy.

Methods: Forty-five volunteers were randomly assigned to one of three groups. All groups attended one line dance class per week. Two groups additionally performed progressively loaded squats five times a week. One group also performed four foot stomps twice daily five times per week. Hip fracture risk (HFR), broadband ultrasound attenuation (BUA), proximal femoral (PF) and lumbar spine (LS) bone mineral density (BMD), squats number, and balance variables were measured.

Results: There were no changes in HFR, BUA, PF or LS BMD, however, a strong positive stomps compliance effect was noted for BUA ($r = 0.73$, $p = 0.003$) and for PF BMD ($r = 0.79$, $p = 0.002$). Squats number increased in all participants, especially in those performing all three activities ($p = 0.001$). Single Leg Stance (SLS) times increased ($p < 0.01$), and Timed Up and Go (TUG) times decreased ($p < 0.01$) in all participants who complied with the protocol of squatting and stomping. Forward and lateral step velocities did not change.

Conclusions: Our novel intervention conferred positive benefits on the skeletons of independent living, postmenopausal women. Other indices of fall and fracture risk, including muscle strength and balance, improved in all participants suggesting a beneficial effect of line dancing on these factors.
CHAPTER ONE: INTRODUCTION

1.1 Hip Fracture in Postmenopausal Australian Women
Sixty six percent, or two of every three Australian women are likely to suffer a low trauma fracture of the proximal femur (hip) before the age of 85 years [1]. The cost of hip fractures to individuals, and to Australian healthcare systems, is disproportionately high when compared to the costs of treating other, more prevalent, medical conditions such as cardiovascular disease and asthma [2]. The direct cost of hip fracture is mainly attributable to the inevitable hospital admissions, surgery needed to stabilize the fracture, and extended periods of rehabilitation. When the indirect costs of hip fracture are considered (e.g. placement in an aged care facility) the burden on taxpayers and Australian healthcare resources is enormous. The current estimate of direct and indirect costs is $1.9 billion per annum, and this is projected to double by 2025 [3, 4].

Risk for hip fracture (HFR) is greatest when bone mass is low and one or more risk factors for falling occur concurrently in the individual. Thus effective management strategies for HFR reduction are necessarily multifactorial: customized to individual needs, and designed to target each specific deficit or risk factor.

Management strategies that target the bone health aspect of HFR include medications, such as hormone therapy and anti-resorptive medications, and some types of exercise. Prescription medications can maintain, or even increase, bone mass in people with very weak bones; however their efficacy is limited by issues associated with compliance and cost[5, 6]. In contrast, bone stimulating exercises have few side-effects and can slow the rate of bone loss from the proximal femur (hip), thus reducing or preventing the need for medications. To be effective for bone health, exercise must be coupled with dietary supplementation of calcium and vitamin D [7, 8].

Exercise that helps prevent bone loss has additional advantages for the musculoskeletal components of falls risk, such as leg strength and balance. T’ai Chi Ch’uan [9], aerobics, agility training, and very fast walking, have been shown to improve balance and reduce the risk of falling [7]; while appropriately structured weight training can improve muscular strength in people of all ages, including the very elderly [10].
1.2 Primary aim
We aimed to examine the effect of a novel exercise intervention on risk factors of falling and fracture in postmenopausal Caucasian women. The study was a prospective randomized intervention. The effects of three activities, chosen to address three specific variables that contribute to risk of hip fracture in otherwise healthy, independent, postmenopausal women aged 55 to 75 years were examined. Foot stomping, progressively loaded squats and line dancing were selected to target bone mass, lower limb strength and balance, respectively. There is some evidence to suggest that foot stomping applies osteogenic loads to the proximal femur bone. Progressively loaded squats activity can strengthen the lower limb muscles in a manner that is practical to activities of daily living [11]. Line dancing was chosen as a novel activity with the potential to affect participants’ dynamic balance and lateral stability. Dance classes provided participants with additional benefits, such as low-level cardiovascular training and the opportunity to develop social contacts.

Secondary aims
In the absence of public funding, any community-based program to reduce fracture risk needs to contain cost. To be sustainable the activities must also be enjoyable and well accepted within the community. The Stamp out Osteoporosis Study (SOS) exercise program was designed to be both appealing and low cost. The exercises could be performed at home as well as in a group setting, and were structured to afford the participants both the simplicity and the flexibility necessary for the program to be sustainable.

1.3 Summary
Forty five postmenopausal women, living independently in the local community who were not taking medications that could influence bone were recruited to participate in the eleven month exercise intervention. All recruits were provided with calcium supplements and randomly allocated to one of three groups. All groups participated in once-weekly line dancing classes in a group setting. Two groups also performed a home program of progressively loaded squats, three times per week. One group only performed foot stomps, at home, bi-daily, five days per week, in addition to dance and squats.
Participants’ falls risk and hip fracture risk were estimated using validated algorithms. Proximal femur and lumbar spine bone mineral density (BMD) was measured prior to and at completion of the intervention an index of bone strength. Calcaneal broadband ultrasound attenuation (BUA) was measured at the start, mid point, and at the end of the intervention. Functional squat strength, static and dynamic balance, and forward and lateral step reaction times were measured at baseline, follow-up, and periodically, throughout the study.

1.4 Hypotheses

Hypothesis 1: Once weekly in-line dancing will improve static and dynamic balance, and parameters of step velocity (distance and time), in healthy, independent living postmenopausal women, aged 55 to 75 years.

Hypothesis 2: Thrice weekly, progressively loaded squats (up to 12 kilograms, three by eight reps per set) will maintain or improve functional lower limb squats performance in healthy, independent living postmenopausal women aged 55 to 75 years.

Hypothesis 3: Four stomps per foot, twice per day, five days per week will improve indices of bone strength at the lumbar spine, neck of femur and calcaneus in healthy, independent living postmenopausal women aged 55 to 75 years.
CHAPTER TWO: BACKGROUND

The condition of low bone mass, when coupled with a high risk for falling, creates an unacceptably high risk for low trauma fracture in any individual. Very low bone mass (or osteoporosis) is one of the major underlying causes of bone fractures in elderly Caucasians [12]. In Australia and the Western world the incidence and cost of osteoporotic fractures continues to rise at alarming rates. The following literature review focuses upon the factors associated with higher hip fracture risk (HFR) and the evidence that a customized program of physical activity might improve the factors associated with high fracture risk in older women of our communities.

2.1 Osteoporosis

Osteoporosis is a progressive condition, where insidious loss of bone mass is associated with decreased bone strength and increased risk of fracture [13]. The gold standard measure of bone mass is bone mineral density (BMD) typically measured by Dual X-ray Absorptiometry (DXA). The World Health Organization has described osteopenia as a BMD t-score between -1.0 and -2.5 standard deviations below the mean of young healthy women. Osteoporosis has been described as a BMD t-score more than 2.5 standard deviations below that same mean. Low trauma fractures occur in people with either osteopenia or osteoporosis [3]. The proportion of people with low bone mass increases with age; in women it rises from 15% in those aged between 60 and 64 years, to 71% in those over 80 years of age. In men the incidence is much lower, being about 1.6% for those between 60 and 64 years, and 19% of those over 80 years [14].

The statistical prevalence of low bone mass in Australia currently translates to about ten percent of the population or two million people, a number that is predicted to rise to three million by 2021 [2]. The condition is more prevalent than high cholesterol, allergies, or the common cold in our communities. Three quarters of those diagnosed with osteoporosis are over 55 years old [2]; three quarters of that age group are women [2].

The etiology of osteoporosis is described as primary and secondary. For Australian women the average age for the onset of menopause is 51 years [15]. Primary
postmenopausal osteoporosis is the adverse response of the female skeleton to the relatively sudden drop in levels of circulating oestrogen. In older age groups primary osteoporosis may be due to reduced absorption of calcium from the gut, and/or reduced synthesis of vitamin D in the skin, which occurs with advanced age and institutional care[16].

Osteoporosis occurs secondarily to the use of certain medications, e.g. glucocorticoid therapy, to hormonal deficits such as hypogonadism or early oophorectomy, and to gastrointestinal tract diseases that interfere with calcium absorption. Malignancy, hyperthyroidism and rheumatoid arthritis are highly associated with concurrent osteoporosis [17]. Once established there is no cure for osteoporosis, however it can be managed with pharmacological interventions such as hormone therapy (HT) and anti-resorptive drugs.

Oestrogen, and combinations of oestrogen and progestin (HT) have been generally prescribed to help to manage cardiovascular events, such as hot flushes (or ‘flashes’, in the American terminology), and can reduce fracture risk in postmenopausal women [18]. However, the protracted use of HT cannot be recommended because of side effects such as an increased risk of breast cancer [19], pulmonary embolism [20], and depression [21]. Until a thorough risk-benefit analysis of the outcomes of HT is published, the conservative recommendation for HT prescription, for any reason, is for a period of not more than 2 to 5 years [22].

Other commonly prescribed medications for fracture risk, the bisphosphonates, e.g. Fosamax™ and Actonel™, are only effective where bone mass is extremely low [23, 24]. Because of problems with drug administration and a wide range of side effects compliance rates with prescription medication for bone health is very poor [23]. Compounding the difficulties with compliance is the cost; the medications are expensive. Until very recently such anti-resorptive medications were restricted to patients who already had at least one low trauma fracture. From April 2007 bisphosphonates have become available on the Pharmaceutical Benefits Scheme (PBS), but only for men and women with diagnosed osteoporosis who are also over seventy years of age.
2.2 Hip Fracture Risk

In Australia and the Western world the individuals with the highest HFR are elderly Caucasian women with low bone mass [25]. However the quantification of HFR is not a simple matter since it requires consideration of a diversity of elements or variables (Figure 1).

![Figure 1 The risk for hip fracture includes multiple factors affecting bone strength and contributing to the risk of falling onto the hip.](image)

2.2.1 Hip Fracture Risk Quantified

The following addresses the variables of hip fracture risk (HFR) that were targeted in the Stamp out Osteoporosis study (SOS).

An individual’s risk of sustaining low trauma fracture/s has been, until recently, a clinical judgment based upon clinical indicators such as a previous, low trauma fracture [26]. Such qualitative assessments are neither amenable to comparison between persons, nor sensitive to changes in one individual over time. To address the problems created when disparate elements must be considered together, an algorithm for HFR that provides a quantitative estimate for Caucasian women with low bone mass has been developed [27, 28]. The essential inputs of the algorithm are age and proximal femur bone mineral density (PF BMD). By itself PF BMD cannot reliably identify individuals who will fracture. It is, however, strongly associated with bone strength [29] and can predict HFR [30]. An electronically accessible version of the algorithm may be found on the World Wide Web at:

http://courses.washington.edu/bonephys/opTZconvert.html (available, 3rd May, 2007). The Study of Osteoporotic Fractures provided data from almost 8000 women aged 65 or more years. Black et al developed an assessment tool that incorporated the variables that clinicians and individual women can measure easily.
The tool, called the FRACTURE Index, assesses the 5-year risk of hip fracture and could help doctors evaluate the need for interventions to reduce risk in older women. The index includes age, BMD T-score, personal and maternal fracture history, weight less than 58 kg, smoking status, and use of arms to stand up from a chair. The Index was validated using the Epidemiologie de l’Osteoporose Study (EPIDOS) fracture study. Personal details such as gender, salient medical and orthopaedic and lifestyle details can be entered into the algorithm fields. The algorithm weights each element according to its known contribution to HFR. For example, age has a proportionally inverse effect on fracture risk [31] until about 74 years, after which risk approximately doubles every five to ten years [32]. The algorithm generates a score, between plus and minus four, indicating one’s potential for hip fracture, adjusted for risk factors, and the likely cost effectiveness of specific medications. A single score is a relatively coarse index, since real risk may change from day to day. However, quantification of risk is useful when it adds a meaningful dimension to preventative and public education programs.

Alternative statistical expressions of HFR that are commonly used in the literature include relative risk (RR) and risk ratios. Relative risk expresses population-based risk, e.g. the risk for Caucasian females of low trauma fracture compared to stroke, or heart disease. High RR is indicated by numerals greater than or equal to 2, moderate risk lies between 1 and 2, and no risk is less than or equal to 1. Risk ratios are useful indices of the relative efficacy of publicly funded initiatives, e.g. of programs to reduce falls in high- versus low-care settings.

2.2.2 Fall Risk
The type of fracture sustained is often related to the direction of the fall. For example, falls in the forward direction will more often cause fractures of the wrist or upper limb, while falls onto the hip are strongly associated with hip fracture [33].

A fall is defined as a sudden, unintentional position change, where the faller lands on the floor, or the ground, without having been exposed to overwhelming external forces [34]. Accidental falls caused by a trip or other inadvertent loss of balance are not uncommon, especially in highly active people. In the elderly most falls are relatively
low-trauma events and, as such, may be preventable. In the young, good leg muscle strength and shorter step reaction times correlate strongly with the size of the trip stimulus required to cause a fall [35]. For the purposes of research the provocation of balance reflexes and postural strategies in younger people is often performed by inducing trips or balance perturbations. In elderly people such activity is inherently risky and requires extensive planning and protective gear. More appropriately studies of falls risk in at-risk populations take the form of large-scale retrospective surveys of actual fall events. Guesens et al. (2003) [36] calculated that 35-40% of Australians over 65 living at home fall at least once a year, and between a third and a half of these people fall twice or more per year.

Apart from causing fractures, the deleterious outcomes of a fall include co-morbidities such as head injury, loss of productivity, and reduced quality of life due to heightened fear of another fall [37]. Consideration of such intangible outcomes makes the true cost of falls difficult to assess. Costs incurred from falls in West Australians over 65 years, in 2001, were estimated at $83 million, or 1.5% of the WA Government expenditure on health [38]. The medical costs associated with treatment of falls are anticipated to double in the next 20 years in line with the proportional increase in the number of aged people in the Australian population.

The primary risk factor for falling (advanced age) is difficult to counter because age is associated with multiple systemic impairments, and invariably, the use of a variety of medications [39]. Fall risk is heightened with the co-existence of disability and immobilization, low levels of physical activity, reduced lower limb muscle strength, poor balance, visual problems, cardiac syncope, and the use of psychotropic medications[40, 41].

Many falls in the elderly are due to the loss of postural strategies and reflexes associated with static and dynamic balance [42]. During stance in neurologically ‘normal’ individuals, placement of one’s centre of gravity (CG) near the perimeter of the base of support (BS) provokes finely tuned postural mechanisms that re-centre the CG and prevent overbalance reactions. For example, in sensing a balance perturbation one will quickly bend the hips and knees (lowering CG), at the same time raising the arms (re-centering). For a variety of reasons that are still not well understood, elderly people
tend to use peripheral strategies such as stepping, rather than central, neuromuscular re-centering actions [43]. Stepping strategies, in a person with declining musculoskeletal strength and agility, could expose that person to greater risk from contributory environmental factors, such as loose, slippery, or uneven surfaces, stairs, inadequate lighting, and inappropriate footwear [37]. Measures of stepping strategy and of postural sway during single leg stance (SLS) are valid indices of fall risk [44].

Most exercise programs for elderly women aim to reduce the frequency of falls rather than to influence bone mass. Therapeutic exercises for lower limb muscle strength, dynamic balance and protective reflexes can reduce the incidence of fall-related injury in postmenopausal women [45]. When sedentary women with low bone mass have concurrent increase risk of falling it is important that therapeutic exercise be supervised [46].

Static and dynamic balance training in the sagittal plane (‘the path of the arrow’ or from the front to the back) was shown to reduce fall risk in osteoporotic women with abnormal balance responses [47]. Coronal plane balance (in the plane perpendicular to the sagittal) and ability to step to the side decline in women between 40 and 60 years of age; falls to the side are strongly associated with hip fracture [48]. A sidestep action requires good neuromuscular control around the pelvis and hips; control that is essential for the maintenance of an erect posture during gait, and for lateral stability. Improvements in lateral stability are particularly important for prevention of sideways or lateral falls [49]. Therefore retraining of trunk postural correction and lateral stepping protective reactions should become important components of interventions designed to reduce falls [50].

A convenient method of quantifying fall risk, developed by the ‘Falls and Balance Research Group of the Prince of Wales Medical Research Institute, Sydney, Australia’ [11] is the Physiological Profile Approach (PPA) to fall assessment and prevention. The PPA employs a kit of validated tools that evaluate five parameters; postural sway, strength of knee extensors and ankle plantar flexors, visual acuity, hand and foot reaction times, and peripheral joint position sense. The PPA kit is rapidly being adopted by fall assessment teams in Australia, New Zealand, Canada and the United Kingdom. However the focus of the current study was principally upon bone strength.
rather than upon fall risk, thus a modified selection of parameters that could identify fall risk was used, e.g. functional leg strength, single leg stance time and the timed up and go tests.

**Line Dance**

Aerobic style dancing has been shown to improve postural sway reactions [51], voluntary step reaction time [52], and prevent falls in elderly women [53]. In-line dancing is an engaging, group based activity that stimulates vestibular and balance strategies. Line dancing is popular in our local community and has not, to the author’s knowledge, previously been deployed as a component in a falls prevention program. Line dancing is a type of partner-less dance, where rows of dancers all face the same direction. People have danced in lines or rows since time immemorial. Many American Indian and African tribal dances consist of sequential repetitions of basic steps (e.g. step to left side, close, step to right side, and close). The form of line dancing that is popular today originated in the United States of America during the 1970s from Country and Western style dances. The earliest recorded dance in the modern style, ‘the Traveling Four Corners’ was adapted from traditional square dancing. The Schottische or basic move features the side step, step across behind, side step, and lift (or hip hitch). Side stepping with Polka and Cha Cha steps, form the quintessential line dance [54]. Rhythm is usually 4/4 time with the emphasis on the first and third beats. A recent trend towards rhythmic syncopation and step speed requires significant dedication, to learning and memorizing complex choreography, from advanced performers.

Line dancing was chosen as an intervention with the potential to decrease HFR because it strongly features side steps of various angles, weight shifts, and single stance pivot turns. Important considerations underpinning the choice of line dancing as a study intervention were the participant’s age and cardiovascular status. Line dancing places a relatively low load on cardiovascular and pulmonary systems and is easy to self-pace. Entry-level dancers require no particular physical grace, no previous training, nor a partner. The tempo and structure of the dances facilitate division into small increments, so that each is easy to teach and to learn. Thus the dance style can stimulate dynamic balance responses with a minimal risk of causing participants to fall. Additional
advantages of a group-based exercise, such as a dance class, is cost effectiveness [55] and promotion of social interaction.

*Lower limb muscle strength and fall risk*

Lower limb muscle strength contributes to both bone strength and balance elements of HFR. Muscle strength correlates strongly with optimal regional bone development in all ages and both genders [56]. Lower limb muscle strength that is adequate for the person to rise smoothly from low chairs, the kneeling position, or ground level postures, is important to prevent falls [57]. A sedentary lifestyle and disuse correlates highly with lower limb muscle weakness in otherwise healthy individuals[58]. Even strong muscles, however, may be functionally compromised by neuromotor influences such as pain, inhibition by overactive antagonists (the opposing muscles), or altered biomechanics (e.g. poor joint alignment) [59].

*Squats exercise*

Gluteus maximus extends the hip joint (e.g. rising from a chair or squat), and maintains stability of the trunk on the pelvis, preventing lurching during gait. The smaller gluteal muscles (medius and minimus) move the thigh laterally, away from the body’s midline. Gluteal muscle group weakness is associated with a loss of postural control of the pelvis in single leg stance (a positive Trendelenberg sign).

Strengthening programs for fall prevention most appropriately target muscles that control squatting. Muscles such as the gluteals, along with the quadriceps group that extend the knee, respond well to squats training. In the absence of contraindications (e.g. patello-femoral joint pain, total hip arthroplasty, etc) a half-squat is the exercise of choice for functional lower limb strengthening in the majority of physiotherapy class and home based programs. Half-squats are useful because they recruit and coordinate the greatest number of thigh and hip muscles in a single activity [60]. To minimize load on knee joints during squats requires attention to points of technique, as described in the Methods section of this document [61]. For the present study, the author measured the total number of consecutive weighted squats, performed to the point of fatigue, as an index of participant lower limb muscle function (strength and endurance).
2.3 Bone Mass

Should a fall occur, the risk of hip fracture is much greater when the proximal femur bone mass is low. The following sections are important background to any discussion of osteoporosis.

2.3.1 The Natural History of the Skeleton

Heredity determines about 80% of human peak bone mass (PBM) [62]. From birth, through youth and adolescence, bone mass accrues rapidly, and (given a positive calcium balance) peaks approximately 6 months after the adolescent growth spurt ceases [63]. People usually gain as much bone during adolescence as they will lose during all of their adult life [64]. Post adolescence, mineralization of the maturing skeleton may continue into the third decade [65]. Healthy, active adults maintain bone mass for several decades by a process of bone turnover called modelling and remodelling that are described in a later section. It is critical to attain an optimum bone mass while young, because a relatively high PBM helps to stave off the onset of osteoporosis in later life [66]. Weight-bearing exercise during growth is a vital stimulus for bone.

In both genders there is a complex interaction of intrinsic factors, e.g. genes, growth factors and hormones with the extrinsic factors of dietary calcium, vitamin D and physical activity, governing the realization of PBM [67]. However males, with greater lean body mass, generally reach a higher PBM than females. In males the decline of bone mass from its peak is slow and steady over the life course i.e., approximately 1% per annum from about forty years of age (Figure 3).

The characteristically sudden loss of circulating oestrogen that occurs at menopause is associated with some 2 to 5 years of more rapid bone loss. During the peri-menopausal period bone losses of 2 to 5% per annum are not uncommon, and even higher rates (5 to 10%) have been recorded [68]. Postmenopausal women are particularly at risk for developing osteoporosis when an inadequate PBM is subsequently eroded by sustained periods of high bone turnover [69]. Some 5 to 8 years post menopause (in healthy women) the rate of bone loss steadies to again be comparable with similarly aged males (see Figure 2).
With advanced age high rates of bone loss can reoccur, mostly in association with low levels of bone strain, e.g. when chronic illness causes prolonged bed rest [70]. Only 2 days of bed rest is sufficient to induce the onset of bone resorption in healthy adult males [71]. Bone loss with detraining is not as appreciable in growing children [72] but is clear in athletes [73]. Detraining causes rapid cellular responses in bone, the results of which are evident within a few months as significant loss of mass and strength in postmenopausal women [74, 75]. Immobilization [76], microgravity or space travel, [77], spinal cord injury [78] and some medications e.g. corticosteroids also effect significant increases in the rate of bone resorption.

2.4 Bone Strength
The strength of a bone depends not only upon its mass, but also upon shape (morphometry), size and dimensions (geometry), and microarchitecture (quality). The elements of bone strength are outlined in this section.

2.4.1 Bone mass
A bone’s volumetric size determines its’ mass. In healthy adults bone mass does not vary greatly; the difference even between sedentary and exercising individuals is less than ten percent [79]. Bone mineral density is employed clinically as a surrogate for bone mass. At the proximal femur (hip) BMD determines between 70 and 80% of bone strength [29]. However BMD and bone strength are not linearly related. Small changes in BMD, either positively or negatively, may convey significant improvements or losses.
in bone strength and the individual’s fracture risk. As BMD declines with age, so does bone strength, especially in human vertebrae [80].

2.4.2 Geometry
Before the introduction of volumetric quantitative computerized tomography (vQCT) which can determine bone geometry in three dimensions, assessments of geometry in vivo in human neck of femur (NoF) were based upon engineering principles that describe the load bearing capacities, and resistance to compressive and bending forces, of cylinders. For example, of two cylinders with other dimensions in common, the cylinder with the largest cross sectional area (CSA) is the stronger. Thus the proximal femur of a man, being larger in CSA, is generally stronger than that of a woman of the same age.

In addition to CSA, the three-dimensional measures that extend the description of bone strength at the proximal femur are; circumference and length of the NoF, and cortical thickness and trabecular volume of the neck and inter-trochanteric regions. The cross sectional moment of inertia (CSMI) is the product of the CSA and the perpendicular distance from the centroid of the area to the moment axis. Of all the descriptors of bone strength CSMI is the strongest indicator of resistance to bending, but the most difficult to obtain, without vQCT equipment.

DXA scans of rat ulnae have shown that certain parameters of strain (high rate) can produce relatively small increases in areal BMD (5.4%) that result in large (54%) increases in bone strength [81, 82]. The observed improvements in bone strength finding probably occurred because new bone formed at the sites that best increased the CSMI. In postmenopausal women, a process of sub-periosteal expansion occurs and tends to increase NoF CSA [83]. The expansion occurs concurrently with endosteal resorption, and reducing trabecular volumes and densities. The geometric changes may offset the bone loss, creating a null net effect for bone strength at the proximal femur in older women [84]. If strain incurred by exercise can effect site specific adaptation at the NoF in postmenopausal women, then even the relatively small responses could have important implications for individual HFR [85].
2.4.3 Microarchitecture
The proximal femur, lumbar spine, and distal radius are examples of skeletal sites containing high proportions of cancellous or spongy bone. The trabecular architecture of cancellous bone gives it different material properties to cortical bone. Connectivity (degree of trabecular strut connection), and anisotropy (the non-uniform orientation of struts) are material properties that endow a healthy cancellous bone with greater elasticity, or yield strength, than cortical bone. Elasticity is the quality of bone tissue that contributes significantly to its resistance to fracture during deformation [86, 87]. Women, as a direct consequence of menopause, have the greatest tendency to disconnection of the trabecular network and loss of bone quality. Age related loss of structural strength is associated with low cortical density, in combination with reduced density of cancellous struts, plus the lower connectivity of trabeculae in the cancellous bone tissue [69]. Cancellous BMD is, however, thought to be more important for bone strength than microarchitecture alone [88].

2.5 Remodelling and Modelling
Remodelling and modelling are the processes by which bone responds to the environment according to its genetic code. Bone cell activity is governed by a complex interplay of mechanical and chemical stimuli. Mechanical stress occurs with muscle pulls, gravity and ground reaction forces. Chemical signals come from circulating hormones such as oestrogen, vitamin D, parathyroid hormone, calcitonin, locally produced molecules including the family of transforming growth factors, and many proteins and cytokines [89].

Remodelling maintains bone structural integrity without altering the bone’s external dimensions or shape. Characteristically, osteoblasts and osteoclasts work together; coupled in time and space, as a functional Basic Multi-cellular Unit (BMU). BMUs feature sequenced activation, resorption, and formation patterns of activity where a cone is cut through old or damaged bone by the osteoclasts, and fresh bone is then deposited by the osteoblasts, to repair the defect [89]. A complete remodelling cycle in humans takes nearly 100 days [90]. The remodelling process is important because it allows adaptation to environmental loads and stimuli to occur in adult bone [91]. If resorption outstrips formation and remodelling can reduce bone mass, potentially causing osteopenia or osteoporosis [91].
Modelling, in contrast, is the term for the processes of growth and development in childhood, and bone loss, building or reshaping that can occur in adults. Osteoblasts and osteoclasts are also involved in modelling, but act independently in both space and time. Mechanical loads above a stimulatory threshold stimulate modelling and may create increases in bone cross-sectional area (CSA) with resultant increased resistance to the stimulating load. When, as occurs with prolonged bed rest, the load history strongly features unloading, modelling is associated with endosteal resorption in long bones, and reduced resistance to loading.

2.5.1 Mechanical loading and adaptation in bone
Mechanical loading, particularly when applied at high magnitude and/or rate, is an important stimulant of bone mass. Loaded bones of animals and man display a continuous adaptation to changing patterns of rest and loading. Mechanical loading is important for bone health at all life stages. During youth and adolescence the loads associated with resistance to gravity and muscular activity that are transmitted to the developing skeleton optimize the genetically predetermined bone shape, size, mass and strength [92]. In adulthood the skeleton becomes less sensitive to mechanical loading, however, with exercise and adequate nutrition, skeletal health can be maintained, and the loss of bone strength that normally occurs with menopause can be reduced [80].

The complex mechanisms by which bone cells sense and respond to mechanical loading are not yet fully understood. Some aspects of a loading stimulus have been found to be more important for bone health than others; for example, unusual temporal patterns of strain, novel strain distributions, high strain magnitudes and high strain rates [93]. The current project based the bone specific foot-stomp exercise on those load characteristics, by providing novel forces of higher than average but non-injurious magnitude (therefore safe for this population), with a high strain rate, and low cycle number.

An early scientist to recognize that bone adapts to chronic loading was Julius Wolff (1868) [94]. Wolff’s drawing, shown in Figure 3, illustrates observed architectural similarities between curved load bearing structures and the cross section of a human proximal femur.
Early researchers considered that large forces that produced strains with the potential for fracture were necessary to stimulate adaptation in bone. However scientists have been unable to isolate any mechanism by which bone cells can compare instances of high strain to ultimate breaking strain. The knowledge that bone cell activity varies with local strain history is an important milestone in our understanding of adaptive processes in bone [95]. Harold M. Frost (1964) termed the responsiveness of bone cells the Mechanostat [95]. Mechanostat theory describes specific, preset strain thresholds, above or below which cellular responses differ. An interesting observation of Frost’s was the similarity of strain thresholds in the bone tissue of all mammals, across species.

Strain, defined as the fractional change in length of a bone, is generally very small in vivo and is normally recorded as microstrain (µstrain). In adult humans a strain threshold that is below approximately 800 µstrains is associated with bone remodelling, and bone loss. Frost termed this strain level the minimum threshold for remodelling (MESr). Remodelling continues to remove bone until a new strain threshold, the minimum threshold for modelling (MESm), is established. The MESm is approximately 1600 µstrain. When strains above the MESm are perceived, the modelling process begins, bone mass increases and bone strength improves [95].

Strain thresholds are higher in the young than the adult of a species [91] in order to allow growth in the immature animal. Peak strain levels (between 2000 to 3500 µstrain) occur consistently in many mammals including man [96, 97]. Bone strains greater than approximately 3000 µstrain overwhelm the ability of remodelling to repair
micro-damage [91] and are associated with the development of stress fractures. Strains in the region of 25,000 µstrain cause frank fracture of lamellar cortical bone [42].

A wide range of strain patterns occur in bone. Patterns vary with anatomical location and type of activity. For example, a person with a serious leg injury may have lower than usual strains in the femur of the affected leg and higher than usual strains in the unaffected one. The dynamic created by bone growth, changes in muscle strength, fluctuating levels of circulating hormones, and variable states of nutrition are all thought to affect the sensitivity of the mechanostat [98].

2.5.2 Mechanotransduction
A widely accepted theoretical model of mechano-transduction implicates peri-osteocytic fluid-flow [99-103]. The fluid flow theory states that tensile and compressive stresses, created by load bearing activity, cause extracellular fluid to shift from regions of high to lower bone strain within the microscopic interconnecting channels in ossified tissue (canaliculi). The flow of fluid creates local mechanical deformations within the walls of osteocytes cell processes in the canaliculi [104]. The interconnecting structure of the network of cell processes makes osteocytes most ideally designed to sense changes in hydrostatic pressure gradients and/or in shear stressors [105]. Osteocytes respond to mechanical stimuli with alterations in intracellular calcium levels, and by secreting insulin-like growth factors (IGF-1), prostaglandins (PGE₂) and cytokines such as nitric oxide (NO) which are among those involved with the coordination of osteoclast and osteoblast activity [106]. The fact that cytokine production alters with the degree of bone strain could explain the directionality of the remodelling cone [107].
Alternative models, of perhaps simultaneous mechanisms for the control of bone cell activity, are presented in brief below.

Central control of bone
The theory of central nervous system (CNS) control suggests that, overarching any local influences, the brain ultimately controls bone formation directly via the nerves, in addition to the circulating humoral mechanisms. The sympathetic nervous system stimulates receptors on osteoblasts and controls the formation of a neural protein, leptin.
Leptin inhibits the osteoblast and bone building [108]. The neuropeptide Y, which is also inhibited by leptin, binds with the Y2 receptor and increases signaling between neurons. Inhibition of Y2 in animals is associated with slowing bone formation [109]. Scientists are pursuing the therapeutic possibilities for osteoporosis sufferers that are offered by these and other discoveries of the neural influences on bone.

The neural system and mechanotransduction

While bone cells and their interconnections may appear to mimic primitive neural systems [110], the neural network is not directly involved in mechanotransduction. Interestingly, the properties of habituation and sensitization that imply some form of memory can be demonstrated in both systems. Research suggests that the presence of the neurotransmitter glutamate in bone may endow it with a simple form of memory [111]. The possibility of ‘bone memory’ is still being investigated.

The circulatory system and adaptation in bone

In a similar way that commonalities exist between the neural and the bone cell networks, so several cytokines and growth factors may play important roles in the regulation of mechanotransduction. At present these factors are very difficult to study in vivo, and thus are still not completely understood. Theoretically the close link between trabeculae and bone marrow could allow growth factors and related molecules with known functions in the circulatory system to affect cellular events in bone. Since intra-osseous blood flow is vital for haematopoiesis it may also be important for remodelling [112]. There is evidence for a vascular bud centered in the BMU, which may be important for the timing of bone resorption and formation. Disruption of small blood vessels (e.g. by lipid emboli) could cause local infarction in bone. Thus, people with arteriosclerosis may develop osteoporosis secondary to the circulatory disease [112].

2.6 Parameters of load - effects in normal bone

Parameters of load that cause adaptation when applied to the skeleton are described in this section. The emphasis on the volitional nature of effort is important because it highlights the role of strain imparted to the bone by muscles [91] against the background of gravitational forces. Table 1 shows the parameters of load that may influence bone: those that featured in this study were magnitude (low), and rate (high).
2.6.1 Load Magnitude

The application of high peak strain magnitudes effectively increases local bone mass in healthy individuals [113-115]. However, repeated high magnitude impacts are associated with degenerative osteoarthritis and cartilage breakdown [116, 117].

For accurate measurement of skeletal load magnitude one or more strain gauges must be bonded with the bone surface, or strain staples inserted directly into the cortex. Such methods are understandably rare in human clinical trials. Ground reaction forces (GRF) are proportional to absolute load magnitudes [118] and can be used as estimates of loading. Force platforms measure the parameters of load magnitude in terms of peak GRF (Newtons), and impulse (peak GRF multiplied by the load duration in seconds).

Evidence suggests that a single large stimulus from a voluntary effort, such as jumping, will be more osteogenic than the cumulative force of smaller ones applied over several load cycles on the same day, e.g. walking [119, 120]. Young gymnasts who do backward handsprings for example, typically absorb GRF ranging from 3 to 5 times body weight [121]. Runners on the other hand, subject the trunk and legs to repetitive forces of approximately twice body weight [122]. Gymnasts have larger, denser bones than otherwise comparable marathon runners [123-126]. While the runners may possess greater cardiovascular endurance than gymnasts, this does not convey bone strength. Gymnasts have stronger bones also when compared with cyclists and swimmers, whose skeletal loads are relatively low [127]. Regardless of exercise style

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Definition (units)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnitude</td>
<td>Peak force per area (grams/millimeter²)</td>
</tr>
<tr>
<td>Duration</td>
<td>Length of time that a force is applied (e.g. minutes)</td>
</tr>
<tr>
<td>Cycle number</td>
<td>Number of repetitions in one set, sets in one bout, rest periods between bouts, bouts per day, days per week etc, etc.</td>
</tr>
<tr>
<td>Frequency</td>
<td>Strains per second (Hertz)</td>
</tr>
<tr>
<td>Rate</td>
<td>Slope of the line describing time to peak load magnitude (grams or K grams/sec)</td>
</tr>
<tr>
<td>Gradient</td>
<td>% change in strain between two neighboring regions e.g. transcortical, antero-posterior tibial tuberosity (E)</td>
</tr>
<tr>
<td>Type</td>
<td>Tension, compression, torsion, shear</td>
</tr>
</tbody>
</table>

Table 1: Parameters of load, definitions and units
the adaptive effects will vary with the individuals’ age, physical health, gender and hormonal status [85].

2.6.2 Duration
Duration refers to the length of time a single load is applied. The fundamental characteristic of effective loading is its dynamism: static loads do not improve bone mass [128]. Thus as long as a stimulus is dynamic the duration of the impulse is relatively unimportant in animal bone [129], and in humans [130, 131]. A matter of seconds may be all that is necessary to initiate adaptive responses in the bone cells [132].

2.6.3 Cycle number
Cycle number describes the total number of load repetitions applied to a bone per 24 hours. Turkey ulnae were maximally sensitive to fewer than 40 cycles of 1000 µstrain [133]. Greater cycle numbers caused no further adaptive responses [97, 133]. Cycles can be subdivided into bouts and sets, e.g. a total of 80 jumps could be prescribed as 10 repetitions per bout, four bouts per set, and two sets per day (morning and evening). However the cycle pattern, at which a specific load will trigger optimal adaptive responses in a particular skeletal region in humans, is not known.

Several (two, three, or four) bouts of loading per day, separated by six-hour intervals, was associated with better mechanosensitivity in rats [118]. Similarly rats that jumped repetitively, but with longer intervals between jumps (30 seconds compared to three) had the greatest increase in bone cell activity, although in this study two separated bouts of jumping elicited similar responses to one only daily bout [134].

2.6.4 Frequency
Strain frequency refers to the number of strains applied to a bone per second, expressed as Hertz (Hz). The impact forces generated by walking and running occur at very low frequencies (e.g. a half to two Hz). During gait, muscle contractions and impact transients generated during heel strike produce a frequencies spectrum in bone between two and 400 Hz. The high end of the spectrum is associated with comparatively low strain magnitudes. The low end of the spectrum characteristically delivers high magnitudes [135]. However activities that supply occasional high frequency strains to the skeleton can be very effective stimuli for bone, e.g. strains applied at 60 Hz to the
bone of animal models (birds and rats) via vibrating devices were more effective, for osteogenesis, than those applied at two Hz [136].

2.6.5 Rate
Frequency and strain rate are related quantities whose effects cannot be considered independently [137]. Strain rate is the temporal slope of the impulse curve from onset to peak strain. Frequency and rate can be difficult to separate in clinical trials of voluntary activity because frequency increases invariably increase the strain rate. Positive effects of high (+/-0.100 N/sec) versus low (+/-0.018 N/sec) rates of loading have been demonstrated in rat ulnae [81] and in sheep [138]. Sheep, for example, that ‘pronked’ for 10 minutes per day had better BMD than those with restraining casts that only allowed walking [139].

Bassey (1994)[140] designed the ‘heel drop’ exercise to observe the effect of a functional activity, of high rate of strain, in healthy young women. To perform ‘heel drops’ one stands, rises to the balls of the feet and then drops, to land on the heels. Fifty rapid, daily, heel drops did not change PF BMD in the Bassey cohort however, a subsequent study of the same protocol in postmenopausal women showed maintenance of calcaneal bone mass, while control participants lost PF BMD [141]. Ground reaction forces developed during the activity was expressed as a ratio of force (Newton) with body weight (Newton). Bassey and Ramsdale report vGRF between 2.5 and 3.0 (N/N), with a rate of rise of 50-100 KN/sec. Similar low magnitude, high rate forces, measured in two male subjects, each with a strain gauge attached to the shaft of the femur, were ‘transmitted, virtually undamped’, to the proximal femur [142].

2.6.6 Gradient
Strain gradients are created by differences in strain between neighboring regions of a material, e.g. between medial and lateral aspects of the mid shaft of a long bone. Gravitational and leverage forces create complex gradients of strain within bone. Lanyon (1996) suggests that the three most effective parameters for bone adaptive responses are; high strain magnitudes, high strain rates, and the application of an unusual or novel, distribution of strain across a specified section of bone [93]. A greater spatial gradient of strain is theoretically more osteogenic than a lower one [139].
2.6.7 Type
Strain type depends upon the geometry of the structure under load and the direction of the applied stress, which itself depends on the nature of the activity. For example, the curved shaft of a femur of an active individual will experience tension on the convex aspect, compression on the concave aspect, and torsion and shear forces throughout the shaft. Researchers are yet to identify the relative contribution of strain type to bones’ adaptive processes. It seems probable that each strain type contributes to the total effect, as a reflection of the three parameters described by Lanyon (1996).

2.6.8 Summary of effective strain protocols and rationale for study activity (foot stomps)
The foot stomping performed by our study participants provided similar low amplitudes and low rates of strain to the heel drops studied by Bassey et al. (1995) and by Hans et al. (2002). Prior to commencement of the SOS a single 64Kg subject performed heel drops followed by foot stomping on a floor-mounted piezoelectric force platform (Kistler 9287A, sampling rate 1000 Hz). The observed similarities of vGRF amplitude and rate support our assertion that stomps could engender similar adaptive changes to heel drops in the region of the proximal femur (Appendix 1). The duration of the stomps activity was a matter seconds and the low cycle number (four stomps performed twice per day at least 5 days per week) was similarly suggested by evidence from the literature.

The potential for squatting and dancing to influence adaptive responses in the lower limb bones of study participants was also considered in the research design. Each of the three activities could be anticipated to create dynamic strain patterns in lower limb bones. Participants who performed squats with the maximum load (12 Kg) may have benefited from somewhat higher strain magnitudes, while the dancing was thought to offer the greatest variety of gradients and types of strain. Strain frequency is difficult to measure non-invasively, thus a further assumption was made, i.e. that a wide frequency spectrum would occur in the lower limb bones of the participants.
2.7 Findings of exercise trials in human bone

A sedentary lifestyle (defined as exercise less than one hour per week) is increasingly common in adult populations [143] and is strongly associated with low bone mass. Reviews of activity interventions for sedentary people show a range of outcomes that vary with the exercise type, its intensity and the anatomical site of BMD measurement [144-148]. As a general rule the effects of mechanical loading are greatest in those with low initial values [149]. An assumption of the principle of specificity of training prevails. Thus, weight-bearing aerobic exercises have been shown to elicit positive responses in the lower limb [150], spine [151], but not the radius [152] of postmenopausal women.

2.7.1 Exercise effects in older women with normal bone mass

Neither moderate exercise with or without calcium [153], nor chronic running with HT [154], will ablate the characteristic bone loss of early menopause. However exercise may moderate high rates of bone loss in healthy postmenopausal women [155].

Walking, running, dance, participation in sports [156, 157], and weight training [158] all have therapeutic effects on the cardio/pulmonary/vascular system, on weight control, and on one’s sense of well-being [159]. Walking can prevent bone loss at the calcaneus [160], proximal femur [161] and lumbar spine [162]. However to be effective for bone walking must be at a speed that maintains the heart rate well above the anaerobic threshold, regular and sustained over many months [162].

Aerobics and weight training improved the percent change BMD in the lumbar spine of postmenopausal women, and aerobics alone improved proximal femur (PF) BMD in a similar cohort [163].

2.7.2 Exercise effects in women with low bone mass

Bone

Walking briskly may moderate bone loss from the lumbar spine of osteoporotic women [164] especially when supplemented with calcium and vitamin D₃ [75]. Iwamoto et al. suggest that supplements increased the women’s skeletal responsiveness to exercise in
those cases where nutrient levels were inadequate. In contrast, three hours of folkloristic dance sessions per week, for 12 months, failed to increase the vertebral BMD in healthy postmenopausal women, but did increase the BMD of an osteoporotic cohort [165].

**Muscle**

Menopause is associated with decreases in lean muscle mass and increases in fat mass[166]. Exercise training can result in significant beneficial changes in lean soft tissue and fat mass in early postmenopausal women. Older women who were not taking HT responded to three one-hour, resistance-training sessions per week for 16 weeks, with significantly increased muscle strength [167]. As importantly, with resistance training the women maintained BMD at spine, hip and radius [168]. Shaw and Snow et al (1998) used weighted vests in a progressively loaded weight-bearing exercise programme that was run three times per week for nine months. The resulting increases in lower limb muscle strength and power correlated significantly with reduction in fall risk in postmenopausal women [169].

**Balance**

The menopausal condition *per se* is unrelated to problems of balance and postural control [170]. Interestingly, osteoporotic women employ different postural control characteristics (greater hip strategies) than non-osteoporotic women, in response to balance perturbations [171]. Fallers, especially those with a history of multiple fall events, have reduced tactile sensitivity, greater visual field dependence, and more body sway than non-fallers [172]. People who are prone to falls respond to balance retraining [53]. Voluntary step reaction time, an important outcome measure of balance [52], improved with specific destabilizing stimuli over very short (i.e. 3 week) training periods [50]. In a similar population postural sway reactions improved with only twelve weeks of dance-based aerobic exercise [51]. However brief programs are often ineffective, because people revert to sedentary habits once the training period ends [173].

Most of the exercise programmes reported in the literature involve the use of costly equipment and/or supervision by qualified personnel. The SOS methodology used
evidence based activities with minimal infrastructure that could be easily performed at home and in many Community settings.

2.8 The Osteogenic Index for designing exercise intervention protocols

Different exercises may have similar cardiovascular training effects, but quite different effects on the adaptive responses of bone. The Osteogenic Index (OI) developed by Turner and Robling [82] quantified the bone-stimulating potential of various loading protocols from animal data. They hypothesized that the saturation of bone adaptation with increasing repetitions is a logarithmic response that is directly related to N, as described in Equation 1.

Equation 1: Osteogenic potential = ln(N+1)

When the log of a number is plotted against itself the result is a hypothetical curve (Figure 4).

![Figure 4](image)

Figure 4 Natural log (ln) N plotted against itself (N) describes the saturation response in bone that occurs with increasing repetitions of the stimulus

Similar to the cycle number response, the measured adaptation of animal bone to variation in bout number can also be predicted (Equation 2)

Equation 2: Recovery (percentage) = 100 (1 - e^{-t/\tau})

In Equation 2; t = number of daily bouts of exercise, i.e. two or three bouts versus five or six, and tau (τ) = a constant set by the researchers at 6 hours.

Equation 2 quantifies the effect of the length of the interval between bouts of exercise performed in any 24 hour period on positive bone adaptive responses in rats. In rats, bone adaptation is enhanced with longer, rather than shorter, periods between exercise bouts [82] as shown charted in Figure 5.
Parameters such as frequency and bout number are common components of any exercise prescription. Based upon the information in Figure 6 the optimal prescription of an exercise for positive bone adaptive responses is (conveniently) twice per day. Synthesis of Equations 1 and 2 creates Equation 3, which expresses Turner and Robling’s Osteogenic Index or the combined effect of all the variables of osteogenic potential of an exercise regime.

Equation 3: \[ OI = x \times \text{body weight} \times \ln(N+1) + x \times \ln(N+1) \times (1-e^{-10\text{hr}/6\text{hr}}) \]

In Equation 3 there are 2 sessions per day; \( x \) = estimated force or load in units of multiples of body weight, \( N \) = cycle number, and time between bouts = 10hr.

The OI of the SOS intervention activities (chapter 3, section 3.2) were calculated using Equation 3, and are shown in Table 2. For example, 2 bouts of foot stomps per day, performed with a force of twice the body weight, separated by a 10-hour period, have a numeric index of 10.3. Participant stomping, 5 times per week with the bi-daily protocol, gives an OI for stomps of 51.5. Similarly, if the same individual performs 3 sets of 8 squats with 10 kg weights (16% of the body weight of a 64 Kg person), once a day, 3 days per week, as per our study protocol, the OI (squats) for that person would be only 11.1. By comparison, an estimated 800 load cycles performed during a line dance
class (similar to a 20 min walk) with a force on the lower limbs of 1.1 times the body weight, provides an OI (line dance) of only 7.35.

<table>
<thead>
<tr>
<th>Exercise</th>
<th>% body weight</th>
<th>Cycles/ bout</th>
<th>Bouts/day</th>
<th>Times/week</th>
<th>OI (week)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stomps</td>
<td>2.0</td>
<td>15</td>
<td>2</td>
<td>6</td>
<td>51</td>
</tr>
<tr>
<td>Squats</td>
<td>1.6</td>
<td>24</td>
<td>1</td>
<td>3</td>
<td>11</td>
</tr>
<tr>
<td>Line dance</td>
<td>1.1</td>
<td>800</td>
<td>1</td>
<td>1</td>
<td>7</td>
</tr>
</tbody>
</table>

Table 2 Osteogenic Indices for SOS exercise interventions for a 64Kg subject

2.9 Bone Measurement

Broadband Ultrasound Attenuation (BUA) by Quantitative Ultrasound (QUS) and BMD by Dual-energy X-ray Absorptiometry (DXA) provide surrogate measures of bone mass. These values taken together with other indices (i.e. falls risk) determine individual fracture risk.

2.9.1 Quantitative Ultrasound (QUS)

The QUS device transmits ultrasonic energy from an emitting transducer through a bone to a focused receiver. Quantitative ultrasonometry can provide many measures: the two most commonly reported variables are broadband ultrasound attenuation (BUA) and speed of sound (SOS). Some QUS devices offer only one measure, others both. An index of stiffness can be derived from the attenuation and velocity measures. The differentiating features of BUA and SOS, in terms of physical parameters, measurement units, and the particular bone quality thought to be measured by each method are listed in Table 3.

<table>
<thead>
<tr>
<th>Method</th>
<th>BUA</th>
<th>SOS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Method</td>
<td>Slope of frequency-dependent attenuation of sound in bone</td>
<td>Distance per transit time of sound energy in bone</td>
</tr>
<tr>
<td>Units</td>
<td>Decibels per megahertz (dB/MHz)</td>
<td>Meters per second (m/s)</td>
</tr>
<tr>
<td>Quality</td>
<td>Bone mass and architecture (Langton 1984)</td>
<td>Bone mass and elasticity (Gluer 1994)</td>
</tr>
</tbody>
</table>

Table 3 Physical differences in measurement parameters of Quantitative Ultrasound
QUS offers the advantages of being relatively quick, cheap, portable, and radiation free. Ultrasound does not directly measure bone mass or mineral density but, unlike DXA, QUS is thought to be sensitive to bone quality [174]. Ultrasound measures of bone quality include the properties; bone density, trabecular orientation[175], the proportion of bone mass that is trabecular and cortical, the composition of organic and inorganic components, and the presence of fatigue induced bone damage.

QUS is an accepted diagnostic tool for the assessment of peripheral sites, e.g. calcaneus, tibia, patella and phalanges. QUS does not directly predict the absolute value given by a DXA scan at the same site [176]. However, it does correlate positively, and linearly, with DXA scores in postmenopausal women with low bone mass [177]. Although QUS can independently predict hip fracture risk in postmenopausal women [178, 179] it is slightly less sensitive (67.6%) than DXA of proximal femur (76.9%) for predicting osteoporosis [180]. Recent work suggests that calcaneal QUS is as sensitive as axial DXA for the prediction, in this group, of risk of fracture at the wrist and at peripheral sites other than spine or hip. [181].

2.9.2 Dual-energy X-ray Absorptiometry (DXA)
The assessment of BMD may be performed with DXA or by computed tomography (CT). The gold standard for measurement of bone mineral content (BMC) is the ash density, i.e. the proportion of mineral (grams) to the bone volume (cm³). DXA is a relatively innocuous scan in terms of patient comfort and low radiation risk (discussed in the next section): it continues to be the most common method of measuring BMD and estimating HFR. CT carries a relatively higher radiation exposure risk than DXA and is less available and more expensive. However CT has advantages for research as it is capable of three dimensional, multi-planar estimates of bone geometry and volume [182].
**DXA radiation exposure**

A DXA device irradiates an anatomical region with two filtered X-ray beams of different energies (60 and 130 kV) and measures the transmitted X-ray intensities. A computer compares the detected signals with a standard (a phantom of aluminium or hydroxyapatite) to determine the areal density of absorbing components in grams of mineral per area of bone (g/cm²) [183]. Radiation emission is measured in rads. DXA devices output millirads (mrad). A standard 2-position chest X-ray emits 40 mrad [87]. The level of background radiation from the environment is approximately 160 mrad per year. Absorption of electromagnetic radiation by a living body is measured in units of Gray (Gy). Accounting for scatter and attenuation gives an effective absorbed dose in Sieverts (Sv). A Sievert is a multiple of a Gray and a quality factor for relative biological effectiveness (RBE) of the radiation. The region of the proximal hip receives approximately 0.5-4.5 µSv, from which there are no known hazards [184]. Hip scans are considered safe to administer to most humans on several occasions. Pregnancy contraindicates any overt radiation exposure.

**BMD measurement precision**

BMD measures from different DXA scanners have been standardized and correlate well with ash weight (mineral content) of bone [155]. However anatomical and age related bone changes make hip DXA measurements difficult to compare between devices, therefore the same machine must be used for serial measurements. Measurement precision of the DXA model used in the SOS can occur between 1.3 and 2.5% [185]. This error is very similar to the mean annual change of BMD for postmenopausal women, therefore DXA scans that are performed less than 12 months apart may not give a reliable BMD estimate [186].

**2.10 Summary**

This chapter outlined the current scientific basis for physical activity interventions that may reduce the incidence of hip fracture in postmenopausal women. The principal hypotheses of the mechanisms of bone adaptation to loading were described, as were the bone responses that can be attributed to particular parameters of loading, the most salient being the focus of our intervention. The evidence for a variety of exercise styles in women with and without adequate bone mass was described. In the following chapter the intervention itself is detailed.
CHAPTER 3 MATERIALS AND METHODS

3.1 Study Design
The Stamp out Osteoporosis Study (SOS) was a tripartite, eleven month, randomized exercise intervention aimed at improving parameters of hip fracture risk in healthy, postmenopausal Caucasian women.

3.2 Ethics
Approval of the research design and protocol was obtained in 2003 from the Griffith University Human Research Ethics Committee (PES/09/03/HREC).

3.3 Study description
An exercise program designed to influence risk factors for falling and fracture was developed. The program consisted of a possible three activities plus supplemental calcium. The activities included in-line dancing, loaded squats and foot stomps. For ethical reasons related to withholding the known benefits of exercise, a traditional, inactive control group was not included in the SOS design. Instead, Group one (calcium and dance only) acted as the control for the other interventions, since the osteogenic index of line dancing is relatively low compared with the other two activities. The inclusion of all groups in the dance activity was also deemed important to maximize participant enjoyment and compliance. Group two participants performed loaded squats in addition to dance and calcium. Group three participants completed twice-daily foot stomps in addition to squats, line dance and calcium supplementation. Table 4 provides a summary of group intervention activities.

<table>
<thead>
<tr>
<th>Group 1 (control)</th>
<th>Group 2</th>
<th>Group 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium supplements (600mg/day)</td>
<td>Calcium supplements (600mg/day)</td>
<td>Calcium supplements (600mg/day)</td>
</tr>
<tr>
<td>Line dance class - side reaction time (once weekly)</td>
<td>Line dance class - side reaction time (once weekly)</td>
<td>Line dance class - side reaction time (once weekly)</td>
</tr>
<tr>
<td>Loaded squats - lower limb endurance (n sets of 8)</td>
<td>Loaded squats - lower limb endurance (n sets of 8)</td>
<td>Foot stomps - bone strength (4 per limb, bi-daily)</td>
</tr>
</tbody>
</table>

Table 4 SOS intervention activities
3.3.1 Participants

**Recruiting and Screening**

Postmenopausal women were recruited from radio and newspaper advertisements in the Gold Coast and surrounding regions. Relatively sedentary women in good general health, at least 5 years post menopause were sought for inclusion. Applicants were screened for exclusion criteria via telephone interview. Those with medical disorders involving the kidney, ovary, thyroid gland, parathyroid gland, gastrointestinal system, or lung, rheumatoid arthritis, or Parkinson’s disease were excluded. Women taking prescribed medications, e.g. hormone therapy (i.e. oestrogen or progesterone taken in any form in the previous 6 months), any drug prescribed for osteoporosis or bone disease, or any corticosteroid (e.g. prednisone) were also excluded, as were those who had any condition of the pelvis or lower limbs that limited normal sit to stand function or gait (e.g. severe osteoarthritis). Recent exposure to high doses of ionizing radiation for any reason e.g. a barium examination, a computed tomography (CT) scan or radioisotope scan in the previous 6 months was also grounds for exclusion. Women with cognitive dysfunction (self reported severe depression or memory difficulties), and certain demographics (e.g. restriction of access to the study venue, personal commitments that would impede compliance, and race other than Caucasian) were also excluded. Eligible volunteers were mailed an information sheet and consent form.

Each volunteers’ tandem gait, over 50 m on a concrete footpath, and stair climbing ability on a flight of regular interior stairs (the journey from the car park to the research laboratory) was inspected by the researcher and assessed in terms of each woman’s general dynamic stability and lower limb function. Any study volunteer who reported significant musculoskeletal pain enough to interrupt this journey would have been advised to discontinue her involvement in the study. No one failed the test.

**Enrolment**

*A priori* projections indicated that eleven participants per group would be needed to detect an effect size for the primary bone densitometry measure, dual-energy X-ray absorptiometry (DXA), with an effect size of 1%, an alpha level of 0.05, and a statistical power of 80%. The effect size reflects previous observations that postmenopausal women may lose 1% BMD over the course of one year [187].
Although some have reported DXA measurement precision of 1.3-2.5%, the precision of the DXA device used in our lab is typically less than 1% for most regions. An additional three participants per group were recruited to allow for an estimated 20% rate of drop out. One hundred and fifteen women were screened and a total of forty five (fifteen per group) were ultimately enrolled.

Randomization

The participant’s names were entered into a spreadsheet (Microsoft ® Excel 2002) in the order in which each enrolled. The software randomly generated a number between 1 and 3 for each new entry. The random number function was repeated until there was an equal number of women in each group (n = 15). The participants were allocated an ordinal number designated for identification (ID) purposes. Each woman’s ID, demographic information and contact details was filed in the SOS Clinical Record File (CRF) and stored in a locked cupboard within the research laboratory. The information was tabled electronically (Microsoft Access 2002) and stored in a password protected file. Participants were informed by mail of their inclusion in the study and group allocation.

3.4 Intervention

3.4.1 Compliance
A calendar, especially designed to have adequate space in which participants could record the details of their compliance with study activities, was issued at baseline. The women were urged to document incidents such as a trip, slip, or fall, as well as injuries or illness, whether related or not to the study. In addition the women were to make note of any changes to the usual pattern of diet or activity. Calendar entries were reviewed at six and eleven months respectively. A sample page from the calendar is provided in Appendix 2.

3.4.2 Calcium Supplementation
All participants were supplied with (free of charge), and advised to take, one 600 mg CalSup™ tablet per day, with a meal, to ensure optimal calcium availability for the duration of the trial. Participants recorded their compliance with daily calcium supplementation on the SOS calendar.
3.4.3 Line Dance Class
Participants were asked to attend one 60 minute line dance class per week. A total of thirty six dance classes were held over a period of eleven months. A professional instructor conducted the classes. The majority of participants were line-dance novices; none were advanced level performers. New dances were introduced only when everyone had learned the basic steps, so that all participants attained competence together. The tempo and complexity of the choreography increased over the course of the study, according to the ability of the majority. All dancers move independently of each other, performing single steps to each beat of the music, in a sequenced pattern that addresses one of the four walls of the room. Dancers may also cross step, shuffle, stamp or tap the forefoot or heel, or turn on the spot. Dances learned included Elvira, Boot Scootin’ Boogie, C. C. Shuffle, Houston Hustle, Senorita Sway, Al’s Stray Cow, Slap Leather, Honky Tonk Stomp, Haunted Heart, South West Cha Cha, Old South Wind, Wild Wild West, Smokey Places, The Woolshed Waltz, Stray Cat Strut, Flying High, Bartender Stomp, Waltz across Texas, and Coasin’. A roll of class attendance was maintained throughout the study in order to record participant compliance with this activity.

3.4.4 Progressively Loaded Squats
Group two and three participants were directed to perform one bout of load-free squats i.e. two sets of eight repetitions, five times per week for the first month of the study, in order to initiate the processes of adaptation and to perfect technique. Supplementary loading was commenced when participants demonstrated good musculoskeletal control of all body parts during free squats. Load was added, one kilogram at a time, when each participant could perform the task easily while maintaining form. To load the squats participants poured tap water, one liter at a time into two initially empty, six litre plastic table water containers (Spring Water™ Australia). The container design included a handle that facilitated comfortable grip by the participants. Each woman was provided with two containers and advised to maintain loading symmetry by filling both equally.

The women were asked to record on the SOS Calendar their compliance with the squats program in terms of the number of squats performed, per date, the load lifted (Kg), and any subjective difficulties with the activity, e.g. knee pain.
The squats technique taught to SOS participants included information on foot position, lower limb and trunk alignment in the sagittal and frontal planes, timing, and periodicity. To minimize a potential for musculoskeletal strain, the importance of continued attention to correct technique was emphasized. Participants observed a demonstration of the squat technique, and were provided with illustrated, written instructions, as follows:

“Stand with feet approximately shoulder width apart, chin up and face forward. Maintain a slightly hollow lower back whilst slowly bending at hips and knees until the pelvis was just above a standard height chair. Hold that position for approximately 2 seconds. Slowly return to erect standing. Maintain the body weight back on the heels so that the toes are visible during the squats and the kneecaps aligned with the mid-foot.”

Participants were encouraged to increase the load incrementally, but only when 2 sets of 8 repetitions of a previous load caused no perceptible leg muscle strain or knee joint pain. The women were advised to report to the researchers immediately should musculoskeletal problems arise in association with squatting (e.g. knee or spinal pain). Those participants who discovered that knee symptoms became a limiting factor for the squats activity were given an alternative strategy; i.e. the substitution of a static, isometric, wall-squat.

The instructions to perform a wall-squat run as follows:

“Stand against a gloss painted surface such as a door jamb. Keep the back against the wall and step forward approximately one thigh length. Slide downwards towards a sitting position, i.e. until hips and knee angles are approximately 100 degrees. Assuming no knee pain, hold the position for as long as possible, counting the squat duration in minutes and seconds. Stop counting and return to the upright position at the point of subjective quadriceps muscle fatigue.”

3.4.5 Foot Stomps
Group three participants were told to stand and stomp, four times with each foot, twice per day, every weekday (i.e. five times per week), for the study duration. Participants were advised to stomp briskly, barefoot, on a firm floor, to avoid stomping on thick carpets, concrete or tiles; rather to choose a surface with some resilience such as timber. Should the surface be overly rigid participants were advised to stomp on a towel or mat, such as found in most bathrooms. To establish this new habit, participants were
encouraged to mentally link foot stomps with some other regular bathroom activity, such as teeth cleaning. Participants were asked to record compliance with the stomps program as weekdays that stomps were NOT performed, and any musculoskeletal problem associated with stomping (e.g. plantar or ankle pain), on the SOS Calendar. Stomping was demonstrated to the women as follows:

“Stand erect, bare foot. Stamp the right foot four times in a row, directly downwards beside the left (on the spot), with enough speed to suggest ill temper, and enough force to crush an empty aluminium soft drink can. Repeat this pattern with the left foot.”

Participants practiced stomping on a sheet of bubble wrap (plastic wrapping material with air pockets 1cm diameter) placed on a timber floor. The technique was deemed adequately forceful when each woman demonstrated that she could burst the air pockets under foot with clear popping sounds.

3.5 Measurements

3.5.1 Behavioral Characteristics and Health History
Information was collected via individual interview at baseline. All nominal data was stored as hand-written participant record files (PRF) in a locked cupboard within the research laboratory.

A questionnaire was developed to record behavioral characteristics and health history (Appendix 4). History of menarche and menopause, and date of surgery and details of ovarian retention, in those women who had undergone hysterectomy, was recorded. Participants’ family history of osteoporosis or spinal deformity, personal history of falls and fractures, personal feelings of vulnerability to falls, current and past use of tobacco and alcohol, and current exercise patterns were documented. A validated food frequency questionnaire (Appendix 3), including supplements, was completed by each participant to calculate an approximate daily dietary calcium intake [188].
3.5.2 Physical Measures

Physical characteristics, i.e. height (meters) and weight (Kilograms) were measured, and body mass index calculated (weight / height $^2$). Each participant’s hip fracture risk, before and after the intervention period, was found by using the algorithm devised by Black et al. [28]. Bone measures (QUS, DXA) were collected at baseline and follow-up. Muscle function and balance parameters were assessed at baseline, follow-up and on seven intervening occasions.

3.5.3 Quantitative Ultrasound

Broadband Ultrasound Attenuation (BUA) of the right calcaneus was measured using the QUS-2 Ultrasonometer (Quidel Inc, Mountain View, CA USA). To measure BUA the participant removed shoes and stockings and sat in one of two chairs that were placed square with the wall behind. The choice of chairs was made so that the seated hip and knee angle could be closely approximated to ninety degrees when the foot rested on the QUS-2. The ultrasonometer was positioned on the floor so that a line running perpendicular to the wall behind the chair ran parallel to an imaginary line joining central points of the right hip, knee and ankle joints, and bisected the QUS-2 device. The skin over the medial and lateral aspects of the posterior calcaneus was prepared by brisk scrubbing with a swab impregnated with 30% alcohol and allowed to dry. Cleansing removed skin oils and dirt, thus minimizing impedance mismatch between body tissues and gel, and optimizing the passage of ultrasound. A thick smear of ultrasonic transmission gel was applied to both sides of the heel. The participant rested in the chair for four minutes, (timed by the instrument), to ensure a standard hydration of skin by the coupling agent (gel). During this time participant details were entered into the instrument’s software. After four minutes had elapsed the participant’s heel was positioned between the transducer-bearing mobile arms of the device; color bars facilitated centering of the heel to the nearest millimeter. The activated device identified and scanned a Region of Interest (ROI) of approximately 0.8 cm$^2$. Total set up and scan time was approximately five minutes. Participant BUA was recorded on the PRF. A printout of data copied and stored in a secure file and an electronic record was added to the SOS database.
**BUA measurement precision**

Short term precision of QUS devices lies between 1.3 and 3.8% [186]. Long term precision of the QUS-2 device (Quidel Inc, Mountain View, CA USA) is approximately 2% [189].

3.5.4 Dual-energy X-ray Absorptiometry (DXA)

Each woman was given a referral to the local diagnostic imaging centre, (South Coast Radiology, Nerang Street, Southport), for DXA. Right proximal femur (PF BMD), and lumbar spine (L2 - L4) (LS BMD) bone mineral density was measured (XR-36, Quickscan with host software, version 3.9.4, and scanner software version 2.0.0, Norland Medical Systems, Inc. USA).

To prevent concurrent radiation exposures, participants were screened for previous diagnostic imaging involving ionizing radiation e.g. mammography or computerized tomography in the previous 6 months. An affirmative response would have generated a request to the woman’s local medical practitioner for advice on safe scheduling of the DXA scan. In the event, all participants were able to keep appointments for densitometry of right proximal femur within 10 days of receiving the referral. When making the appointment participants were advised to wear loose, comfortable clothing, avoiding garments with metal zippers, belts, or buttons. The women were informed of the painless and brief (approximately six to eight minutes) nature of the scan and of the low risk from radiation exposure associated with it.

Procedural advice was given verbally, to wit:

“**You will lie on a padded table with an X-ray generator below and a detector above. Your right foot will be placed in a brace that maintains a modest degree of hip inward rotation. The scanner will pass slowly over the hip area. All other body parts should not move during the scan. The computer generates an image that will appear on a monitor screen.**”

South Coast Radiology provided analyzed results. Each participant’s BMD scores (g/cm²) were recorded in the PRF and a digital record was saved in the SOS database. The original documents were returned to the owners, with a lay description of their meaning.

3.5.5 Muscle Measures

All functional measures were made on the same testing days.
Squats

The equipment and method of performing loaded squats was explained in a previous section (3.4.4). Baseline lower limb strength and change at subsequent testing sessions was measured as the maximum number of consecutive loaded squats (12 Kg) before the onset of muscle fatigue, joint discomfort, or loss of form.

3.5.6 Balance Measures

Four measures of balance were taken, always in exactly the same order; stepping velocity (forward, then lateral stepping), the test of static balance, then dynamic balance.

Static Balance

Static balance was measured by the Stork test [190]. The protocol was described to each participant exactly, thus:

“Stand quietly in bare feet, with hands by sides, eyes open, near but not contacting, a wall. Prepare to stand for as long as possible, on the right leg, by lifting the left foot off the floor and placing it against the right shin.”

A single practice session was allowed. Single leg stance time (SLS) was measured with a stop watch (seconds). The tester stopped the watch immediately the participant displayed a gross correction, defined as a postural adjustment of a limb or the trunk, or if the non-stance foot touched the floor. Isolated corrective movements of the stance ankle were allowed. SLS time was chosen from the best of three repetitions of the test. When SLS with eyes open reached 30 s the test was stopped and the protocol repeated with the participant’s eyes closed. The resulting measures were summed to create a total, e.g. 30 (eyes open) + 3 (eyes closed) = 33 s.

Dynamic Balance

A valid screening tool for functionality and high fall risk in non-institutionalized elderly women is the timed ‘Up and Go’ (TUG) test. The TUG test (reliability of 98%, sensitivity 87%) [191] was used in the current study. The TUG test requires: a standard height chair, positioned with its back against a wall, and a clear area of at least 3.5 meters in front; a painted marker, clearly visible on the floor, exactly 3 meters from the front of the chair.

The participants were instructed as follows:
“Sit on the chair, against the back rest and, on the count of 3, rise from the chair, trying not to use the arms to assist, walk around the marker at your own pace, return to the chair, and sit back into the seat. This is not a race; the quality of your movement is being observed and recorded.”

Time in seconds, from when the participant’s back left the chair support to when her back regained contact with it, was recorded for a single trial.

3.5.7 Step Velocity Measurement
The test procedures were demonstrated to each participant, as follows: For the ‘fall forward’ simulation the instructions were:

“Stand straight with weight equally distributed on both feet. Lean forward from the ankles ‘like the leaning tower of Pisa’. When you feel you need to take a step to prevent falling forward, do so with your right foot.”

For the ‘fall sideways’ simulation the lateral step procedure was similar to the forward test, except that the participant was instructed to lean to the left and to step across in front of the left foot with the right. A two meter metal tape measure, which was secured to the floor beside the participant, enabled measurements of step length to the nearest millimeter. An assistant stood ready to act as spotter if necessary. Participants were allowed to familiarize themselves with the procedure and, when able to simulate the maneuver, a single repetition of the test was recorded.

Prior to each step test the computer program (.vi) was activated (clicked the ‘run’ button). Electronic data collection was similarly halted, at test completion (via the SOSD front panel). Points were manually identified on the chart’s horizontal axis where force fell to and rose from zero. SOSD data were subsequently calculated and displayed as time (ms) on the front panel.

Forward and Lateral Step Velocity
We measured the velocity of the step needed to prevent a fall from a stable, erect standing position, in the absence of a trip stimulus or external balance perturbation. Step reaction velocity was calculated from time and distance measures as in Equation 4.

Equation 4: Velocity (m/s) = distance (mm) / time (ms)
Step Velocity Equipment

Time of flight, from toe-off to landing, was detected by a sensor, which was positioned centrally, under the ball of the bare right foot. The sensor was a force sensing resistor (Interlink Electronics™, Camarillo, California), 2 cm square, 2 mm thick, electrically insulated, and secured to the foot with double-sided adhesive gel mounts (BioDerm™ BioMedical Life Systems Inc., Vista, California). The mounts were 1 mm thick, with other dimensions matching those of the sensor.

A simple electronic circuit linked the sensor to the serial port of the sound card in a Compaq notebook (Pentium 4/Celeron processor). To prevent entanglement the connecting circuitry was secured at the participant’s knee and waist with elasticized straps. The external circuit was powered by a nine volt battery. An inbuilt oscillator converted battery power (DC) to the alternating current needed by the sound card. The sensor/sound card method provided the researchers with a substitute for expensive sampling equipment, i.e. a data acquisition card.

A virtual instrument (.vi) called the Stamp out Osteoporosis Study Step Reaction Time Device (SOSD) was created using graphical programming software (LabVIEW, Student edition version 6, National Instruments Corporation, Austin, Texas). The SOSD sampled electronic signals, via the sound card, and displayed data points on a chart similar to that illustrated in Figure 6. The SOSD program correlated time of flight data with time according to the computer’s clock (milliseconds).
Figure 6 LabVIEW front panel showing data collected from the force sensing resistor during a simulated fall forward test in one participant

3.6 Stamp-out Osteoporosis Study Device (SOSD) short and long term precision
SOSD measurement reliability was determined from an independent sample of healthy, postmenopausal women, concurrently with the main study. A variation of the original ethical approval for this activity was obtained from the Griffith University Human Research Ethics Committee in July 2004. Eleven volunteers matching the characteristics of study subjects were recruited by advertisement and an information sheet and associated consent form supplied.

Validation study participants were tested exactly as described in section 3.5.7, forward and lateral step velocity. The women performed three repetitions of the forward step test, and three of the left lateral step test; the tests were repeated on the same day of three consecutive weeks.
3.6.1 Validation of instrumentation
Short (same day) and long term (weekly) SOSD reliability (intra-subject measurement variation) was evaluated by repeated measures ANOVA. Two questions were posed:

1) Were the variances of the forward and lateral step velocities of the validation study participants the same for each of the three repeated tests?

2) Were the variances homogeneous over the three test weeks?

The coefficients of variation (CV) for short and long term repeated measures of forward and lateral step velocities were calculated and used as the precision error of the instrument. CV multiplied by 2.77 became the least significant change (LSC) figure against which SOS participants’ responses were compared.

Validation study hypotheses were that:

**Hypothesis 1**: No difference will exist between *same day* trials for forward and lateral step reaction velocities of the same participant.

**Hypothesis 2**: No difference will exist between *the weekly* tests of forward and lateral step reaction velocities of the same participant.

3.7 Primary Study Testing Schedule
Balance, squat strength and step reaction time testing was completed at the Southport Community Centre, Lawson Street, Southport, at baseline, follow-up and periodically throughout the study period as shown in Table 5. Test stations were set up with screens to limit the observation of anyone not immediately involved with each test. Retests were conducted by the same research assistants in the same sequence according to a predetermined protocol. Test data was entered into files using Microsoft Access (2002). The files were linked only by the participants’ secure identity code.
<table>
<thead>
<tr>
<th>Week</th>
<th>1</th>
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<th>15</th>
<th>20</th>
<th>26</th>
<th>32</th>
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</table>

**Legend:**
- **BMD**: Bone mineral density of the proximal femur
- **BUA**: Broadband Ultrasound Attenuation
- **MS**: Muscle strength (number of squats and amount of load carried)
- **SLS**: Static Balance (Stork test)
- **TUG**: Timed Up and Go (TUG test)
- **SV**: Step reaction time and distance

Table 5 SOS Test Schedule

### 3.8 Statistical methods

#### 3.8.1 Descriptive Analyses

Statistical analyses were performed using SPSS v 12.0.1 for Windows (SPSS Inc. Illinois USA). Alpha levels were set at 0.05.

Means, standard deviations, and ranges of age, weight, height, BMI, daily calcium, HFR, initial BUA, and initial PF and LS BMD, squats number, and balance variables were calculated.

Line dance compliance was determined by calculating number of dance sessions attended as a percentage of total possible dance sessions. Compliances with squats and stomps activities were independently determined by calculating the number of times each activity was performed over the study duration from subject log records as a percentage of total possible times.
Correlation analyses of age, height and weight were performed with each of the dependent variables. The influences of participant characteristics and compliance (total number of squats and/or stomps) on outcome variables were examined by multiple regression analyses.

Participants were categorized as having either a high or low risk of falling according to the time to complete the TUG test.

3.8.2 Intervention effects
Within- and between-group effects on BUA, PF and LS BMD, squats number, SLS, TUG and step velocities were examined via repeated measures ANOVA. Post-hoc analyses were performed using the Scheffe test.

Paired t-tests were also used to detect change for SLS and TUG times, and for forward and lateral step velocities in the total sample to maximize power to detect an effect of line dancing on balance parameters.

An analysis of least significant change (LSC) was performed on baseline and follow-up step reaction measures using precision data collected in the device reliability trial described above.
4.1 Statistical Power
A priori projections indicated that a minimum of 11 women per group, for a total of thirty three women, would be required to address the study hypotheses of an effect on BMD by dual energy X-ray absorptiometry (DXA). The calculations incorporated an effect size of 1%, an alpha level of 0.05, and a statistical power of 80%. The effect size reflects previous observations that postmenopausal women may lose 1% BMD over the course of one year [187].

All data were analyzed using SPSS v 12. *Post hoc* power analysis of findings based on final participant numbers, group means, and standard deviations revealed relatively low actual powers of 38% for BUA, 26% for BMD, 46% for leg strength, 25% for balance, 39% for forward step velocity and 26% for lateral step velocity.

4.2 Participant Characteristics
The baseline characteristics of all study recruits are described in Table 6 (a). Characteristics of participants who completed the study are shown in Table 6 (b). Comparison of the upper and lower ranges in Table 6 illustrates the participants who dropped out were the heaviest women. ANCOVA adjusting for body weight did not affect the significant difference among groups for LS BMD.

<table>
<thead>
<tr>
<th></th>
<th>a. Recruits (n = 45)</th>
<th>b. Participants (n = 31)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age (years)</strong></td>
<td>Range: 52 - 78</td>
<td>Mean ± SD: 64.3 ± 6.6</td>
</tr>
<tr>
<td><strong>Height (m)</strong></td>
<td>Range: 1.49 - 1.74</td>
<td>Mean ± SD: 1.61 ± 0.07</td>
</tr>
<tr>
<td><strong>Weight (Kg)</strong></td>
<td>Range: 50.3 - 115.0</td>
<td>Mean ± SD: 69.8 ± 12.6</td>
</tr>
<tr>
<td><strong>BMI (Kg/m²)</strong></td>
<td>Range: 19.8 - 45.20</td>
<td>Mean ± SD: 27.0 ± 4.4</td>
</tr>
<tr>
<td><strong>Years since menopause</strong></td>
<td>Range: 6 – 33</td>
<td>Mean ± SD: 14.9 ± 10.2</td>
</tr>
</tbody>
</table>

Table 6 (a) Characteristics of all recruits and (b) Participants on completion of study. Over-weight women were more likely to drop out.
Recruitment, screening and health history interview determined that none of the participants performed any regular physical activity other than general household duties and short walks (< 15 min per day). Average calcium consumption for all subjects was 675 grams ± 300 g. There were no dietary calcium differences between groups.

4.3 Normality of distributions between groups

Tests for homogeneity of variance indicated the groups were represented by normal distributions for most parameters. No differences existed between groups for baseline measures of age, height, weight, BMI, years since menopause, daily calcium intake, HFR, BUA and PF BMD, muscle strength, or balance. Group characteristics can be observed in Table 7.

Table 7 Baseline participant descriptive and dependent variables, means and standard deviations, per Group, after randomization. Group 2, were significantly heavier and had greater LS BMD than the other Groups (1 and 3).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Group 1 (n =13)</th>
<th>Group 2 (n =15)</th>
<th>Group 3 (n = 15)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>63.31 ± 6.71</td>
<td>67.80 ± 11.94</td>
<td>66.07 ± 12.04</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.60 ± 6.4</td>
<td>1.63 ± 5.0</td>
<td>1.58 ± 7.3</td>
</tr>
<tr>
<td>Weight (Kg)</td>
<td>67.6 ± 8.6</td>
<td>75.1 ± 16.1</td>
<td>66.5 ± 8.9</td>
</tr>
<tr>
<td>BMI (Kg/m²)</td>
<td>26.3 ± 3.3</td>
<td>28.50 ± 6.1</td>
<td>26.4 ± 2.6</td>
</tr>
<tr>
<td>Years since menopause</td>
<td>16 ± 5</td>
<td>11 ± 8</td>
<td>15 ± 9</td>
</tr>
<tr>
<td>Calcium intake (mg/day)</td>
<td>704 ± 271</td>
<td>692 ± 342</td>
<td>640 ± 300</td>
</tr>
<tr>
<td>HFR (-)</td>
<td>-0.155 ± 1.4</td>
<td>-0.038 ± 1.9</td>
<td>0.78 ± 1.9</td>
</tr>
<tr>
<td>BUA (dB/MHz)</td>
<td>80.9 ± 14.7</td>
<td>87.2 ± 16.5</td>
<td>76.9 ± 19.5</td>
</tr>
<tr>
<td>PF BMD (g/cm²)</td>
<td>0.7766 ± 0.096</td>
<td>0.8371 ± 0.144</td>
<td>0.7598 ± 0.127</td>
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<tr>
<td>LS BMD (g/cm²)</td>
<td>0.8803 ± 0.340</td>
<td>1.0698 ± 0.152 a</td>
<td>0.9592 ± 0.225 a</td>
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<tr>
<td>Squats (count)</td>
<td>8 ± 9</td>
<td>11 ± 10</td>
<td>11 ± 10</td>
</tr>
<tr>
<td>Single leg stance (s)</td>
<td>14 ± 11</td>
<td>20 ± 11</td>
<td>14 ± 11</td>
</tr>
<tr>
<td>Timed up and go (s)</td>
<td>9 ± 1</td>
<td>10 ± 2</td>
<td>11 ± 1</td>
</tr>
<tr>
<td>Forward step velocity (m/s)</td>
<td>1.57 ± 0.62</td>
<td>1.35 ± 0.75</td>
<td>1.37 ± 0.59</td>
</tr>
<tr>
<td>Lateral step velocity (m/s)</td>
<td>0.93 ± 0.62</td>
<td>0.90 ± 0.74</td>
<td>0.78 ± 0.52</td>
</tr>
</tbody>
</table>

a = significantly different from both Groups 1 and 3, p < 0.05

Group two had significantly higher LS BMD at baseline than Group one (mean difference = 0.22 gm/cm², p = 0.02) and Group three (mean difference = 0.24 gm/cm², p = 0.007) respectively. The latter finding may reflect a trend towards greater body weight in Group 2 participants.
4.3.1 Relationships between participant age, HFR, BUA, and PF BMD
At the study inception, in this cohort, there was no relationship between participant age and HFR. Age was inversely, but weakly, related to BUA ($r = -0.266$, $p = 0.05$) and PF BMD ($r = -0.391$, $p = 0.01$) (Figures 7a, b & c). Participant PF BMD was related positively to BUA ($r = 0.533$, $p = 0.01$) and strongly negatively to HFR ($r = -0.697$, $p = 0.05$) (Figures 7d & e). BUA was similarly positively related to HFR, albeit not as strongly ($r = -0.475$) (Figure 7f).

4.4 Outcome Measures
Mean changes ($\pm s$) in outcome measures following one year of line dancing (LD), line dancing and squats (LDS) or line dancing, squats and stomps (LDSS) in healthy postmenopausal women are presented in Table 8.
Figure 7 Relationship of age to (a) HFR, (b) BUA, (c) PF BMD, respectively.

Figure 7 Relationship of PF BMD to (d) HFR and (e) BUA respectively. Relationship of BUA to (f) HFR.
<table>
<thead>
<tr>
<th>Outcome measure</th>
<th>Group 1 (LD) (n = 9)</th>
<th>Group 2 (LDS) (n = 10)</th>
<th>Group 3 (LDSS) (n = 12)</th>
<th>All groups (n = 31)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HFR</td>
<td>0.03 ± 0.14</td>
<td>-0.04 ± 0.15</td>
<td>0.05 ± 0.72</td>
<td>-0.06 ± 0.48</td>
</tr>
<tr>
<td>BUA (dB/MHz)</td>
<td>0.43 ± 4.4</td>
<td>2.3 ± 4.4</td>
<td>-2.6 ± 3.1</td>
<td>-0.07 ± 4.4</td>
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<tr>
<td>PF BMD (g/cm²)</td>
<td>-0.026 ± 0.03</td>
<td>-0.009 ± 0.03</td>
<td>-0.004 ± 0.04</td>
<td>-0.012 ± 0.03</td>
</tr>
<tr>
<td>LS BMD (g/cm²)</td>
<td>0.0048 ± 0.05</td>
<td>0.0004 ± 0.04</td>
<td>-0.011 ± 0.43</td>
<td>-0.006 ± 0.44</td>
</tr>
<tr>
<td>Squats (count)</td>
<td>12 ± 12ᵃ</td>
<td>21 ± 20ᵃᵇ</td>
<td>39 ± 26ᵃᶜᵈ</td>
<td>14 ± 11ᵃ</td>
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<tr>
<td>Single leg stance (s)</td>
<td>15 ± 13ᵃ</td>
<td>13 ± 10ᵃ</td>
<td>13 ± 11ᵃ</td>
<td>13 ± 11ᵃ</td>
</tr>
<tr>
<td>Timed up and go (s)</td>
<td>-2 ± 1ᵃ</td>
<td>-2 ± 2ᵃ</td>
<td>-2 ± 1ᵃ</td>
<td>-2 ± 2ᵃ</td>
</tr>
<tr>
<td>Forward step velocity (m/s)</td>
<td>0.22 ± 0.56</td>
<td>0.31 ± 0.88</td>
<td>0.3 ± 0.85</td>
<td>0.036 ± 0.82</td>
</tr>
<tr>
<td>Lateral step velocity (m/s)</td>
<td>0.36 ± 0.55</td>
<td>0.36 ± 0.34</td>
<td>0.13 ± 0.66</td>
<td>0.27 ± 0.53ᵉ</td>
</tr>
</tbody>
</table>

BUA – broadband ultrasound attenuation; PF – proximal femur; LS – lumbar spine; BMD – bone mineral density;  
a = significantly different from baseline at p = 0.01;  
b = significantly different from group 1 at p = 0.05;  
c = significantly different from group 1 at p = 0.01;  
d = significantly different from group 2 at p = 0.05;  
e = significantly different from baseline at p = 0.05

Table 8 Mean change ± standard deviation in the SOS main outcome measures, per Group, and for the combined cohort
4.4.1 Hip Fracture Risk
At baseline, the algorithm used to assess HFR predicted that approximately half of the study participants were more likely to fracture than age-matched peers. During the period of the study four participants reported suffering a single fall each due to an accidental trip or slip either at home or in the street. No fractures were reported. Figures 8 (a) and (b) show the degree to which study participants were at risk of fracture before and after the intervention. A negatively signed number indicates a lower likelihood of fracture and a positive number implies greater likelihood of hip fracture (HFR). Participant HFR did not change over the course of the study. While there were no differences between groups at follow-up, a non-significant trend towards the ‘less likely’ (to fracture) side of the scale occurred and can be seen in Figure 8.

Figure 8 HFR score of all study participants (a) baseline, and (b) final
4.4.2 Broadband Ultrasound Attenuation
There were no detectable within- or between-group differences in calcaneal BUA at follow-up.

Line dance = LD; Line Dance and Squats = LDS; Line Dance, Squats and Stomps = LDSS

Figure 9 Six and twelve month BUA change

Effect of stomp compliance on BUA change
In those subjects that stomped, however, change in BUA was strongly positively related to stomp compliance ($r = 0.73$, $p = < 0.05$) (Figure 10).

Figure 10 Twelve month actual BUA (dB/MHz) change according to stomp compliance

4.4.3 Proximal femur and lumbar spine bone mineral density (BMD)
There were no significant BMD differences within or between groups at the proximal femur or lumbar spine following the intervention. A tendency for an effect of squatting
and for stomping is suggested from the appearance of greater PF BMD loss in Group one, who danced, compared to Groups two and three, however the effect was not significant (Figure 11a). The percentage of change of PF BMD for Group one was -2.23%, compared with -0.46% for Groups two and three combined.

![Figure 11(a) 12 month change in PF BMD](image1)

There was no effect of stomps on LS BMD within or between groups (Figure 12b). The LS BMD differences were unchanged at follow up, i.e. the significantly greater LS BMD of Group two, compared with Groups one and three at baseline, remained at follow-up ($F = 6.48$, $p = 0.03$).

![Figure 11(b) Twelve month LS BMD change](image2)
Effect of stomp compliance on PF BMD change

In the 12 participants that stomped, change in PF BMD was strongly positively related to stomps compliance ($r = 0.79$, $p < 0.05$) (Figure 13).

$$y = 0.0004x - 0.0606$$

$$R^2 = 0.6935$$

Figure 13 Relationship of PF BMD change to stomps compliance

Lumbar spine BMD was only weakly related to participant stomps compliance ($r = 0.25$, $p = 0.04$).

4.4.4 Squats
All groups demonstrated a significant improvement in functional squats capacity (Group 1, 226%; Group 2, 242%; Group 3, 363%; $p < 0.001$). Group 3 exhibited the greatest increase in squats number ($p < 0.03$). Although Groups 1 and 2 appeared to improve less than group 3, there were no significant differences between the groups (Figure 14).

Figure 14 Twelve month change in the number of loaded squats
Effect of squats compliance on BMD change

The reported total number of loaded squats so performed ranged between 300 and 23,000, over the study duration. Women with better compliance (n > 6,000 squats) showed the greatest mean improvement in PF BMD. Squatting (r = 0.883, p = 0.001) was more strongly associated with change in PF BMD than was stomping (r = 0.268, p = 0.001).

In the 21 participants that squatted 17% of the change in PF BMD was predicted by squats compliance. A strong, positive relationship was found between functional squats capacity and squats compliance (r = 0.64, p < 0.01) (Figure 15).

![Figure 15 Twelve month change in squats performance according to squats compliance](image-url)
4.4.5 Balance

*Single leg stance time*

Single leg stance (stork) time increased in all participants ($\alpha = < 0.001$) with no differences detected between groups (Figure 16). Groups 1 and 2 both improved stork times by 18 s, while Group 3 increased by 13 s, which can be expressed as 162%, 129% and 87% improvements respectively.

![Figure 16 Twelve month change in single leg stance](image)

*Timed ‘Up and Go’*

Fallers in non-residential postmenopausal women have been identified by a TUG time of greater than 12 seconds[192]. At baseline almost 40% of the participants who completed the study performed the TUG test in 11 or 12 seconds. All other participants TUG test times were under 11 s (i.e. were at a relatively lower risk for falls). There were no evident differences between groups at baseline or follow-up. TUG times did not correlate with age or with the HFR of the participants at baseline or follow-up. TUG time decreased in all participants ($p < 0.001$) with no differences detected between groups. At baseline Groups one and two TUG time was 10 s, and Group three was 11 s. At the final testing day all groups had reduced the TUG times by an average of 2 s.
4.4.6 Parameters of step velocity

There were no detectable differences between groups for any of the parameters of forward or lateral step velocity.

**Forward step velocity**

Forward step distance increased in all participants over the study duration (20 ±12 cm, \( p < 0.001 \)). As mean forward step time also tended to increase (200 ± 121 ms) (NS) mean forward step velocity did not change significantly between baseline and follow-up (Figure 17).

![Figure 17 Twelve month change in forward step velocity](image)

**Lateral step velocity**

Lateral step distance increased in the combined group analysis (16 ± 11 cm, \( p < 0.001 \)). Mean lateral step time tended to decrease although the trend was non-significant (-300 ms) (Figure 18). The combined changes in lateral step distance and time produced a significant increase in lateral step velocity (baseline, 0.9 m/s² versus final, 1.12 m/s²);
p < 0.05) for the total subject sample. Least significant change calculations using
precision study data (section 4.5) suggest that the above detected differences in step
parameters between baseline and follow-up measures were not greater than those that
may be explained by measurement precision error.

4.4.7 Compliance findings
Study drop out rate was 32%. Mean line dance compliance was 70%, mean squats
compliance was 65%, and mean stomp compliance was 80%.

4.5 SOSD validation findings

4.5.1 Descriptive statistics
There were no differences in mean age and height between the SOS participants (cohort 1) and the instrument validation subjects (cohort 2) (Figure 19). Validation subjects were somewhat heavier than study participants but the variances between the groups were similar (means for validation subjects = 77.9 Kg, and SOS participants = 68.6 Kg respectively, p = 0.05).
4.5.2 Device reliability

Short term reliability

There were no differences between three consecutive trials on the same day for the same subject for forward and lateral step velocity. However the coefficients of variation, for forward and lateral step velocity of the first test of week, were 29% and 27% respectively.

Long term reliability

There was no difference between the means of 3 trials on each of 3 consecutive weeks for the same participant for measures of forward and lateral step velocity. However the mean coefficients of variation for forward and lateral step velocity of each test on weeks one, two, and three were 30% and 33% respectively.
The Stamp out Osteoporosis Study (SOS) exercise intervention was designed specifically for independent, community dwelling, postmenopausal women who are not at a high risk for hip fracture, because simple, mainly home-based exercise programs, as this was, do not effectively influence fracture risk in women whose risk is high [193]. By their voluntary participation, the women who enrolled for this study clearly demonstrated a desire to reduce any potential or known risk, whilst refraining from engagement with vigorous or unfamiliar activities. The study activities (line dancing, progressively loaded squats and foot stomping) were appropriate for our participants, being well grounded in the current evidence, and neither physically demanding nor unusual in our community.

The SOS dependent variables included, change in calcaneal broadband ultrasound attenuation (BUA), proximal femur bone mineral density (PF BMD), capacity to perform loaded squats, to maintain balance in single leg stance (SLS) and during the Timed Up and Go test (TUG), and to step forward and sideways quickly in response to a potential fall. Our measures were selected because they reflect parameters of fracture risk known to respond to exercise, however we acknowledge that they are only some of the large number of contributing factors that need to be addressed when considering fracture risk in older people.

5.1 Hip Fracture Risk (HFR)

Hip fracture risk was estimated at baseline with the FRACTURE Index, which is a relatively simple algorithm, published on the World Wide Web by Black and others [28]. The FRACTURE Index algorithm provides an estimation of an individual’s five-year risk of hip fracture, relative to that of all Caucasian women of similar age. Since its principle data inputs are PF BMD and age, expressed in five year bands, the algorithm could not be used to show change in HFR over our study duration (12 months). Calculation of baseline HFR for SOS participants served two useful purposes: it provided personal information of interest to each woman, and it indicated (to the researchers) cases where a special duty of care could apply. The FRACTURE Index
has since been updated by its authors; the newer version can be found at http://courses.washington.edu/bonephys/FxRiskCalculator.html.

5.1.1 Bone mass measures

Broadband Ultrasound Attenuation (BUA)

Over a woman’s lifespan her BUA decreases linearly with her age [194], a trend which was similarly observed in SOS participants. However our study activities (stomping, squatting and line dancing) appeared to have no effect on BUA. Contrary findings have been observed by other researchers, in sedentary, pre- and postmenopausal women, who took up and persevered with exercise programs, such as brisk walking, for 12 months [160, 195]. Possibly, the absence of significant BUA change in SOS participants was related to the low number of stomps (4, bi-daily) required of each woman; the bone strains generated by stomping may have been insufficiently different from participants’ usual activity patterns to stimulate calcaneal adaptation. While as few as five strain events (jumps) have been shown to improve BMD in young rats [196], the minimum number of low amplitude, high rate strains required for measurable change in BUA in older women has not yet been established. Actual strains (Newtons) achieved by a single volunteer who performed a series of heel drops stomped upon the Kistler force plate in our lab is shown in Appendix 1 (p 73). Alternatively, a lack of any form of daily incentive and/or feedback about stomp efficacy may have created compliance issues for our participants. Other researchers, who provided each woman with a home use platform in order to measure parameters of loading associated with ‘heel drops’, felt that their device also benefited compliance [197]. Such infrastructure was beyond the SOS budget.

BUA (in early postmenopausal women) is more appropriately used as an independent index of fracture risk, than as a correlate with other densitometry measures, such as BMD [198]. Therefore our reported lack of influence for participant BUA could be interpreted positively, i.e. that HFR also remained unchanged; particularly in the thirty two percent of SOS participants who could be described as early (between 5 and 10 years) post-menopause, in whom a moderate inverse relationship between baseline BUA and HFR was observed. Given that HFR is based on 5 year age groupings, it was not a sensitive measure of change over a one year period.
Bone Mineral Density (BMD)

Our study supports the observation that proximal femur BMD is likely to be maintained, rather than increased, in postmenopausal women in response to exercise alone [199]. While a significant between-group effect for PF BMD was not found in the present study, the percent change in PF BMD was least in Group three, who performed all three activities (including stomps), compared with the other Groups. Group three, the stomps group, had a lower mean PF BMD than both the other groups, at baseline and follow-up, suggesting with previous observations, that greater adaptive responses occur in those individuals with the lowest bone mass [149]. Of the three SOS groups, the greatest bone loss occurred in women who only danced, while the combination of loaded squats and dancing was associated with proportionally less bone loss at the proximal femur than dance alone. This effect was visible even though Group two (dance and squats) had a much greater mean PF BMD than did Group three (all three activities). At the lumbar spine Group two also showed a smaller change in BMD compared with Groups one and three. We interpret the Group two result to mean that either stomps cannot ‘value add’ to the existing effect of squats at the lumbar spine, or the additional weight of the Group two participants was protective against bone loss.

While accounting for a very large portion of bone strength, BMD may not detect subtle changes in bone morphology that can markedly increase the resistance of a bone to bending or fracture [200]. Physical activity is known to effect such changes [201]. It is possible, although unlikely given the timeframe and intensity of our protocol that changes in bone geometry occurred in our subjects in response to the intervention. As bone geometric parameters were not measured in the current study, the influence of our novel physical activity regime on morphological aspects of bone strength and resistance to hip fracture is unknown.

5.2 Fall risk

5.2.1 Functional squat capacity
During loaded squats, Caucasian women aged 44 to 66 years, who lifted higher loads had lower rates of loss of PF BMD [202]. Each woman in the Cussler et al 2003 study performed eight core exercises, including six to eight repetitions of squats, leg press, seated rows, weight lifting and weight bearing walking, skipping and stair climbing at
up to 70 to 80% of her maximum ability (1 Repetitive Maximum). The exercises were
done under supervision, three times per week for one year. The maximum load that
SOS participants lifted during squats was not high (6 Kg in each hand), even for older
women. This load ceiling was implicit in our method (i.e. water in six-liter plastic
containers) however, the method itself proved very convenient and cost effective for the
majority of our participants. A pelvic girdle with carrying straps was fabricated, and
provided a suitable substitute for the upper limbs, for one woman who reported back
pain associated with the squats. Since SOS participants were unable to increase the
weight carried beyond 12 Kg, those who could do so incrementally increased the
numbers of repetitions and sets performed. While, not surprisingly, a strong negative
correlation was observed between age and squats compliance in SOS participants, our
study suggests, that for older women, an appropriate functional squats activity should
feature increased number of loads lifted rather than increases in weight.

In the present study Group three, who performed all three activities, improved in
functional squat capacity significantly more than Group two, who performed squats and
dancing. Analysis of compliance data showed that the latter group contained the
highest proportion of women who reported suffering knee pain associated with the
squats. Osteoarthritis is common in postmenopausal women, and the inhibiting effect
of knee pain in the study participants was not unexpected. However, even careful
training, gently graduated and self paced progression of loads, and individualized
attention to technique modification in the symptomatic women, did little to offset the
negative effects of knee pain upon squats compliance. While the squat appears to be
appropriate functional training for leg strength, it may be necessary to substitute a static
strengthening activity, such as isometric work, for women with osteoarthritic knees.

5.2.2 Balance
In accordance with the work of other researchers [203] static balance improved in our
participants over the study year. Learning, and increased confidence as participants
became familiar with the test protocols, could be anticipated to exert early influences
upon outcomes. As expected, given the known timing of neuromuscular responses to
physical activity, the most noticeable changes occurred over the initial eight weeks
(three tests) of the intervention. Static balance scores maintained a virtual plateau over the subsequent nine months (nine tests).

Postural control and balance as measured by the ‘Timed Up and Go’ (TUG) test respond well to weight bearing exercise in women who are at risk for fractures [204]. Only two percent of SOS participants were classified at baseline with reduced dynamic balance, according to the 12-second cutoff on the TUG test. All participants’ dynamic balance improved over the study period. Anecdotal evidence of the sensitivity of the TUG test was seen when a 69 year old participant who, whilst on her way to a study testing session, tripped over a crack in the footpath and fell onto her hands and knees. Still shaken but undeterred, the woman was tested within a half hour of the fall event. This participant’s TUG score, which had previously averaged 11 seconds, spiked to 14.8 seconds after the incident, and returned to her usual level on all subsequent test days. This case study illustrates the relevance of immediate assessment, support and reassurance for the faller (by the research team), combined with encouragement for ongoing participation in all usual activities (the weekly dance class) to her optimal recovery.

5.2.3 Forward and lateral step velocity
Time taken to react with a voluntary step in response to a simple balance perturbation is an important measure of fall risk in elderly people [49]. With age, substantial declines occur in the step reaction time [205], however, the age range of our study cohort was not wide enough for such a pattern to be detectable. Mean forward step time was quicker than lateral time (522 ± 223 ms, vs 767 ± 314 ms respectively). The longer time taken to step sideways may reflect a component of cognitive uncertainty that has been shown to increase step times in older women by approximately 100 -300 ms [206]. Specific balance training can improve step reaction time in as little as three weeks in adults of all ages [50]. As all SOS participant step times reduced over the study duration, no study activities appeared to affect either forward or lateral step reaction times. The absence of a training effect may be because neither the intervention itself, nor the step reaction test design, required increased step velocity from the participant.
The length of step taken to prevent a fall is proportionally larger, but slower, in older than in younger people [207]. In our study improvements in forward step distance occurred concurrently with increased time of flight for all participants, resulting in no net change for the calculation of mean forward step velocity. However, when compared to the forward direction mean step distance changed proportionally less for the lateral step test, and lateral step time decreased, generating a statistically significant improvement in lateral step velocity. This improvement occurred in spite of physical limitations that constrain lateral stepping in older people in terms of increased collisions between the limbs, greater support hip muscle torque, and difficulties with lateral trunk movements [207].

If an exercise program containing a patterned square steps in various directions can improve velocity of gait in the elderly [208], line dancing with its typically lateral and cross-step choreography should have similar effects for stepping. However in the present study, calculations of Least Significant Change using the coefficient of variation as an index of SOSD error may negate the significance of this finding in real terms. Measures of lateral stepping may have to be more sensitive than those used in this study.

Participant compliance in the current study compares favorably with other published data for long term exercise participation for postmenopausal women [209, 210], however the drop-out rate did influence the power of our data. Line dancing was included in the SOS activity program as a form of incentive and to avoid treatment withholding of the anticipated balance benefits of the activity. Clearly, without a control for dancing, the positive findings for balance and step velocity cannot be attributed to dance, but there are grounds for optimism.

5.3 Future research questions
Further research, with larger participant numbers and better instrumentation, will be necessary to establish the specific parameters of foot stomping, such as magnitude, rate of load application, and cycle number (reps and sets) required to optimally affect measures of bone health in women with low bone mass. It will be necessary to pursue the potential for line dance to influence balance and step reaction time. The tendency of
participants to self-select in favor of dancing will be included in consideration of future research design.

5.4 Conclusions
We hypothesized that: Once weekly in-line dancing would improve static and dynamic balance, and parameters of step velocity (distance and time); Thrice weekly, progressively loaded squats (up to 12 kilograms, three by eight reps per set) would maintain or improve functional lower limb squats performance, and; Four stomps per foot, twice per day, five days per week would improve indices of bone strength at the lumbar spine, neck of femur and calcaneus, in healthy, independent living postmenopausal women, aged 55 to 75 years.

We found that, in women with adequate dietary calcium, not taking hormone therapy, it is possible to improve balance, and lower limb function, and perhaps induce positive adaptive responses at the proximal femur, while not stretching the physical capabilities of our participants. Line dancing and foot stomping are both novel activities in the literature. With the addition of the squats exercise, the intervention was not only appealing to the women of our community, but required little in terms of physical support for them. Simplicity and low cost are important elements of a sustainable program. Thus the program is a feasible strategy to improve factors for hip fracture in Caucasian women who live independently in our community.
Appendix 1

Figure 20 (a) the Vertical Ground Reaction Forces (vGRF) generated by a 64 Kg female performing two foot stomps of similar magnitude, followed by two more foot stomps of progressively increasing magnitude. Figure 19 (b) the same subject performing eight consecutive heel drops on the Kistler Force plate.

Figure 20 (a) Foot stomps VGRF  (b) Heel Drops VGRF
## Stamp out Osteoporosis Study

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**February 2004**

Post-graduate Researcher: Ms Cath Young  
School of Physiotherapy and Exercise Science  
Griffith University, Gold Coast campus  
PMB 50, GCMC. 9716 Southport  
Tel: 07 5552 8930  Fac: 07 5552 8673:  
Email: c.young@griffith.edu.au
Appendix 3

The SOS. Diet and Behaviour Questionnaire
Confidential This is an investigator administered questionnaire.

Do you **smoke**? □ no □ yes
If yes, how many cigarettes per day? □ If you have stopped smoking, how long ago did you stop? □ If you used to smoke, how many did you smoke per day on average?

How much **beer, wine, or spirits** do you drink, on average?
□ 0-4 glasses per week □ 1-2 glasses per day □ 2-4 glasses per day □ >4 glasses per day

Do you drink more than 3 cups of coffee per day? □ no □ yes

Daily Calcium Intake:
Indicate your average daily **milk** intake (include drinks such as tea, coffee & cooking).
□ 0 □ 1-50 ml □ 50-200 ml □ >200-500 ml

What type of milk do you mainly use?
□ homogenized (standard) □ Trim □ PhysiCal □ other (please specify)

Is your average daily cheese (not cottage cheese) intake?
□ none □ less than 40 grams □ more than 40 grams

Is your daily **yoghurt and/or icecream** intake:
□ none □ less than, or □ more than, 1 pot yoghurt or 2 scoops ice cream

Are you taking **calcium supplements**? □ no □ yes
If yes, which brand, and how much per day?

Do you take an **antacid**? □ no □ yes
If yes, which brand? How much do you take? How often do you take it?

Do you take **regular exercise**?
□ no □ yes

What type? Please list in the table below, all activities that place stress on your body e.g. lifting grandchildren, gardening, bowls, walking, swimming, dancing etc…

<table>
<thead>
<tr>
<th>Activity</th>
<th>Number of times per day, or per week</th>
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<td>The Thesis table has been truncated in the interests of space</td>
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Comments or relevant information related to any of the entries above may be placed in the space below.
Appendix 4

The Stamp out Osteoporosis Study Subject Screening Questionnaire
Confidential This is an investigator administered questionnaire.

Age  Date of Birth  Height  Weight

Race:
- Caucasian
- Asian
- African
- Indigenous Australian
- other………..

Past Medical History:
Kidney Disorders  ☐ no  ☐ yes  When?  For how long?
Ovarian Disorders  ☐ no  ☐ yes  When?  For how long?
Thyroid/Parathyroid Disorders  ☐ no  ☐ yes  When?  For how long?
Digestive Disorders  ☐ no  ☐ yes  When?  For how long?
Asthma  ☐ no  ☐ yes  When?  For how long?
Other longstanding medical problems  ☐ no  ☐ yes  When?  For how long?

Please specify

Previous fractures?  ☐ no  ☐ yes  List type and when they occurred
(please exclude fractures caused by violence such as a motor vehicle accident).

What was your age when your periods started?  and
stopped?

Have you had a hysterectomy?  ☐ no  ☐ yes  age

If yes, were your ovaries removed?  ☐ no  ☐ yes  ☐ don’t know

Are you on hormone therapy (HRT)?  ☐ no  ☐ yes  If yes, what are you taking, including dose?

Have you ever been on HRT?  ☐ no  ☐ yes  If yes, what was is it?
How long did you take it for? How long ago did you cease taking it?

Are you on treatment for osteoporosis (non-HRT)?  ☐ no  ☐ yes  If yes, name drug, dosage, and how long you have taken it.

Are you on treatment with oral steroids (prednisone)?  ☐ no  ☐ yes

Have you ever been on treatment with steroids?  ☐ no  ☐ yes
If yes, when? For how did you take it? How long ago did you cease taking this?

Is there a family history of spine fractures or osteoporosis?  ☐ no  ☐ yes
Mother?  Father?  Sisters?  Aunts?
Appendix 5

Attendance role of women at the weekly dance classes over 2004.

The declining attendance at the line dance classes was directly related to two quite separate influences. In the early months of the study some of the women regretfully admitted that their natural ability as dancers did not match their initial curiosity about what was, to them, a novel dance style. Some of the women struggled to remember the lessons from week to week and found that frustrating. Consequently feelings of inadequacy may have affected attendance. The women who dropped out towards the end of the study each expressed personal regret at having to miss the dance classes. The women found pressing, but initially unforeseen family obligations, or declining health reduced their ability to attend.
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