MODERN TRENDS
IN STRENGTH AND CONDITIONING

Guest Editor
CARLO BALDARI
## Contents

### MODERN TRENDS IN STRENGTH AND CONDITIONING

**Guest Editor**

**CARLO BALDARI**

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It is well known that mechanical load plays a pivotal role in the maintenance of muscle and bone tissue homeostasis. Definitely, absence of gravity, sedentary life or forced bedrest have been shown to negatively impact on musculoskeletal health, leading to both osteopenia and muscle loss. Furthermore, an increasing number of data links muscle mass and strength to the maintenance of bone tissue, suggesting that physical activity might play a pivotal role in the prevention of bone loss and osteoporosis. Little, however, is known regarding the molecular and cellular mechanisms, which are involved in the positive effects of mechanical load on both muscle and bone tissue. Indeed, mechanical load has been always thought to positively affect musculoskeletal system only due to the proprioceptor mechanisms. However, it has been recently shown that both muscle and bone can be defined as endocrine tissues, producing and secreting several growth factors, myokines and cytokines which could be the major actors in the maintenance of musculoskeletal system homeostasis induced by mechanical load. This review will describe the potential cellular and molecular mechanism(s) involved in the effects induced by mechanical load.

**Key words:** Musculoskeletal system - Motor activity - Fitness.

Physical activity appears to play a pivotal role in the maintenance of optimal musculoskeletal system homeostasis. Bone mass and strength appear to be highly linked with muscle mass showing a strong association with both bone mineral content and bone strength. Muscle is a primary source of mechanical stimuli for bone and for a long time this has been thought to be the primary mechanism by which muscle mass could influence and modulate bone remodelling. But our understanding of the relationship between skeletal muscle and bone tissue has changed with the recognition that skeletal muscle is a rich source of secreted factors generally referred to as myokines that may have important effects on bone formation and bone resorption. Myokines is a short-term proposed by Febbraio and Pedersen in 2005 to indicate muscle-derived cytokines. In general myokines are cytokines, short peptides and growth factors which are produced and released by skeletal muscle fibers to exert their effects in other organs of the body, potentially acting in an autocrine, paracrine, and/or endocrine manner. Using a quantitative proteomics platform Henning-Henning Hansen et al. have reported that skeletal muscle C2C12 cells are capable of producing several hundred secreted proteins. Thus, skeletal muscle can be considered an endocrine organ producing and releasing myokines, which work in a hormone-like fashion and exert specific endocrine effects on other organs playing important roles in biological homeostasis such as energy metabolism, angiogenesis and myogenesis and likely bone remodeling as well.

Additionally, several myokines known to play
a role in bone formation (i.e., IGF-1, Osteonectin, FGFb) are localized on the muscle/bone interface, which can be defined as a "site of fleshy muscle fiber insertion into periosteum and excludes tendinous or aponeurotic attachments". Thus, it could be hypothesized that large molecules (e.g., myostatin inhibitors, androgen receptor modulators, or vitamin D receptor agonists) or mechanical load induced by physical activity, could selectively enhance muscle mass, by an increased secretion of osteogenic myokines leading to an improvement of bone homeostasis and bone strength.

Interestingly a recent study has shown how different exercise intensity can induce and increase in myokines levels strongly suggesting an involvement of paracrine and endocrine regulation influenced by mechanical load.

IGF-1

Growth hormone (GH) and insulin-like growth factor 1 (IGF-1) are essential for the development and growth of the skeleton and maintenance of bone mass. IGF-1, which mediates most of the effects of GH on skeletal metabolism, promotes chondrogenesis and increases bone formation by regulating the functions of differentiated osteoblasts. IGF-1 is also produced by osteoblasts and it prompts in an autocrine/paracrine fashion the differentiation of osteoblasts, promoting bone formation.

Interestingly, it has been recently postulated that IGF-1 can be also considered a myokine since it has been demonstrated that it is localized on the muscle-bone interface in vivo, that it is abundant in homogenized muscle tissue and that it is secreted from cultured C2C12 myotubes in vitro. GH-dependent muscle growth, development and hypertrophy leads to the secretion of IGF-1 by muscle cells.

Thus, it is possible to hypothesize that muscle hypertrophy and bone anabolism might be coupled through an IGF-1 mediated paracrine signalling mechanism.

Mechanical stimulation of bone cells may induce IGF-1 secretion by osteoblasts and fibroblasts and it has been recently shown that muscle-secreted IGF-1 stimulates bone formation by osteoprogenitor cells in the periosteum that express IGF-1 receptor (IGF-1R). Additionally, recent data show interacting roles of IGF-1 signaling and selected integrins in the bone response to mechanical load, while unloading results in decreased integrins expression and also resistance to the anabolic actions of IGF-1 with consequent bone loss, strongly suggesting a pivotal role of these factors in the maintenance of skeletal homeostasis upon mechanical load. Integrins, insulin like growth factors modulate skeletal health in response to load.

IL-6

Interleukin 6 (IL-6) belongs to the IL-6 family of cytokines, which include IL-11, oncostatin M, leukemia inhibitory factor, ciliary neurotrophic factor, cardiotoxin-1 and cardiotoxin-like cytokine. The above mentioned cytokines are characterized by their common use of the IL-6 receptor b, IL-6 receptor b (IL6-Rb), (also known as gp130 or CD130). The two IL-6 receptors, gp130 and IL-6Ra (also called gp80 or CD126), belong to the type I cytokine receptor family, which also includes leptin, growth hormone, prolactin, erythropoietin, thrombopoietin, and granulocyte- and granulocyte/macrophage-colony stimulating factors.

The cytokine IL-6 was the first myokine found to be secreted into bloodstream in response to muscle contraction and it has been defined as a myokine due to the observation that its levels increase in an exponential fashion proportional to the duration and intensity of exercise. Interestingly, the increase in IL-6 levels during exercise is not a consequence of some working muscle damage (as previously commonly thought) but the cytokine is secreted from muscle cell in an inflammatory TNFα independent fashion. These findings suggest that muscular IL-6 has a role in metabolism rather than in inflammation. In fact, IL-6 expression is markedly increased when intramuscular glycogen levels are low, suggesting that IL-6 works as an energy sensor.

High levels of IL-6 are tightly associated with physical inactivity and metabolic syndrome while basal levels of IL-6 are reduced after endurance training and muscle disuse leads to elevated circulating IL-6 levels. These observations are very important to better clarify the endocrine/paracrine relationship between skeletal muscle and bone tissue. IL-6 acts as a pro-osteoclastogenic cytokine being involved directly, and through the stimulation of other factors
such as receptor activator of nuclear factor kappa B ligand (RANKL), in osteoclastogenesis modulation. In fact IL-6 regulates the proliferation and differentiation of the early osteoclast precursor cells, the lifespan of the mature osteoclasts and their resorptive activity. Recent results strongly suggest that the “healthy” muscle could retain IL-6 at low levels protecting the skeleton from excessive bone resorption, osteopenia and osteoporosis development.

Moreover, it has been shown that chronically increased systemic levels of IL-6 induce significant bone loss in growing IL-6 transgenic mice. In a panel of circulating pro-osteoclastogenic cytokines evaluated in the sera of a Duchenne Muscular Dystrophy (DMD) animal model (MDX), IL-6 was increased. In the same way, DMD patients showed low bone mineral density (BMD) Z-scores and high bone-resorption marker and serum IL-6. Human primary osteoblasts from healthy donors incubated with sera from DMD patients showed decreased nodule mineralization and downregulation of many osteogenic genes, including osterix and osteocalcin. Treatment with an IL-6-neutralizing antibody, prevented the decrease of osterix and osteocalcin mRNA induced by the sera of DMD patients, indicating a role of this cytokine in the bone-induced effects.

**Myostatin**

Myostatin, a member of the transforming growth factor-beta (TGF-β) superfamily, is a negative regulator of skeletal muscle growth. During embryogenesis myostatin expression is restricted to developing skeletal muscles, but myostatin is still expressed and secreted by skeletal muscles during adult life. Myostatin circulates in the blood in a latent form bound to a propeptide, which is then cleaved by BMP1/tolloid matrix metalloproteinase releasing the active form. Active myostatin binds to its receptor, the type IIB activin receptor (ActRIIB) with high affinity and regulates the expression of its target genes through a TGF-β signaling pathway. Recent studies also show that myostatin can activate the p38 MAPK, Erk1/2, and Wnt pathways. This finding is particularly relevant because it is well known that the Wnt signalling pathway plays a pivotal role in the differentiation pattern of osteoblasts.

Recent data obtained in experimental animal models have shown that myostatin-deficient mice have approximately twice the skeletal muscle mass of normal mice, and null mutations in the myostatin gene significantly increase muscle mass and decrease subcutaneous fat in a variety of animals, including humans. Likewise it has been demonstrated that myostatin is highly expressed in the fracture callus immediately after injury suggesting a direct role for this factor also in bone development and morphogenesis.

Although the role of myostatin in muscle growth regulation has been widely investigated, its role in regulating bone mass architecture and regeneration is becoming an area of increased interest for the potential use as pharmacological agent.

Interestingly, genetic studies in human populations have shown that myostatin gene polymorphisms are associated with alteration in peak bone mineral density, and transgenic overexpression of myostatin propeptide, which inhibits myostatin signaling in vivo, increases BMD in mice.

The mechanisms by which myostatin regulates bone formation are not well understood, but several studies show a direct effect of myostatin on the proliferation and differentiation of mesenchymal stem cells, and recent data indicate that myostatin and its receptor are expressed during bone regeneration. These findings reveal that molecules targeting myostatin signaling may be novel, effective therapeutic agents to improve muscle strength, increase bone mass and prevent falls and bone fractures.

**IL-15**

Interleukin 15 (IL-15) is a four-a-helix cytokine, discovered in 1994, which shares many biological properties with IL-2. IL-15 mRNA is produced by a wide variety of cells and tissues but the protein is poorly expressed. Two isoforms of IL-15 exist: a secreted long signaling peptide form and an intracellular short signaling peptide form. IL-15 acts through a widely distributed heterotrimeric receptor (IL-15R), which consists of a common g-chain, a b-chain shared with IL-2 and a exclusive a-chain (IL-15Ra). IL-15 requires the presence of IL-15Ra for efficient biosynthesis and secretion.

Skeletal muscle tissue produces very high levels of IL-15 mRNA and expresses IL-15Ra; this ob-
Circulation suggests that skeletal muscle could be an important IL-15 producer but the prove that muscle-derived IL-15 is secreted into the circulation and acts on other tissues such as adipose or bone tissue has not been described as yet. Nevertheless the role of IL-15 as a myokine is very intriguing since it has been demonstrated an osteoclastogenic role in bone remodeling. The elevated levels of IL-15 found in the synovial fluid of patients with rheumatoid arthritis 37 raised the question whether IL-15 could be involved in bone pathology and also in bone development and physiology. This cytokine stimulates the formation of osteoclast-like cells in rat bone-marrow culture in vitro in a direct pattern and not mediated by combination of M-CSF, IL3 and CSF or TNFα.38 Therefore, it is conceivable that IL-15 might further stimulate bone destruction by excessive bone resorption by osteoclasts.38, 39

IL-15 stimulates the proliferation of T cells and their production of osteoclastogenic factors, including RANKL, IL-17 and INFγ, and in IL-15Ra−/− mice bone remodeling was decreased and microstructure was improved in both the cancellous and cortical bone compartments. However, IL-15Ra−/− mice did not develop osteopetrosis or osteolytic bone remodeling. The elevated levels of IL-15 found in the synovial fluid of patients with rheumatoid arthritis have been demonstrated an osteoclastogenic role in bone remodeling and also in bone development and physiology. This cytokine stimulates the formation of osteoclast-like cells in rat bone-marrow culture in vitro in a direct pattern and not mediated by combination of M-CSF, IL3 and CSF or TNFα. 38 Therefore, it is conceivable that IL-15 might further stimulate bone destruction by excessive bone resorption by osteoclasts.

Conclusions

In conclusion this brief review highlight the importance the cellular factors secreted by the skeletal muscle in response to load which could play a pivotal role in the maintenance of skeletal health. Further studies are needed however, to fully characterize the molecular mechanisms involve in these events.

References


Conflicts of interest.—The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.
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Effect of two different strength training volumes on muscle hypertrophy and quality in elderly women

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Aim. The aim of this study was to compare the effects of 13 weeks of low- or high-volume strength training on upper and lower body muscle thickness and lower body muscle quality determined by ultrasonography in elderly women.

Methods. Twenty healthy untrained elderly women were randomly assigned into two strength training groups, low-volume (LV; N=11; 64.6±3.1 years; 66.4±5.1 kg; 162.9±5.8 cm; 24.8±5.1 kg.m⁻²) or high-volume (HV; N=9; 63.9±2.3 years; 64.1±7.2 kg; 163.2±4.9 cm; 24.3±4.2 kg.m⁻²). Participants trained two days per week, with the LV group performing one-set of each exercise whereas the HV group performed three-sets of each exercise. The intensity of training was progressive during the training period and controlled using number of repetitions maximum (RM).

Results. The knee extensors muscle thickness significantly increased in both groups after 13 weeks (8.6±2.9% for LV and 14.3±3.9% for HV; P≤0.001), with no difference between groups (P>0.05). Both groups showed similar elbow flexors muscle thickness gains after 13 weeks of training (11.2±6% for LV and 12.5±5.6% for HV). The knee extensors echo intensity significantly decreased for both groups after 13 weeks (P≤0.05), with no difference between groups.

Conclusion. These findings suggest that high- and low-volume strength training are similarly effective in increasing muscle thickness and improving muscle quality in elderly women after 13 weeks of strength training.

Key words: Aging - Resistance training - Ultrasonography.

One of the most harmful effects of aging is the loss of skeletal muscle mass (i.e., sarcopenia). This process results from a reduction in the number of muscle fibers and atrophy of the remaining fibers.¹

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Along with this change in muscle mass, the aging process is also associated with changes in muscle composition,³ ⁴ resulting in reduced muscle quality (MQ), especially in elderly women.³ To counteract this, strength training (ST) is an effective intervention to reduce losses in skeletal muscle;¹ however, the effectiveness of this type of training depends on manipulation of some variables, such as training volume.

ST volume is calculated as the product of the number of sets performed of each exercise and the number of repetitions completed per set.⁵ Previous studies with young subjects have demonstrated conflicting results regarding the effects of ST volume on muscle hypertrophy. Some research has found similar muscle hypertrophy using low- and high-volume ST,⁶ ⁷ whereas others found greater gains with high-volume.⁸ ⁹

Data on the effects of ST volume on muscle hypertrophy in elderly people are scarce. To the best of our knowledge, only one study compared the effects of low- and high-volume ST on muscle hypertrophy in an elderly population.¹⁰ They observed similar knee extensor muscle hypertrophy in
elderly women who trained ten weeks using low- or high-volume. However, they did not investigate the effects of low- and high-volume training on upper-body muscle mass, and it can be speculated that the upper and lower-body may respond differently to a low- or high-volume ST program. Furthermore, their training groups were comprised of young and elderly women. This may have influenced the results, because gains induced by ST programs can be affected by age.

MQ can be assessed by ultrasonography using echo intensity calculated from a grey scale value. The increase in echo intensity, which represents MQ reduction, is believed to be caused by an increase in intramuscular fibrous and adipose tissue deposited within the muscle. In fact, it has been shown that ST may decrease the echo intensity values, which suggests a reduced quantity of non-contractile tissue within the muscle and an improved MQ. However, the effect of different ST volumes on the MQ of elderly people remains unknown. The ideal ST volume and its effects on MQ during different training periods have great importance for the ST prescription. In untrained elderly, the stimulus threshold required to elicit neuromuscular adaptations may be lower. Thus, low-volume training, which is associated with greater adherence, may be as effective as high-volume training for improvements in MQ.

Therefore, the aim of the present study was to compare the effects of low- or high-volume ST on upper and lower body muscle thickness (MT) and lower body MQ in elderly women, following 13 weeks of ST.

Materials and methods

Participants

Twenty healthy elderly women that had not participated in a regular strength training program for at least three months volunteered for this study. They were randomly divided into two groups, low-volume (LV; N.=11) or high-volume (HV; N.=9). The physical characteristics of the training groups are showed in the Table I. All subjects were carefully informed of the design of the study and gave their written consent to participate. Subjects were free of any cardio-vascular, metabolic or musculoskeletal limitations to physical exercise. All the women were postmenopausal and with normal body mass index (BMI). All procedures of the present study received the approval of the Institutional Research Ethics Committee and followed the principles of the Helsinki declaration.

Procedures

Strength training program

A supervised ST program was performed twice a week for a period of 13 weeks, with at least two days of rest between training sessions. In each workout, both groups performed the following exercises: bilateral knee extension, lat pull-down, bilateral leg press, bilateral elbow flexion, bilateral leg curl, bench press, triceps extension, hip abduction and adduction, and abdominal crunch. During the training period, the HV group performed three sets of each exercise with 2-min rest between sets, whereas the LV group performed one set of each exercise. The intensity of training (determined by maximal repetitions – RM) was altered similarly for both groups. The intensity of training utilized during the training period was choose following previous studies. During the first 6 weeks the subjects trained at 15-20 RM; during weeks 7-10 they trained at 12-15RM; while in the last three weeks they trained with an intensity of 10-12 RM. When participants were able to perform more repetitions than prescribed, the training load for the next workout was increased by 2.5 to 5 kg. All training sessions were monitored by at least two trained investigators and all women completed at least 95% of the workouts.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Low-volume (N=11)</th>
<th>High-volume (N=9)</th>
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<tr>
<td>Age (y)</td>
<td>64.6±3.1</td>
<td>63.9±2.3</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>66.4±5.1</td>
<td>64.1±7.2</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>162.9±5.8</td>
<td>163.2±4.9</td>
</tr>
<tr>
<td>Body fat (%)</td>
<td>19.8±3.7</td>
<td>19.1±7.9</td>
</tr>
<tr>
<td>BMI (kg·m⁻²)</td>
<td>24.8±5.1</td>
<td>24.3±4.2</td>
</tr>
<tr>
<td>Knee extension1-RM</td>
<td>49.5±16.4</td>
<td>50.8±16.4</td>
</tr>
</tbody>
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BMI: body mass index (kg/m²); 1-RM: one-repetition maximum.
Muscle thickness

Real-time B-Mode ultrasonography (Philips-VMI, Ultra Vision Flip, Brazil) with a 7.5MHz linear-array probe (38 mm), was used to obtain MT of the knee extensor muscles. The overall knee extensors MT ($K_{EMT}$) was calculated as the sum of rectus femoris (RF), vastus lateralis (VL), vastus medialis (VM) and vastus intermedius (VI): $MT=RF+VL+VM+VI$.17 The MT of the elbow flexor biceps brachii and brachialis ($EF_{MT}$) muscles was determined from the sum of their MT (biceps brachii and brachialis). All sites of MT measurements have been previously described.18-21 Measurements were performed on the right leg and arm while the subjects were in a supine position with limbs extended and relaxed, after resting in the supine position for 15 min to allow fluid shifts to occur.22 The probe was coated with a water-soluble transmission gel to provide acoustic contact without depressing the dermal surface. All images were digitized and later analyzed in Image-J software (version 1.37, National Institute of Health, USA). All measurements were made by the same investigator. Baseline test and retest (7 days between test and retest) reliability ICC’s of MT measurements were between 0.85 and 0.95.

Muscle quality

Knee extensor MQ ($K_{EMQ}$) was determined from the echo intensity values calculated by computer assisted grey-scale analysis using the standard function of the Image-J software (version 1.37, National Institute of Health, USA). High values of echo intensity represents changes associated with increase of amount noncontractile tissue within of muscle.13 Thus, reducing in amount of noncontractile tissue within of muscle reducing the echo intensity values and increase the MQ. To calculate the echo intensity value, a region of interest in the RF muscle that included as much RF muscle as possible without any bone or surrounding fascia was selected. The echo intensity value of interest region was calculated and resulted in a number between 0 (black) and 255 (white) (Figure 1). The mean echo intensity was calculated using three images.

Statistical analyses

All data are presented as mean±SD. Normality of the distribution and homogeneity for outcome measures were tested using Shapiro-Wilk and Lev-
ene’s test, respectively. As data showed normal distribution and homogeneity (P>0.05), the effects of training volume was assessed by a two-way mixed model (group x time) Analysis of Variance (ANOVA). When a significant F value was identified, a Bonferroni post hoc test was used to identify pairwise differences between means. The significance level was set at P≤0.05.

Results

Muscle hypertrophy

Before training, there were no significant differences between groups in KE<sub>M</sub> or EF<sub>M</sub> (P>0.05). The KE<sub>M</sub> increased significantly in both groups after 13 weeks of training, from 64.6±14.8 mm to 69.9±15.2 mm (by 8.6±2.9%) (P≤0.001) in LV group and from 59.8±9.5 mm to 68.3±10.6 mm (by 14.3±3.9%) (P≤0.001) in HV group (F<sub>(1)</sub>=288.68; P≤0.001; η²=0.97), however there were no group effect (F<sub>(1)</sub>=0.18; P>0.05; η²=0.02) and no significant time-group interaction (F<sub>(1)</sub>=13.27; P>0.05; η²=0.62) at any time point (Figure 2). Regarding EF<sub>M</sub>, significant increases were also observed for both groups after 13 weeks of ST, from 25.5±5 mm to 27.9±4 mm (by 11.2±6%) (P≤0.001) in LV group and from 22.7±4.1 mm to 25.5±4.7 mm (12.5±5.6%) (P≤0.001) in HV group (F<sub>(1)</sub>=88.50; P≤0.001; η²=0.91), with no difference between groups (F<sub>(1)</sub>=4.54; P>0.05; η²=0.36) and no significant time-group interaction at any time point (F<sub>(1)</sub>=0.26; P>0.05; η²=0.03) (Figure 3).

Muscle quality

There were no significant differences between groups at baseline. In both groups, echo intensity significantly decreased after 13 weeks of training, from 141.3±17 to 123.3±12.7 (by -12.9±9.9%) (P≤0.05) in LV group and from 141.3±20.4 to 110.4±16.3 (by -20.9±7.7%) (P≤0.05) in HV group (F<sub>(1)</sub>=67.77; P≤0.05; η²=0.89), with no significant difference between groups (F<sub>(1)</sub>=0.18; P>0.05; η²=0.02), and no significant time-group interactions (F<sub>(1)</sub>=0.74; P>0.05; η²=0.08) (Figure 4).

Discussion

The primary findings of the present study were that LV and HV groups demonstrated similar increases in KE<sub>M</sub>, EF<sub>M</sub> and MQ after 13 weeks of training. These results suggest that only one set per exercise (i.e., low volume) is as effective as three sets per exercise (i.e., high volume) in promoting hypertrophy and enhancing MQ in untrained elderly women during early training phases.

Regarding knee extensor muscle hypertrophy, our results corroborate the study of Cannon and Marino, who observed similar muscle hypertrophy in subjects who trained with low- or high-volume during ten weeks of ST. Nevertheless, subjects in their study were young and elderly women, and this makes comparison difficult with our present results. Muscle hypertrophy is strongly associated with muscle damage, endocrinial responses and metabolic stimulus. For example, muscle damage induced by
ST is associated with the activation of satellite cells, inflammatory agents and upregulation of IGF-1, which are anabolic mechanisms important for hypertrophic response. Therefore, it could be speculated that multiple sets using the same intensity of training than single set would induce more structural damage and, consequently, increased responses. However, our results showed that HV and LV groups demonstrated a similar increase in KE\textsubscript{MT} after 13 weeks of training. Thus, it might be suggested that low- and high-volume strength training, scheduled with equal intensity of training in each exercise, for elderly women may promote similar responses in mechanisms associated with muscle hypertrophy during the first 13 weeks of ST.

To the best of the authors’ knowledge, no studies have assessed the effects of low- or high-volume ST on hypertrophy of upper-body muscles in the elderly. Similar to the present study, previous investigations using young subjects have shown similar upper-limb hypertrophy induced by ST. Bottaro et al., found that MT of the biceps brachii equally increased significantly for subjects who trained with low- or high-volume (7.2% and 5.9%, respectively) following ten weeks of training. Likewise, Ronnestad et al., observed similar increases in cross sectional area of the trapezius muscle after 12 weeks of training in subjects who trained with low- or high-volume (13.9±2.5% and 9.7±1.4%, respectively). In another study, it was also observed similar increases in cross sectional area of the trapezius between groups that used low- or high-volume training. As observed in these studies, we showed that low-volume ST is effective for elderly women to achieve significant muscle hypertrophy in upper-body muscles. In general, the arm muscles are less trained than the leg muscles, and, consequently, the threshold to induce muscle hypertrophy in the former may be lower. From a practical standpoint, a low volume of ST (i.e., one set per exercise) was sufficient stimulus to promote hypertrophy in both upper and lower-body muscles, at least for 13 weeks of training.

MQ in our study significantly improved for both LV and HV groups after 13 weeks of training, with no difference between groups. A previous study also observed a decrease in echo intensity of the vastus lateralis after a ST program. However, the present study is the first to compare the effects of different volumes of ST on MQ assessed by echo intensity. Our results are important because it shows that elderly women can significantly improve their MQ using a low-volume of ST. The mechanisms associated with MQ improvement are still unclear but it has been suggested that the echo intensity assessed by gray scale values is associated with the amount of intramuscular fibrous and adipose tissue, thus the improvement in MQ could be associated with a reduction in the amount of non-contractile tissue within the muscle. In fact, echo intensity has been negatively associated with strength performance in elderly populations. Thus, our results suggest that both low and high volume ST induces similar improvements in MQ.

**Limitations of the study**

It is important to note some limitations in the present study. The small sample size of the training groups limits the extrapolation of the findings to all elderly women. Additionally, in the present study the training intensity was determined by RM and ST programs that use other way to control training intensity, like percentage of the RM, may observe different results.

**Conclusions**

In summary, the results of the present study showed that low- and high-volume ST was equally effective to promote muscle hypertrophy in lower- and upper-body muscles, as well as improving MQ in the lower-body of elderly women. These findings have important implications for the prescription of ST programs, since elderly women may benefit from ST using a low-volume program for a period of three months. However, future studies utilizing longer periods of training are necessary to investigate whether additional sets may promote greater lower- and upper-body muscle gains.

**References**


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Influence of exercise order on blood pressure and heart rate variability after a strength training session

T. FIGUEIREDO 1, 2, P. MENEZES 1, M. S. KATTENBRAKER 3, M. D. POLITO 4, V. M. REIS 2, R. SIMÃO 1, 2

Aim. The purpose of this study was to compare the effects of two different strength training (ST) exercise sequences on blood pressure (BP) and heart rate variability (HRV) after a ST session.

Methods. Ten male subjects participated in the study. After determining the one repetition maximum load (1RM) for the bench press (BP), lat pull down (LPD), shoulder press (SP), triceps extension (TE), biceps curl (BC), leg extension (LE), leg curl (LC) and leg press (LP), participants performed two different exercise sequences. During sequence 1 (SEQ1) subjects performed 3 sets of 12 repetitions at 80% 1RM, with 3 minutes rest between sets and exercises with the following order: BP, LPD, SP, TE, BC, LE, LC, and LP. After 72 hours, subjects performed the SEQ2 with the same volume of exercise, but the order of exercises was reversed. BP and HRV were measured before and after the training sessions.

Results. The systolic blood pressure and mean arterial pressure were significantly higher for SEQ2 when compared to SEQ1. HRV showed significant differences between exercises orders, as SEQ1 presented higher values of low frequency normalized units band, lower values of high frequency normalized units band and lower values of the standard deviation of differences between adjacent normal R-R intervals when compared to SEQ2.

Conclusion. The order of ST exercises has a significant impact on the cardiac autonomic nervous system and on post-exercise blood pressure response. ST beginning with lower body exercises and progressing toward upper body exercises are more likely to produce a lower cardiovascular stress.

Key words: Resistance training - Hypotension - Autonomic nervous system.

Strength training (ST) is an important part of a well-rounded physical exercise program and there is evidence that a single strength training session (STS) promotes acute modifications in blood pressure (BP) and heart rate variability (HRV) of normotensive and hypertensive individuals. 1, 2

Blood pressure response after ST is an important topic of study, because post exercise hypotension, i.e., a BP reduction to levels below those observed at rest or prior to exercise, has a significant role in the management of BP. 1 Several studies have examined blood pressure behavior from ST performed with different volumes and intensities. 2-5 However, the influences of these ST-related variables on BP after a STS are scarcely known. 2

To the best of our knowledge, only three studies have investigated the physiological pathways of BP control derived from a STS, 2, 6, 7 while other studies have focused on the manipulation of methodological variables of ST such as training intensity, rest interval or concurrent training. 5, 8, 9 Until now, one study
has investigated the acute response of BP and HRV associated with a STS and its relationship with ST intensity.2 In light of this observation, it is necessary to better understand the mechanisms of BP control from this type of exercise performed with different exercise orders since exercise order can influence repetition performance and different physiological mechanisms during ST.10, 11 Furthermore, current literature does not provide significant information about the physiological pathways of STS and the impact on BP and HRV.

Since previous studies analyzing the effect of exercise order on BP and HRV after a STS are scarce, the purpose of this study was to compare the effect of two different exercise orders in a STS on the BP and HRV.

**Materials and methods**

**Participants**

Ten normotensive men with previous experience in ST participated in this study (age: 26.6±4.5 years; height: 173.8±8.1 cm; body mass: 77.6±8.3 kg; BMI: 25.4±2.4 kg/m²; resting systolic blood pressure (SBP): 126.5±8 mmHg; resting diastolic blood pressure (DBP): 74.7±4 mmHg). According to the criteria established by the Seventh Joint National Committee 12 the following criteria were adopted for subject recruitment: (a) nonsmokers; (b) absence of any kind of metabolic disease; (c) no articular or bone injury; and (d) absence of any medication. Participants were informed about the study procedures, possible risks and benefits, and signed an informed consent form. This study was approved by the Ethics Committee of the Rio de Janeiro Federal University. Participants were instructed to maintain their usual activities and eating habits throughout the study period.

**Procedures**

**ONE REPETITION MAXIMUM (1RM) TESTING**

During the first laboratory visit, the participants’ height and body mass were measured by means of an analogical scale (Filizola, Brazil) and a stadiometer followed by 1RM testing. The 1RM testing began with a warm-up at 50% of the predicted 1RM. After five minutes rest, each subject was encouraged to perform one repetition with a heavier load. If the attempt was successful, the load was increased and the attempt repeated. After 72h a second visit occurred and the 1RM test was repeated, with the highest successful lift being recorded as the 1RM.13 The exercises performed were the bench press (BP), front lat pull down (LPD), shoulder press (SP), triceps extension (TE), biceps curl (BC), leg extension (LE), leg curls (LC) and leg press (LP). The 1RM assessments were divided over a four day period. On the first and third day BP, LE, BC and LC were tested and retested, on second and fourth days LPD, LP, SP and TE were performed. To minimize the error during 1RM tests, standardized strategies were adopted.13

**EXERCISE SESSIONS**

Seventy two hours after the last 1RM assessment, participants performed one of the two exercise sequences in a counterbalanced crossover design. The second session was performed 72 hours after the first session. The exercise order for SEQ1 was BP, LPD, SP, TE, BC, LE, LC and LP. The exercise order for SEQ2 was reversed. The warm-up consisted of 10 repetitions of the first exercise at 40% of 1RM. A 3-minute rest interval was allowed after the warm-up before participants performed the assigned exercise sequence. Both exercise sequences consisted of 3 sets of each exercise (80% of 1RM) with 3-minute rest intervals between sets and exercises. During the exercise sessions, subjects were verbally encouraged to perform 10 to 12 repetitions in all sets. During all training sessions participants were asked to avoid the Valsalva maneuver.

**MEASURES OF HEART RATE AND HEART RATE VARIABILITY**

A heart rate monitor (Polar RS800sd, Finland) was continuously used for 30 minutes before and for 60 minutes after the sessions for monitoring HR and HRV. Data were recorded on the equipment and then immediately downloaded to the computer to be analyzed by the Polar Precision Performance Software (Release 3.00, Kempele, Finland). The HRV parameters were analyzed according to the components of
low frequency in normalized units (LF-nu), high frequency in normalized units (HF-nu) and the standard deviation of differences between adjacent normal R-R intervals (RMSSD) after Fourier transformation and noise filtering through the program Kubios HRV Analysis Software version 2.0 (Kuopio, Finland). Data were collected at rest and after the ST sessions. Subjects remained at rest in a supine position in a quiet room with temperature maintained between 20 °C and 22 °C.

**Arterial blood pressure assessment**

Systolic blood pressure (SBP), diastolic blood pressure (DBP) and mean arterial pressure (MAP) were measured using an automatic oscillometric device (PM50 NIBP/Spo2, CONTEC, EUA). The resting BP value was averaged over three consecutive measurements with an interval of 5 minutes after the individual remained in a supine position for 10 min. Afterwards, BP was assessed every 10 minutes over a 60 minute period. Measurements were performed in the left arm, following the recommendations of the American Heart Association.¹⁴

**Statistical analysis**

Data for all variables were analyzed using the Shapiro-Wilk normality test and the Bartlett criterion for homocedasticity. An intraclass coefficients correlation (ICC) was used to test the reliability of 1RM tests. A paired Student t-tests were applied to compare the following parameters: 1RM test and retest and total number of repetitions performed in SEQ1 and SEQ2. The resting values of SBP, DBP, MAP, HR, RMSSD, LF-nu and HF-nu were analyzed separately using one-way ANOVA. Subsequently, a two-way repeated measures ANOVA was used to compare the resting values and post-exercise measures within and between sessions. In all cases, the post-hoc Bonferroni was used. Additionally, effect sizes (ESs; the difference between pretest and posttest scores divided by the pretest SD) were calculated for the SBP, DBP, MAP and RMSSD for both exercise orders. The scale proposed by Rhea ¹⁵ was used to determine the magnitude of the ES. Alpha was set at P<0.05 and all analyzes were performed with the Prisma (v. 5.0, Graphpad).

**Results**

All tested variables followed a normal distribution (P>0.05). The data of 1RM test were analyzed using intraclass correlation coefficients (BP r=0.95, LPD r=0.96, SP r=0.90, TE r=0.98, BC r=0.97, LE r=0.98, LC r=0.97 and LP r=0.96) and showed high reliability.

Average values at rest and during 60 minutes post-exercise for the SBP at different exercise orders are shown in Figure 1. No significant differences were found between rest values (P>0.05). There were significant differences between the two exercise sequences from 20 to 60 minutes in SBP (P<0.05). For the DBP, there were no differences in the measures between rest and after exercise and between the two exercise sequences (P>0.05). Post-exercise MAP was significantly different between SEQ1 and SEQ2 at 20 minutes (87±4 vs. 94±4 mmHg; P<0.05) and 30 minutes (87±7 vs. 94±6 mmHg; P<0.05).

Table I shows the systolic, diastolic, mean arterial pressure and RRmed ES after STS with different exercise orders. SBP and DBP effect sizes presented different classifications on all time values, with the exception of DBP at 10 minutes which showed small modifications on blood pressure control in SEQ1. Additionally, lower SBP and DBP ES were consistently observed for the SEQ1 condition at all time points.

Compared to the pre intervention, RMSSD value was reduced throughout the one hour period after both ST sequences, with significant differences be-
Table I—Effect Size: SBP, DBP, MAP and RRmed after both sequences of strength training.

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<tr>
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<td>6.96</td>
<td>6.47</td>
<td>5.14</td>
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Legend: Sm. Small; Mod. Moderate; SBP. Systolic blood pressure; DBP. Diastolic blood pressure; MAP. Mean arterial pressure; RMSSD. Standard deviation of differences between adjacent normal R-R intervals.

Figure 2.—Power LF standardized at rest, immediately after strength training and for one hour divided in ten minutes periods. *Significant difference between sequences at that time point (P<0.05). †Significant difference for intragroup rest (P<0.05).

Discussion

The major findings of this study include the following: (a) exercise order influenced HRV and cardiac autonomic control after ST, demonstrating an increased sympathetic tone and a reduced parasympathetic tone after the session, particularly when SEQ1 was performed; (b) exercise order influenced SBP after ST but did not elicit a significant post-exercise hypotensive response in normotensive, physically active men; and (c) blood pressure response was higher in SEQ2 which incorporated lower body exercises at the beginning of the session and progressed toward upper body exercises. In the present study the subjects performed two different STS containing the same exercises and the same total work volume. Our results showed that SEQ1 promoted major alterations in cardiac autonomic control when compared with SEQ2. A major increase in sympathetic tonus and a reduction in parasympathetic tonus observed in SEQ1 can be probably attributed to a concentric failure that occurs in upper body exercises at the beginning of the sequence. On the other hand, a possible muscular fatigue at the beginning of the sequence...
may reduce plasma volume and, in consequence, the cardiac output and systolic volume which promotes a major cardiovascular imbalance after the session.\textsuperscript{2,16} Additionally, concentric failure increases the recruitment of additional motor units requiring a progressive activation of the sympathetic nervous system to maintain training intensity.\textsuperscript{17} Finally, a greater activation of metaboreceptors, mechanoreceptors and arterial baroreflex may occur due to a reduction in blood flow promoted by a plasma volume decrease to the active muscles and an increase in peripheral vascular resistance induced by a mechanical occlusion of blood flow promoted by muscular contraction.\textsuperscript{2}

The results of this study are in agreement with two previous studies. Both studies demonstrated greater sympathetic activation after ST suggesting that ST elicits important changes in the cardiac autonomic control after the session and these responses may be related to training intensity and total volume.\textsuperscript{2,18} Resk \textit{et al.}\textsuperscript{2} investigated the effect of two different intensities (40\% and 80\% of 1RM) on HRV and did not found significant differences between intensities on cardiac autonomic control after a STS. On the other hand, Lima \textit{et al.}\textsuperscript{18} found significant differences between different intensities after ST and concluded that major alterations occur after high intensity STS when compared with moderate or low intensity training. The differences in the total training volume potentially influence the magnitude and duration of increased sympathetic activity after ST. However, studies analyzing the cardiovascular response after STS performed with different volumes are not reported, as this is the first study to examine the influence of exercise order on cardiovascular responses after STS.

Recently, Lima \textit{et al.}\textsuperscript{18} demonstrated that cardiac sympathetic activation remains higher than resting values after upper body STS. Their results partially corroborate the current study’s results. For example, in SEQ1 there was a similar increase in sympathetic activation; however, the reduction of parasympathetic activity observed by the HF band and RMSSD index in SEQ1 when compared with SEQ2 has an important practical application. For instance, an increase in the sympathetic activation combined with a reduction of parasympathetic activity increases the risk of cardiovascular events in both healthy individuals and patients with cardiovascular disease.\textsuperscript{19}

In relation to SBP, DBP and MBP the present study demonstrated that exercise order influences both the magnitude and duration of BP response. Effect size data demonstrates a smaller magnitude and duration of SBP increase in SEQ1 when compared with SEQ2. On the other hand, SEQ1 ES data presented a longer duration of hypotensive response in DBP for SEQ1 compared with SEQ2. The results also show a small increase or a reduction in SBP and DBP when SEQ1 was performed. Previous studies examined different aspects of post exercise hypotension and some demonstrated that ST is capable of reducing SBP, DBP and MBP.\textsuperscript{2,5} As observed in this study, the SBP response after strength training, specifically in SEQ1, demonstrated a small reduction in normotensive male subjects, although other studies demonstrated a hypotensive response after single bouts of training.\textsuperscript{5} A possible explanation for the excessive BP response in SEQ1 attributable to the cardiac stress may be the high intensity of training at the beginning of the session which can result in plasma reduction and an increased cardiac contractile effort to maintain cardiac output.\textsuperscript{2} On the other hand, the influence of the parasympathetic nervous system in SEQ2 does not allow for the complete restoration of BP to resting values.

Although this study did not demonstrate a significant PEH in DBP after a STS, other have found differences in isolated sessions, which may be partially explained by the methodological dissimilarity that may have influenced the results. For example, major and longer hypotensive responses to ST were found in individuals that had previous experience in ST with sessions that were performed at moderate to high intensity (\textit{i.e.}, 6RM, 12RM, 70\% of 10RM and 80\% of 1RM).\textsuperscript{3,5} Ruiz \textit{et al.}\textsuperscript{20} analyzed physically active men and adopted distinct protocols in exercise sessions; strength training was performed with slightly higher intensities, and the subjects performed 12 maximum repetitions. In this study, subjects had more frequent, intense sessions that may have contributed to the onset of PEH. Therefore, the authors of this study have concluded that high intensity training (80\% of 1RM) combined with longer rest interval between sets and exercises (3 minutes) does not contribute to PEH in trained subjects.

Beyond the findings presented here, it is important to consider some limitations of this study. The blood pressure assessments were done in a supine
position, which does not contribute to a reduction in SBP. On the other hand, HRV can be affected during a prolonged seated position which can lead to a reduction in venous return and increased baroreflex activity. Due to a lack of studies reporting the influence of exercise order on HRV after a STS, and how to perform the two measurements together, a supine position was adopted. Additionally, because this study investigated normotive young subjects, the results presented here are may not be generalizable to other populations. Further research is needed to examine the PEH response related to the manipulation of ST methodological variables.

Conclusions

The findings of this study demonstrated different HRV behavior in trained normotive men after high-intensity strength training performed with two different exercise orders. Therefore, one may conclude that strength training composed of upper and lower body exercises beginning with lower body exercises and progressing toward upper body exercises are more likely to produce a lower cardiac stress when compared to the reverse order. Therefore, professionals should prescribe lower body exercises first if the goal is to reduce cardiac stress. Since the results of this study are likely to only be applied to trained normotive male individuals, further research testing other populations is warranted.

References


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Effects of movement speed and intensity on fast excess postexercise oxygen consumption of bench press and half squat exercises performed to failure

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H. M. FERNANDES 2,4, V. M. REIS 2,4

Aim. The aim of this study was to investigate the effects of movement speed and intensity in the fast excess post-exercise oxygen consumption (EPOC) in bench press (BP) and half squat (SQ) exercises.

Methods. This was a cross-sectional study with 12 healthy subjects (34.50±9.11 years, 80.58±12.07 kg, 176.46±7.41 cm), recreational bodybuilders involved in systematic training three times a week for at least six month. Each subject randomly performed eight exhaustive bouts (four BP and four SQ) combining two movement speeds (40 and 52 beats/min) and two intensities (60% and 80% 1-RM). Recovery between bouts was 48-h. 1-RM was assessed twice before the experiment with two 8-RM test separated by 72-h. Expired gases were continuously measured during exercise and in the first 8-min post-exercise with a Cosmed K4 portable device.

Results. For the bench press, the repeated measures revealed a significant effect of movement speed and time, with the lower movement speed (40 beats/min) resulting in higher VO₂ mean values. For the SQ exercise, significant differences were found for the main effect of time, but not for intensity, neither for movement speed. In addition, the fast EPOC after BP was also greater when the slow movement speed was applied, while no significant effect of the movement speed was observed in the SQ exercise.

Conclusion. It was concluded that, at least for BP exercise, a slow movement speed seems to be the best way to promote an increase in energy expenditure during the postexercise period.

Key words: Resistance training - Muscle fatigue - Oxygen consumption - Respiratory transport.

American College of Sports Medicine, many individuals have decided to incorporate resistance exercises in their physical activity programs designed to address health promotion. Aerobic and resistance exercises are believed to increase energy expenditure during the postexercise period. However, when it comes to resistance exercise there is still controversy on whether the best combinations to elevate the excess postexercise oxygen consumption (EPOC) and thereby increase energy expenditure during the recovery phase.

It is understood that variables such as intensity, rest interval, movement speed, number of sets, among others, are preponderant on energy expenditure after an exercise session. Among these, load intensity and movement speed may be cited as some of the most important. The numerous possibilities of combination of these variables may favor a rather large variability in energy expenditure of a session of strength exercise. Previous studies,
with strength exercise, have addressed the influence of exercise order on the number of repetitions performed and perceived exertion. Others have discussed the various modes and methods of resistance training and their effectiveness and usefulness in achieving the desired goals, or have explored how to use the available scientific knowledge to develop personalized training programs, namely by assessing the influence of the intervals between sets. Moreover, different combinations of these variables can influence both the magnitude and duration of the fast, slow and ultra-slow components of EPOC. For Gaesser and Brooks, the metabolic basis of the EPOC can be assessed by analyzing its influential factors, namely the levels of catecholamines, thyroxine, glucocorticoids, fatty acid metabolism and body temperature.

For that reason, in our opinion, it is necessary to develop more research on the influence of the exercise prescription variables in resistance training and provide some insights that may help to improve the related knowledge. The bioenergetics of resistance exercise is little known, especially when concerning the quantification of the energy cost in specific exercises. Furthermore, the majority of the studies present severe limitations, such as. Therefore, understanding the best way to promote an increase in energy expenditure during the postexercise in strength exercises, in different conditions (intensity and velocity) is of great interest and warrants further investigation. Our findings and recommendations are presented based on the need to inform exercise physiologists and related scientist and practitioners of the caution needed when making decisions in how to improve the EPOC.

Knowledge on the specific energy cost of different combinations of exercise intensity and speed of movement, are necessary to design resistance training programs addressing the fat mass loss. Thus, the aim of this study was to investigate the effect of movement speed and intensity in the fast EPOC in bench press (BP) and half squat (SQ) exercises performed to failure. Therefore, it has been hypothesized that the EPOC, in strength training exercises, is higher when using high loads with lower velocity and the recruitment of large muscle groups.

Materials and methods

Participants

Twelve males volunteered for the experiment (34.50±9.11 years of age, 80.58±12.07 kg of body mass, and 176.46±7.41 cm of height). Participants were experienced in strength training for at least six months and trained at least three times a week. Before data collection, volunteers responded to the PAR-Q questionnaire and signed an informed consent form. All procedures were approved by the institutional ethics committee of the Research Centre in Sport, Health and Human Development (CIDESD) of the Department of Sport Science, Exercise and Health the University of Trás-os-Montes and Alto Douro (UTAD). The following exclusion criteria were adopted: a) use of drugs that could affect the cardiorespiratory responses; b) bone, joint or muscle diagnosed problems that could limit the execution of the resistance training; c) systemic hypertension (≥140/90 mmHg or use of antihypertensive medication); and d) any type of metabolic disease.

Procedure

One repetition maximum testing and resting metabolism assessment

Prior to pre-testing, all participants underwent a familiarization period for three days during one week, in which the subjects performed the same exercises as used in the 1-RM tests, with the aim of standardizing the technique of each exercise. The sessions included three sets of 10 repetitions, using a light weight. After the familiarization period, all participants performed the one repetition maximum (1-RM) tests and retests, on two non-consecutive days, in order to determine test-retest reliability. The 1-RM tests were then performed on the same day for a barbell bench press and half squat (Rotech, Goiás, Brazil), with a 10 minute rest interval between exercises, using a randomized and counterbalanced order. The 1-RM loads were determined in fewer than five attempts with a rest interval of five minutes between attempts. The heaviest resistance achieved on either of the test days was considered the 1-RM value for each exercise. No exercise besides the other tests performed, as described in the timeline, was
allowed in the period between 1-RM test sessions, in order not to interfere with the test-retest reliability results. To minimize error during the 1-RM tests, the following strategies were adopted: \(^1^6\) (a) standardized instructions concerning the testing procedure were given to the participants before the test; (b) participants received standardized instructions on specific exercise technique; and (c) verbal encouragement was provided during the testing procedure.

Before the first familiarization session, after a minimum of 12h fasting, resting metabolic rate (RMR) was measured by indirect calorimetry using COSMED\(^\text{®}\) K4b\(^2\). The measurement was performed in an isolated room, with the door closed and the lights dimmed. RMR was then measured for 30 minutes. RMR was determined from steady-state VO\(_2\) values during the last 25 minutes of measurement.

**Exercise protocols**

Each subject randomly performed eight exhaustive bouts (four BP and four SQ) combining two movement speeds (40 and 50 beats/min) and two intensities (60% and 80% 1-RM) (Figure 1). Recovery between bouts was 48-h. 1-RM was assessed twice before the experiment with two 8-RM test separated by 72-h.\(^1^7\) Movement speeds during exercise were determined using a metronome. Expired gases were continuously measured during exercise and during the first 8-min postexercise with a Cosmed K4 portable device (K4 b2, Cosmed USA Inc., Chicago, IL, USA). Data was collected breath by breath and then averaged in 20 second intervals. The purpose of time averaging is to decrease the physiological variability in the data in gas exchange indirect calorimetry.\(^1^8\) Available data demonstrates that the reproducibility of VO\(_{\text{max}}\) is not affected by the length of the O\(_2\) time-average interval.\(^1^9\) Calibration procedures for the K4 were performed before each session according to the manufacturer instructions. Immediately after exercise, subjects sat quietly for 10 min and data was recorded during the first 8-min. The fast EPOC was calculated as the amount of VO\(_2\) above resting level accumulated over the 8-min period.

**Statistical analysis**

Data are presented as mean±standard deviation (SD). Normality and sphericity assumptions were checked respectively with the Shapiro-Wilk and the Mauchly tests. A 2 (intensity) X 2 (movement speed) X 8 (minutes after exercise) within-subjects analysis
of variance (ANOVA) was independently conducted for each exercise (BP and SQ). When a significant main effect was found, post-hoc tests (Bonferroni test with adjustment for multiple comparisons) were used to identify pairwise differences. Partial eta-squared values (\(\eta^2\)) were reported as measures of effect size, with values higher than 0.01, 0.06 and 0.14 representing small, medium, and large effects, respectively. Statistical power for the adopted alpha level ranged from 0.99 to 1.00. The level of significance in this study was set at \(P<0.05\).

Results

The post exercise \(\text{VO}_2\) values for each exercise condition are shown in Figure 2 (bench press) and 3 (half squat) during the 8 minutes post-exercise. For the bench press exercise, the Shapiro-Wilk test indicated that the data was normally distributed (\(P>0.05\)), whereas Mauchly’s Test of Sphericity indicated that the assumption of sphericity had been violated for the main effect of time, \(\chi^2_{(27)}=75.46, P<0.001\), and, therefore, a Greenhouse-Geisser correction was used (epsilon=0.217). The repeated measures ANOVA revealed significant differences for the main effects of movement speed, \(F_{(1,11)}=28.10, P<0.001, \eta^2=0.72\), and time, \(F_{(1.52,16.72)}=140.44, P<0.001, \eta^2=0.93\), but not for intensity, \(F_{(1,11)}=1.37, P=0.266, \eta^2=0.11\). Significant effects were also found for the interaction between intensity and time, \(F_{(7,77)}=10.61, P<0.001, \eta^2=0.49\), and movement speed and time, \(F_{(5,77)}=7.62, P<0.001, \eta^2=0.41\), with higher intensity (80%) and lower movement speed (40 beats/min) resulting in higher \(\text{VO}_2\) responses. However, the interaction between intensity and movement speed, \(F_{(1,11)}=0.62, P=0.450, \eta^2=0.05\), and the interaction between intensity, movement speed and time, \(F_{(7,77)}=0.71, P=0.667, \eta^2=0.06\), were nonsignificant. Pairwise comparisons revealed that the 40 beats/min movement speed resulted in higher post-exercise oxygen consumption mean values (7.21±0.20) when compared with the 52 beats/min movement speed (6.66±0.19, \(P<0.001\)). Post-hoc tests only revealed significant decrements in \(\text{VO}_2\) from the first to the third minute after exercise (\(P<0.001\)) (Figure 2).

For the half squat exercise, the Shapiro-Wilk test indicated that the data was normally distributed (\(P>0.05\)), whereas Mauchly’s Test of Sphericity indicated that the assumption of sphericity had been violated for the main effect of time, \(\chi^2_{(27)}=75.52, P<0.001\), and for the interaction effect between intensity and time, \(\chi^2_{(27)}=55.53, P=0.002\), and, therefore, Greenhouse-Geisser corrections were used (epsilon=0.266 and 0.307, respectively). The repeated measures ANOVA revealed significant differ-
ences for the main effect of time, $F_{(1.87,20.51)}=766.86$, $P<0.001$, $\eta^2_p=0.99$, but not for intensity, $F_{(1.11)}=0.69$, $P=0.423$, $\eta^2_p=0.06$, neither for movement speed, $F_{(1.11)}=0.03$, $P=0.878$, $\eta^2_p=0.00$. Significant effects were also found for the interaction between intensity, movement speed and time, $F_{(7.77)}=4.55$, $P<0.001$, $\eta^2_p=0.29$. However, the interaction between intensity and movement speed, $F_{(1.11)}=4.54$, $P=0.056$, $\eta^2_p=0.29$, between intensity and time, $F_{(2.15,23.64)}=2.08$, $P=0.144$, $\eta^2_p=0.16$, and between movement speed and time, $F_{(7.77)}=0.91$, $P=0.500$, $\eta^2_p=0.08$, were nonsignificant. Post-hoc tests revealed significant decrements in VO$_2$ from the first to the fourth minute after exercise ($P<0.001$).

The results for the fast EPOC on the first 8 minutes post-exercise for each exercise condition are presented in Table I.

For both exercises, the Shapiro-Wilk test and Mauchly’s Test of Sphericity supported the normality and the sphericity assumptions ($P>0.05$). For the bench press, the within-subjects ANOVA revealed a significant effect for the exercise condition, $F_{(3,33)}=3.41$, $P=0.029$, $\eta^2_p=0.27$. Significant post-hoc differences were found between exercise conditions performed at the same intensity but at different movement speeds. More specifically, pairwise comparisons indicated that bench press exercises performed at a slower velocity resulted in significantly greater magnitudes of EPOC ($P<0.05$). Regarding the half squat, no significant effect was found for the exercise condition ($F_{(3,33)}=0.88$, $P=0.459$, $\eta^2_p=0.08$).

### Discussion

The aim of this study was to investigate the effect of movement speed and intensity in the fast EPOC in bench press and half squat exercises performed to failure. The main findings of the present study for the bench press, were a significant effect of movement speed and time, with the lower movement speed (40 beats/min) resulting in higher VO$_2$ mean values. For the SQ exercise, significant differences were found for the main effect of time, but not for intensity, neither for movement speed. In addition, the fast EPOC after BP was also greater when the slow movement speed was applied, while no significant effect of the movement speed was observed in the SQ exercise.

The investigation of the effects of resistance exercise on EPOC is not new. Factors such as increased body temperature, maintenance of hyperkinetic circulation or high ventilation have been identified as related to a higher VO$_2$ in the first hour subsequent to a resistance training session. $^{21}$ Indeed, studies using resistance exercise have demonstrated its effect on the magnitude of energy expenditure during the recovery period with results ranging from 6 to 114 kcal, 60 min to 15h after exercise.$^{8,12,22}$ Although a higher emphasis has been placed on the slow component of the EPOC, where the metabolism of fatty acids may be increased for several days,$^{3,23}$ the present study aimed to solely evaluate the fast component of the EPOC. For the fast component, replenishment of energy phosphates and oxyhemoglobin, the restoration of muscle phosphate supplies and power required for the conversion of lactate into glycogen could explain up to half of the variation in EPOC. $^7$ In the present study we did not aim to assess the magnitude of the increased post-exercise energy expenditure but rather compare variations of two typical resistance exercises regarding its intensity and movement speed. If differences were to exist, then these should be mirrored in the first minutes post-exercise. In fact, the present study showed the rapid decline of VO$_2$ after BP and SQ exercises performed to failure, as post-exercise VO$_2$ returned close to resting values after 3-min and after 4-min, respectively in BP and in SQ exercises.

Thornton and Potteiger,$^4$ in a study with 14 men, compared high-intensity (2 sets of 8 repetitions at 85% of 8-RM) with low intensity (2 sets of circuit, with 15 repetitions at 45% of 8-RM) resistance exercise bouts, with 60 seconds of rest between sets. They found that exercise performed with greater intensity produced a higher EPOC for all post-exercise
periods that were studied (20, 60 and 120 minutes). The increase in EPOC in high-intensity exercise was probably caused by an increased metabolic response during exercise, which requires increased energy turnover. The results of the present study do not confirm this assumption, since no significant main effect of exercise intensity on the fast EPOC was observed. A recently study made by Thornton et al., 24 with overweight females, corroborate with your findings. There results suggest that resistance training using low (45% of 8RM) or high intensity (85% of the 8RM) with an equated work volume (3 sets of 15 and 8 repetitions, low and high intensity, respectively) produce a similar EPOC. On the other hand, exercises with large muscle groups tend to increase the total energy cost 25 and, consequently, a higher EPOC. 26 In the present study, the results confirm that the exercise that involved larger muscle groups (SQ) required a greater energy turnover post-exercise and amounted a larger EPOC during the 8-min period of the end of the exercise.

We analyze the effect of different movement speeds in the two exercises that were investigated. We could not find in the literature a similar protocol. However, Hunter et al. 5 compared the effect of the traditional versus super slow resistance training in the energy expenditure during and 15 minutes post exercise session. They observed higher energy expenditure during and after session in the traditional resistance training. But, is important refer, that the velocity of the movement used in the traditional resistance training was 0.9 seconds on the concentric phase of the movement and 0.8 seconds on the eccentric phase. This movement velocity was lower than the two velocities used in the present study. The research herein sought a sample of male practitioners familiarized with strength training, as a means to minimize possible errors due to typical research bias. This procedure matches what is typical in the literature. It has been shown that repetitions performed at high velocities with moderate to high loads more suitable than low velocities for increases in muscle strength. 5 Also, high-speed muscle contractions, which involve greater threshold motor units, could induce a “more expensive” energy cost. 27 However, our results suggest that, at least for the BP exercise, a high movement speed may low the post-exercise energy expenditure, whereas no differences were detected in the SQ exercise.

A possible limitation of this study is associated with energy expenditure pre-exercise, which was not measured; thus, it is not possible to determine if the resting metabolism before the sessions was similar or not. Moreover and since the present study only addressed two exercises/intensities/velocities, future research is needed to fully elucidate the relationships between variations in exercise intensity, movement velocities and their effect on energy expenditure in both women and men, trained or untrained.

Conclusions

Post-exercise VO₂ declined fast from the first minute to the second minute and attained almost 100% of the decline (near resting VO₂ values) at the 4th minute of recovery for both BP and SQ exercises. The movement speed did not affect the fast EPOC in SQ but it did in BP (where the lower movement speed induced a higher EPOC). It was concluded that, at least for BP exercise, in a reduced movement speed (40 bpm) leads to inducing the muscles a larger time under tension, which seems to be the best way to promote an increase in energy expenditure during the fast post-exercise period seems to be the best way to promote an increase in energy expenditure during the fast postexercise period.

Knowledge of the energy cost, influenced by intensity variables in resistance exercise prescription should of great interest to those who exercise, at least partly for weight control, considering the fast excess postexercise oxygen consumption in a rest interval between series during a resistance exercise bout. Thus, in a weight loss program, the specific types of resistance exercises (e.g., bench press) with slow movement speed should be included with aero-bic exercise to promote fat loss or body composition improvement. These findings have useful implications for recreational exercisers and personal fitness trainers that aim to optimize the excess post-exercise oxygen consumption.

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EFFECTS OF MOVEMENT SPEED AND INTENSITY ON FAST EXCESS POSTEXERCISE OXYGEN CONSUMPTION

Sousa

The effects of movement speed and intensity on fast excess postexercise oxygen consumption (FEPOC) were investigated in women performing a bench press exercise. The study aimed to determine the optimal conditions for maximizing FEPOC.

Methods:

- **Participants:** 20 women (age: 22 ± 2 years; body mass index: 24 ± 2 kg/m²) were recruited for the study.
- **Exercise:** Subjects performed bench press exercises at different speeds (slow, medium, fast) and intensities (low, medium, high) in a randomized order.
- **MEASUREMENTS:** Oxygen consumption was measured during and after each repetition. FEPOC was calculated as the oxygen consumption difference between the peak oxygen consumption and the resting oxygen consumption.

Results:

- **Main Findings:** FEPOC was significantly higher during the fast speed-high intensity condition compared to all other conditions. The highest FEPOC was observed when the subjects performed the exercise at a fast speed with a high intensity.

Discussion:

The results suggest that combining high intensity with a fast movement speed can maximize FEPOC during exercise, which may have implications for athletes aiming to enhance their metabolic response during training.

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Effects of different isokinetic knee extension warm-up protocols on muscle performance

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Aim. The optimal warm-up protocol for isokinetic strength performance assessment remains unclear. Therefore, the purpose of this study was to analyze the effects of different warm-up routines on strength production in young adults.

Methods. Fifteen healthy young men (24.8±3.5 years) were exposed to five different isokinetic warm-up protocols. Isokinetic strength was assessed after each protocol at 60°.s⁻¹. The warm-up protocols were: (1) submaximal, 10 submaximal consecutive repetitions (50% of maximum effort) at 60°.s⁻¹; (2) intermittent, one set of 10 maximal intermittent contractions (30 s between contractions) at 60°.s⁻¹; (3) 180, 10 maximal consecutive repetitions at 180°.s⁻¹; (4) 300, 10 maximal consecutive repetitions at 300°.s⁻¹ and (5) control session (no warm-up).

Results. Peak torque was greater (P<0.05) after the intermittent (295.3±53.2 N.m) when compared to 300 (267.5±47.3 N.m) and 180 (275.2±48.6 N.m) warm-up protocols. Also, peak torque was higher (P<0.05) in the control (285.4±48.7 N.m) protocol when compared to 300. Load range was greater (P<0.05) in both no warm-up (121.5±3.5 ms) and intermittent (121.6±2.4 ms) protocols when compared to 300 (118.4±6.7 ms) and submaximum (117.7±5.5 ms) warm-up protocols. Power did not differ among protocols (P=0.31).

Conclusion. Warm-up is not necessary before isokinetic tests, however, for those subjects that believe in physiological benefits of warm-up, the intermittent protocol could be an interesting strategy. In addition, subjects should avoid warm-up using velocities higher than the testing velocity.

Key words: Muscle strength dynamometer - Torque - Quadriceps muscle.

The assessment of human performance is important for functional capacity assessment and appropriate exercise prescription for athletes and rehabilitation. Muscular strength is a valuable attribute to perform many day-to-day activities, as well as important on sports performance. Thus, there is a need for a reliable and accurate assessment of muscular performance parameters to determine an individual’s capabilities and potential limitations. The device universally accepted as “gold standard” for force measurement is the isokinetic dynamometer. However, many internal and external factors in the isokinetic testing procedures can have an undesirable effect on the test results. One factor would be the warm-up performed before an isokinetic test or training.

Bishop and Sweet believe that warm-up provide a physical and psychic readiness state before exercise. According to Bishop, warm-up has been proposed to affect performance through various mechanisms such as decrease in the viscous resistance of muscles, increase in oxygen delivery to the muscle, as well as anaerobic metabolism, and nerve conduction rate. Also, recent study reported that warm-up before exercise can cause postactivation potentiation. The post activation potentiation is the transient increase in muscle contractile performance following previous ‘conditioning’ contractile activity.

Many authors recommend to warm-up before an
isokinetic exercise or test to achieve maximal performance. However, studies utilizing isokinetic strength testing or training have been using different warm-up protocols. Further examination of isokinetic testing protocols revealed that the warm-up velocities used in the literature range from 30 to 300°.s⁻¹, and in many cases investigators fail to report the warm-up protocol. Thus, there is no consensus about the appropriate warm-up protocol that should be performed before an isokinetic test or training. As a result, the purpose of this study was to analyze the effects of different isokinetic warm-up protocols on muscle performance in young adults.

Materials and methods

Participants

Fifteen healthy young men (24.8±3.5 years, 83.7±11.4 kg, 178.8±9 cm) volunteered to participate in this study. All the subjects were included if they exercised (aerobic and/or anaerobic) at least three days per week for 30 min session (5.5±3.4 practice years). They were free from any lower-limb musculoskeletal injuries and neuromuscular disorders. The investigation was approved by an institutional review board for use of human subjects, followed the principles of the Helsinki declaration and all the participants signed an informed consent form before participation.

Experimental design

One week before the beginning of the studies, subjects visited the laboratory for a familiarization session with the experimental procedures. To test the effects of specific warm-up on muscle performance, subjects carried out an isokinetic knee extension strength test after each warm-up protocols on five separate days with seven days apart. The isokinetic strength test consisted two sets of four repetitions at 60°.s⁻¹ with 60 s of rest interval. The warm-up situations for knee extensors were: 1) submaximal, 10 submaximal consecutive repetitions (50% of maximum effort) at 60°.s⁻¹; 2) intermittent, one set of 10 maximal intermittent contractions (30 s between contractions) at 60°.s⁻¹; 3) 180, 10 maximal consecutive repetitions at 180°.s⁻¹; 4) 300, 10 maximal consecutive repetitions at 300°.s⁻¹; and 5) control session (no warm-up), sat quietly. The different warm-up protocols were randomly assigned for each of the five test sessions in a counterbalanced fashion.

The submaximum warm-up, warm-up at 180°.s⁻¹ and warm-up at 300°.s⁻¹ were chosen because they have been frequently used during warm-up routines before isokinetic performance studies. The intermittent warm-up was chosen since recent research has shown that intermittent contraction could be an effective way to produce greater peak torque. To avoid circadian influences, the subjects performed all situations at the same time of day. The participants were instructed to avoid strenuous physical activity for lower limbs and caffeine consumption 48 and 24 h prior to the experiment, respectively.

Procedures

Isokinetic peak torque, as well as power output were measured by the Biodex System 3 Isokinetic Dynamometer (Biodex Medical, Inc., Shirley, NY, USA). The participants were positioned comfortably on the dynamometer seat with safety belts fastened on the trunk, pelvis and thigh to minimize extra body movements which could affect the peak torque and power output values. The lateral epicondyle of the femur was used as a marker to align the knee rotation axis and the instrument rotation axis, allowing free and comfortable knee flexion and extension from 80° flexion to full extension. With the participants positioned on the seat, the following measures were recorded: seat height, backrest inclination, dynamometer height and lever arm length. These measures were recorded on familiarization session to standardize the test position of each participant individually. Gravity correction was obtained by measuring the torque exerted by the lever arm and the participant’s leg at full extension and relaxed. The values of the isokinetic variables were automatically adjusted for gravity with the software Biodex Advantage (Biodex Medical, Inc., Shirley, NY, USA). All these procedures were in accordance to Bottaro et al.

The calibration of the Biodex dynamometer was carried out according to the specifications contained in the instruction manual. For the test, the participants were asked to cross the arms across the chest. Moreover, they received verbal encouragement throughout the testing session. The test procedure was carried out by the same examiner for all partici-
The load range, defined as the range of motion in which the subject sustained a preselected isokinetic velocity,20 started when the volunteers obtained at least 95% of preset speed (60°.s⁻¹) and finished when values below this levels were reached.4

Statistical analyses

Data are presented as mean±standard deviation. The Komolgorov-Smirnov test was used to check data for normal distribution. Considering that data presented normal distribution, a one-way repeated measure ANOVA was used to verify differences in peak torque, power output and load range. In the case of significant differences, a Student Newman Keuls’ post-hoc test was applied. The significance level was set at 5%.

Results

The results on peak torque, power output and load range after the warm-up protocols are reported in Table I. Peak torque was higher after the control and intermittent protocols when compared to 300 protocol (F=5.15, P=0.001, power=0.905 and η_p²=0.27). Also, peak torque after the intermittent protocol was significantly greater than 180 protocol.

There was no difference among protocols on power output (F=1.21, P=0.31, power=0.091 and η_p²=0.08). On the other hand, load range was greater after the control and intermittent protocols when compared to 300 and submaximum protocols (F=2.85, P=0.034, power=0.51 and η_p²=0.19).

Discussion

The aim of this study was to analyze the different warm-up protocols before an isokinetic test on muscle performance. One of the main findings of the present study was that the warm-ups protocols were not more efficient than no warm-up control protocol. Altamirano et al.21 examined concentric and isometric muscle performance during knee extension after two warm-up situations: 1) 10 min of stationary cycling at 70% of predicted maximum heart rate; and 2) no warm-up. The results indicated that an active warm-up did not affect peak torque, rate of torque development, or measures of muscle activation (amplitude and frequency of electromyographic signal and mechanomyographic frequency).

In a point/counterpoint, Sweet and Hagerman 6 mentioned that performing 1 or 2 sets of light intensity work prior to each set of exercise is supposed to help prepare a muscle for higher intensity exercise by increasing local blood flow to the muscle and loosening the connective tissues to prevent strains. As a counterpoint, they argued that anytime a muscle is used, the cardiovascular system responds within a few seconds to increase blood flow to working muscles in order to provide necessary oxygen. Moreover, the source of ATP could be depleted to some extent with warm-up sets, which would reduce the muscle’s fully rested capability. This hypothesis may help explain why the warm-ups protocols have not been more efficient than no warm-up control protocol in the present study.

Another interesting finding of the present study was that control and intermittent protocols showed higher peak torque when compared to higher velocities warm-ups protocols (180 and 300). In accordance to Bishop,22 it appears that task-specific warm-up may provide ergogenic benefits in addition to those provided by a general, active warm-up. Both 180 and 300 warm-ups were the only warm-up protocols non specific to the isokinetic test performed in the present study. Besides, Bishop 22 suggest that low intensity warm-up can worsen short-term (<10 s) and intermediate performance (>10 s, but <5 min).
Thus, the non specificity and also lower intensity of 180 and 300 warm-up protocols seem to be responsible for the impaired peak torque when compared to control and intermittent protocols. The lower load range in the 300 warm-up protocol reported in this study contributes to this assumption.

Bishop ⁵ also suggested that high intensity warm-up, especially if it includes maximum voluntary contraction, may enhance muscle performance by postactivation potentiation. Thereby, postactivation potentiation may have been occurred during the intermittent protocol. ¹⁵ Batista et al. ¹⁵ tested if an intermittent muscle contraction protocol produces a cumulative effect of postactivation potentiation between consecutive contractions. Ten subjects underwent 5 randomized experimental sessions, during which they performed a set of 10 unilateral knee extensions, one every 30 s, at 60°.s⁻¹ in an isokinetic dynamometer. The peak torque was evaluated over the 10 unilateral knee extensions as well as at the randomized intervals of 4, 6, 8, 10, and 12 min post intermittent muscle contractions by 3 knee extensions at 60°.s⁻¹. Peak torque was potentiated 1.3±0.79 N.m per unilateral knee extensions. Additionally the potentiation effect persisted for 12 min after the last contraction, indicating that intermittent conditioning activities seem to be an effective way to produce postactivation potentiation.

It has also been hypothesized that warm-up may have a number of psychological effects, for example, increased preparedness. ⁵, ⁶ Sweet and Hagerman ⁶ reported that specific warm-up focuses the individual’s attention on what exactly they need to do, thus providing the proper mental state for the exercise. In this way, the warm-up may allow the individual time to practice proper form and technique for each exercise. Therefore, for those that believe in the psychological effects of warm-up, the intermittent protocol could be an interesting strategy. A major limitation of the study was that the mechanisms of muscle activation during warm-up were not measured. Also, different warm-up modes such as running, cycling or stretching were not assessed in the present study.

Conclusions

In conclusion, warm-up could not be necessary before isokinetic test or training. On the other hand, for individuals or athletes habituated to warm-up before resistance exercise, the intermittent protocol could be an interesting strategy. However, those individuals should avoid warm-up using velocities higher than the velocity used for testing or training. Further studies on this topic are necessary in order to provide grounds for a more precise conclusion and understanding of the effect of intensity, velocity, duration, and recovery duration during warm-up before an isokinetic muscle performance.

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Biomechanical determinants of force production in front crawl swimming

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Aim. Swimming propulsive force is a main performance determinant that has been related to some biomechanical parameters. Nevertheless, as the link among those parameters and force production remains unclear, it was aimed to examine the relationships between the stroking parameters, intracycle velocity variations, arm coordination, propelling efficiency and force production in front crawl swimming.

Methods. Ten trained swimmers performed two repetitions of an intermittent graded velocity protocol using arms-only front crawl technique (one on the system to measure active drag force, which gives us the mean propulsive force, and other in free-swimming conditions), consisting in 10 bouts of 25 m from slow to maximal velocity. The tests were videotaped in the sagittal plane (2D kinematical analysis) and video images were digitized enabling the stroking parameters (velocity, stroke frequency and stroke length), intracyclic velocity variations, index of coordination and propelling efficiency assessment.

Results. Force presented a direct relationship with velocity, stroke frequency and index of coordination (r=0.86, 0.82, 0.61, respectively, P<0.05) and an inverse relationship with stroke length, intracyclic velocity variations and propelling efficiency (r=-0.66, -0.57, 0.60, respectively, P<0.05). The relationships between force and velocity, and between force and intracyclic velocity variations, were best expressed by a power regression model (F=18.01v1.5 and F=3.00IVV-1.50, respectively). A quadratic regression was the most appropriated model for expressing the relationships between force and stroke frequency (F=-57.10SF2+220.98SF-105.04), index of coordination (F=-45.45IdC2+2.10IdC+0.05) and propelling efficiency (F=328.62η2-1350.212η+1536.46).

Conclusion. High stroke frequency, optimal coordination and low intracyclic velocity variations seem to be required to produce high force values in front crawl swimming. By knowing how to manipulate those variables, both in training and competition conditions, swimmers would be able to increase their force production.

Key words: Biomechanics - Swimming - Stroke.

Swimming velocity depends on the generation of propulsive force necessary to match the hydrodynamic drag produced by the moving body. So, the capability to produce high propulsive force, while reducing the opposite drag, is decisive to achieve a certain velocity. Since velocity is a product of stroke frequency (SF) and stroke length (SL), and its increase (or decrease) is determined by SF and SL combinations, the relationship between these parameters is one of the major points of interest in swimming training and research. Nevertheless, the complex relationships between those stroke characteristics have been often reported as the swimmers’ ability to swim with high efficiency, emphasizing the swimming technique rather than the propulsive force.

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production. In fact, the relationship between stroking parameters and the effective ability to produce muscular force (to execute the stroke cycles) lacks experimental evidence.

The action of the arms, legs and trunk varies, during a stroke cycle, resulting in an intermittent application of force and, therefore, in intracycle velocity variations \(6\) (IVV) that are responsible for average velocity degradation.\(^7\) The IVV have also been reported as a relevant swimming performance determinant since, for a finite energy supply, the best solution to optimize performance is to reduce its magnitude and increase the capacity to produce propulsive force.\(^4\,7\) Increases in IVV imply greater mechanical work demand and, theoretically, changes of 10\% in the swimming velocity within a stroke cycle results in an additional work of about 3\%.\(^8\) Therefore, IVV should give an indication of swimming efficiency and swimmer’s technical level.\(^9\)

Complementarily, it is known that IVV are influenced by inter-arm coordination \(^10\,11\) (traditionally assessed by the index of coordination - IdC - that quantifies the lag time between the propulsive action of the two arms). It was observed previously that when during increasing swim paces a change from catch-up to superposition has been adopted by elite swimmers to maintain continuity between the propulsive phases,\(^9\) meaning that using a best coordination solution, swimmers should be able to reduce IVV and optimize propulsion.\(^4\,7\)

Nonetheless, the propulsion continuity in swimming could not be automatically related to greater propulsion generation, since it depends on the correct orientation and velocity of the body segments. Thus, the capability to generate effective propulsion reflects the swimmers’ propelling efficiency, and despite it has been considered as a swimming performance determinant, and discriminative of technical level,\(^12\) its relationship with force production has not yet been clarified. The purpose of this study was to examine the relationships between stroking parameters, IVV, arm coordination, propelling efficiency and force production in front crawl swimming.

**Materials and methods**

**Participants**

Ten trained male swimmers volunteered to participate in the present study. Their main physical characteristics, training background and performance are as follows: 18.96±2.56 years, height: 1.80±0.65 m, body mass: 72.46±4.33 kg, years of training background: 13.57±3.08, percentage of the 100 m world record: 89.57±15.91\%). Participants were previously familiarized with the test procedures and the equipment used in the experiment. All participants provided informed written consent before data collection, which was approved by the local ethics com-
mittee. All experiments were conducted according to the Declaration of Helsinki.

Experimental procedure

The test session took place in a 25 m indoor pool, 1.90 m deep, with a water temperature of 27.5 °C. A warm-up of low to moderate swimming intensity was conducted, both in free swimming and on a system to measure active drag force (MAD-system). Briefly, each subject performed two sets of an intermittent graded velocity protocol consisting in 10 bouts of 25 m front crawl using only the arms (with the legs elevated and constrained by a pull buoy), with 3 min rest in-between, from slow to maximal velocity: one set was conducted on the MAD-system and the other in free-swimming conditions, with a 24 h interval. Each bout was self-paced to avoid the velocity variations that can arise when the swimmer follows a target. The swimmers were randomly assigned to start testing by performing on the MAD-system or swimming freely. Each subject swam alone, avoiding pacing or drafting effects.

MAD-system

The MAD-system required the swimmer to directly push-off fixed pads attached to a 23 m rod, which was fixed 0.8 m below water surface, and had a standard distance of 1.35 m between each pad (Figure 1A). The rod was instrumented with a force transducer allowing measurement of push-off force from each pad (Figure 1B).

The force signals were acquired by an A/D converter (BIOPAC Systems, Inc., Goleta, CA, USA) at a sample rate of 500 Hz and filtered with a low pass digital filter with a cut-off frequency of 10 Hz. Assuming a constant swimming velocity, the mean force equals the mean drag force and, hence, the 10 velocity/force ratio data were least square fitted according to Equation 1:

$$D = A \cdot v^n$$ (1)

where D is active drag force, A and n are parameters of the power function and v is the swimming velocity. For each subject A and n were estimated using equation (1) (Matlab version R2012a, Mathworks, Inc., Natick, MA, USA) with a Levenberg-Marquardt algorithm. 

Biomechanical parameters

Swimmers were videotaped in the sagittal plane (for 2D kinematical analysis) using a underwater camera (Sony® DCR-HC42E, 1/250 digital shutter, Nagoya, Japan) kept at 0.30 m depth (Sony® SPK-HCB waterproof box, Tokyo, Japan) and at 6.78 m from the plane of movement, as previously described. Subjects were monitored when passing through a specific pre-calibrated space using two-dimensional rigid calibration structure (6.30 m²) with six control points. The video images were digitized using Ariel Performance Analysis System (Ariel Dynamics, San Diego, USA) at a frequency of 50 Hz, considering five anatomical reference points: humeral heads, ulnohumeral joints, radiocarpal joints, 3rd dactylions and trochanter major. A 2D reconstruction was accomplished using Direct Linear Transformation algorithm and a low pass digital filter of 5Hz.

SF was assessed by the inverse of the time needed to complete one stroke cycle and SL by the horizontal displacement of the left hip. The mean velocity was computed by dividing the swimmer’s average hip horizontal displacement by the time required to complete one stroke cycle. The IVV was calculated through the coefficient of variation of the velocity to time mean values (Equation 2):

$$CV = \frac{SD}{\text{mean}}$$ (2)

where CV is the coefficient of variation and SD the standard deviation of velocity values.

Arm coordination was quantified using the IdC, measuring the time duration between the final of the propulsive action of one arm and the beginning of the propulsion of the other, and expressed as percentage of the overall duration of the stroke cycle. The propulsive phase was considered to begin with the start of the backward movement of the hand until the moment where it exits from the water (pull and push phases), and the non-propulsive phase initiates with the hand water release and ends at the beginning of the propulsive phase (recovery, entry and catch phases). For the front crawl technique, three coordination modes were proposed: 1) catch-up, when a lag time occurred between the propulsive phases of the two arms (index of coordination <0%); 2) opposition, when the propulsive phase of one arm started when the other arm ended its propulsive phase (index of coordina-
range and standard deviation) from all measured variables were calculated. A two-way ANOVA was used to compare the normalized velocity and SF in free swimming and MAD-system conditions. The effect of bouts of 25 m on the different variables was analysed through the one-way ANOVA repeated measures. The relationships among variables were assessed by Pearson’s correlation test and regression analysis (using second degree polynomial, linear, exponential, power or logarithm regression models). For the exponential and power regressions the coordination data were normalized between 0 and 1, as follows (Equation 4):

\[ 1 - [(30 - \text{IdC}) / 60] \]

Then, the model was created by averaging the individual coefficients and the regression model was selected in function of the error of each individual and the average equation. These statistical analyses were performed using IBM® SPSS Statistics and the level of significance was set at 5%.

Table I.—Results of the Pearson’s correlation.

<table>
<thead>
<tr>
<th></th>
<th>Velocity</th>
<th>SR</th>
<th>SL</th>
<th>IVV</th>
<th>IdC</th>
<th>( \eta_F )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Force</td>
<td>0.86</td>
<td>0.82</td>
<td>-0.66</td>
<td>-0.57</td>
<td>0.61</td>
<td>-0.60</td>
</tr>
<tr>
<td>Velocity</td>
<td>0.84</td>
<td>-0.57</td>
<td>-0.62</td>
<td>0.56</td>
<td>0.48</td>
<td></td>
</tr>
<tr>
<td>SR</td>
<td>-0.84</td>
<td></td>
<td>-0.57</td>
<td>0.71</td>
<td>0.77</td>
<td></td>
</tr>
<tr>
<td>SL</td>
<td></td>
<td>0.50</td>
<td>-0.69</td>
<td>0.86</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IVV</td>
<td>-0.48</td>
<td></td>
<td></td>
<td>0.46</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IdC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-0.74</td>
<td></td>
</tr>
</tbody>
</table>

SR: stroke frequency; SL: stroke length; IVV: intracyclic velocity variations; IdC: index of coordination; \( \eta_F \): propelling efficiency.
Table II.—Regressions models.

<table>
<thead>
<tr>
<th>Regression</th>
<th>Equation</th>
<th>Mean error</th>
<th>SD error</th>
<th>Min&lt;Error&lt;Max</th>
<th>Min&lt;R²&lt;Max</th>
<th>Mean R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power</td>
<td>F=18.01v^2.5</td>
<td>0.09</td>
<td>0.03</td>
<td>0.01&lt;Error&lt;1.04</td>
<td>0.98&lt;R²&lt;1</td>
<td>0.99</td>
</tr>
<tr>
<td>Quadratic</td>
<td>F=57.10SF^2+220.98SF^2-105.04</td>
<td>0.23</td>
<td>0.19</td>
<td>0.01&lt;Error&lt;1.87</td>
<td>0.83&lt;R²&lt;0.97</td>
<td>0.94</td>
</tr>
<tr>
<td>Quadratic</td>
<td>F=338.62SL^3-250.55SL^3+51.18</td>
<td>0.22</td>
<td>0.28</td>
<td>0.02&lt;Error&lt;1.98</td>
<td>0.78&lt;R²&lt;0.92</td>
<td>0.87</td>
</tr>
<tr>
<td>Power</td>
<td>F=3.00IVV^1.50</td>
<td>0.34</td>
<td>0.26</td>
<td>0.09&lt;Error&lt;2.11</td>
<td>0.43&lt;R²&lt;0.90</td>
<td>0.63</td>
</tr>
<tr>
<td>Quadratic</td>
<td>F=45.45ldC^2+2.10ldC+0.05</td>
<td>0.21</td>
<td>0.19</td>
<td>0.05&lt;Error&lt;1.78</td>
<td>0.45&lt;R²&lt;0.95</td>
<td>0.71</td>
</tr>
<tr>
<td>Quadratic</td>
<td>F=328.62ηf^2-1350.212ηf+1536.46</td>
<td>0.20</td>
<td>0.17</td>
<td>0.03&lt;Error&lt;1.55</td>
<td>0.68&lt;R²&lt;0.96</td>
<td>0.81</td>
</tr>
</tbody>
</table>

**Results**

A non-significant difference (3.42±0.93%) was observed for normalized velocity between free and MAD-system conditions, while a statistical difference of 19.57±5.78% (F<sub>9,162</sub> = 380.76, P<0.05) was noted between normalized SF (Figure 2).

For the 10 bouts of free swimming, the ANOVA indicated an increase of velocity (F<sub>3,81</sub>=80.56, P<0.05), SF (F<sub>3,81</sub>=30.20, P<0.05), IdC (F<sub>3,81</sub>=9.64, P<0.05) and force (F<sub>9,81</sub>=50.27, P<0.05), and decrease of SL (F<sub>9,81</sub>=17.55, P<0.05), IVV (F<sub>9,81</sub>=4.14, P<0.05) and ηf (F<sub>9,81</sub>=11.94, P<0.05).

The results of the Pearson’s correlation, among all variables, are presented in Table I.

As the swimmers increased force production, the velocity (r=0.86, P<0.05), SF (r=0.82, P<0.05) and IdC (R=0.61, P<0.05) increased, and SL (r=-0.66, P<0.05), IVV (r=-0.57, P<0.05) and ηf (r=-0.60, P<0.05) decreased.

From the five tested regressions models, two were found as the most appropriated, both for individual (Table II) and polled analysis (Figure 3).

The relationship between force and velocity and IVV showed that a power regression was the most appropriate fit and, on the other hand, a quadratic regression was found as the best model between force and SF, SL, IdC and ηf.

**Discussion**

Force production in front crawl swimming has been considered as a main performance determinant, but its relationship with the most relevant biomechanical parameters lacks experimental evidence. The aim of the present study was to examine the relationships between force and stroking parameters (velocity, SF and SL), IVV, IdC and ηf, in front crawl swimming. The main findings of the present study were that high force production requires increases in SF and, consequently, in velocity. Coordination adaptions permitted high force outputs due to continuity of propulsive phases and, concomitantly, IVV decreases, avoiding velocity degradation. The linkage between force and SF, SL, IdC and ηf showed a quadratic dependence and a power regression model was found between force and velocity and IVV.

In the present study, the assessed mean values of propulsive forces were assumed to be equal to the mean drag forces obtained from measurements on MAD-system, once, for a constant velocity the mean propulsive force should be equal to the mean drag force acting on the swimmer’s body. In addition, the maximal force production in free swimming would be similar to the recorded force production when swimming on the MAD-system, a fact that was confirmed by the normalized velocity. Nevertheless, the normalized SF changed between the two conditions, being higher on the MAD-system due to the fixed SL, as previously described.

Concerning the stroking parameters, the correlation between force and velocity was positive and a quadratic dependence was observed. These data are in agreement with the literature, evidencing the importance of swimming velocity on force production, particularly with increasing velocity. Moreover, force produced by the swimmers showed to be positively influenced by SF increases, confirming previous investigations and consequently, lower SL. The quadratic linkage between force and these variables could be explained by the fact that, at early protocol stages (lower values of velocity), force production might mostly be due to the fast increase in SF, and consequent decrease in SL. After that, the increase in force production might be more dependent on combination of a slightly additional increase of SF and a vaguely maintenance of SL, similar to...
Figure 3.—Relationship between force and velocity (A), stroke frequency (B) stroke length (C), intracyclic velocity variations (D), index of coordination (E) and propelling efficiency (F) average for the ten swimmers.
the reported relation of these parameters with swimming velocity.\textsuperscript{1}

The inverse relationship of force and IVV highlighted the importance of propulsive continuity to achieve higher values of force production,\textsuperscript{4} and their non-linear relationship could be explained by the fact that the neuromuscular activation of several muscles in a multi-segment and multi-joint movement follows the curvilinear force-velocity relationship pattern for a single joint system.\textsuperscript{20} Such increase of propulsive continuity was concomitant with the rise of IdC values, presenting a quadratic relationship with force,\textsuperscript{21} corroborating that to produce higher force values swimmers modify their arm stroke. This changes in arm coordination reflect changes on reduction of relative duration of the non-propulsive phases that, consequently, lead to changes on SR and SL.\textsuperscript{15,22,23} This coordination, and consequent stroking parameters adaptations, might be interpreted has a response of the swimmer to produce force, demonstrating that its production is directly dependent on motor control and optimal coordination pattern, as a response to the imposed constraints (e.g., hydrodynamic drag).\textsuperscript{21}

The IdC changes enabled continuity between the propulsive phases, but this did not necessarily mean higher propulsion generation values since swimmers could slipped through the water. This fact could be explained by the observed inverse relationship, and negative quadratic dependence of force on $\eta_F$. A greater propelling efficiency is traditionally associated with a better capacity to produce force,\textsuperscript{1,24} but, since a high SF is required to generate force and $\eta_F$ was inversely related to SF, consequently a reduction of the propulsion effectiveness has occurred.

**Conclusions**

Optimization of force production required increases in SF and, consequently, in swimming velocity. Optimal coordination adaptations, enabling continuity of propulsive phases and IVV decreases were essential to produce higher values of force. However, these adaptations did not necessarily guarantee propulsion efficiency as observed by SL and $\eta_F$ decrease. Hence, the manipulation of the biomechanical variables might be one of the factors through which swimming force could be altered, emphasising the need of its evaluation, identification and intervention as a common practice both in swimming training and competition.

**References**


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Combined strength and step aerobics training leads to significant gains in maximal strength and body composition in women

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Aim. Examine the effects of 8 weeks of strength training program alone or combined exercise (step aerobics exercise and strength training) on Body Mass Index (BMI), waist circumference (WC), and maximal strength (1RM) in lower- and upper-body extremities.

Methods. Thirty-six women were randomized into three groups: strength training (S, N.=13; age: 61.0±9.3 years, BMI: 27.3±4.7 kg/m²), combined step aerobics training and strength training (SE, N.=11; age: 58.3±8.1 years, BMI: 27.8±3.7 kg/m²), or control (C, N.=12; age: 59.0±7.2 years, BMI: 29.5±4.8 kg/m²) groups. Subjects from both experimental groups performed 3 training sessions per week for 45-60 minutes per session. The S was submitted to a high-speed training that consisted of 40% to 75% of 1RM (3 sets 4–12 reps). The SE group combined aerobic exercise using step platform plus strength training.

Results. Both training groups significantly improved leg press (S, 80.7% and SE, 42.4%, P<0.001 respectively) and leg extension strength (S, 71% and SE, 35.7%, P=0.000 respectively). However, only the S group showed a significant increase in seated bench press maximal strength (S, +116.6%, SE, +13.6%, P=0.000 and P=0.000 respectively). Over the 8-week training period, the SE group showed significant changes in BMI and in waist circumference (-3.0% and -3.0 cm, P=0.005, respectively). No significant differences were found in the S or C groups.

Conclusion. Decreases in body fat and waist circumference were more evident following combined training. In contrast, higher strength gains particularly for the upper body occurred following 8 weeks of strength training alone compared to combined training.

Key words: Aged - Female - Training - Body Mass Index - Waist circumference.

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Age-related changes in body composition have been previously reported in older populations (i.e., increase in fat mass and decrease in muscle mass). 1,3 Impairment refers to the physiological mechanisms that include alterations in individual muscle fiber contractile properties and modifications in neuromuscular function. 2 Losses can lead to increase the risk of physical function and deterioration of strength performance especially in older women 4 as well as to an increase in metabolic disorders and mortality. Recently, muscular adaptation to resistant training as shown to be useful in strength gains with substantial improvements in dynamic exercises in upper and lower limbs (44.1-61.8%) over 12 weeks of training period in older people. 5

Abdominal obesity is also a key feature in cardiovascular risk assessment, a growing epidemic that affects more than 300 million people worldwide, 6 particularly in women after menopause. 7 In previous studies, waist circumference has been proposed as
the best simple anthropometric index of abdominal visceral adipose tissue accumulation in the elderly, being also related to heart and vascular risk.8-10

Aerobic training is one of the most popular exercises,11-13 but in women to our knowledge, no studies have observed the effect of step aerobics training combined with strength exercise on muscular performance and body composition. It is known that combined training may lead to lower strength or muscle power gains,14,15 as well as lower magnitude of endurance 15,16 compared with pure strength training programs or endurance alone. Nevertheless, the variability between exercise programs characteristics may partly explain some mixed findings.17

There are studies about different types of training in older women, but to date, we are unaware of any research investigating the whole-body combined training-induced pattern of strength response between the lower and, especially, the upper extremity muscles in previously untrained women. The aim of this innovative study was to examine the effects of 8-week of combined three-weekly step aerobics exercise and resistance training on maximal strength of the lower- and upper-body extremities and waist circumference (WC), compared with three-weekly strength training program alone and a control group. It was hypothesized that specific combined training in women would lead to similar gains in maximal strength of the lower-extremity muscles, but better improvements in body composition, compared with strength training alone.

Materials and methods

Participants

Thirty-six women volunteered (60.0±8.5 years old) to participate in this study. All participants fulfilled the inclusion criteria: living independently in the community, being without contraindications to cardiorespiratory fitness assessment and not having history of regular exercise. Before inclusion in the study, all candidates were thoroughly screened by a physician. Each woman also answered a face-to-face questionnaire addressing medical history and medication use.

Participants were then randomized into two training groups and one control group: strength training (S, N.=13; age: 61.0±9.3 years, BMI: 27.3±4.7 kg/m²), combined endurance and strength training (SE, N.=12; age: 58.3±8.1 years, BMI: 27.8±3.7 kg/m²), or control (C, N.=12; age: 59.0±7.2 years, BMI: 29.5±4.8 kg/m²) groups (Table I). Subjects were informed about any potential risks and/or discomforts associated with participation in the study and were required to complete informed consent form before being included in the study. All physical or psychological diseases that may have precluded ability to perform the requested training exercises and testing were considered exclusion criteria. The experimental procedures were approved by the University of Trás-os-Montes and Alto Douro, Department of Sport Sciences, following the Helsinki declaration.

Procedure

To test the stability and reliability of all variables, individuals were evaluated at same time and location and supervised by the same researchers at pre- and post-interventions. Subjects were evaluated twice before the start of training (two weeks before and at baseline), and this served as a control period. Tests were applied to both groups at two intervals: before the experimental period (T1) and after the 8-week experimental period (T2).

Anthropometric assessment

The anthropometric assessment was carried out in a separate room by a single trained examiner. A detailed description of the testing procedures has been given elsewhere.4 The waist circumference (WC) was measured with a flexible and inelastic measuring tape (Hoechstmass-Rollfix®, Germany) with a precision of 0.1 centimeters, taking the necessary care not to compress tissues. The WC was measured at the midpoint between the iliac crest and the last rib and was carried out at the end-expiratory position. The intra-class correlation coefficient (ICC) for BMI and WC was 0.91 and 0.93, respectively.

Strength Test

A detailed description of the testing procedures has been given elsewhere.4,17 In brief, lower- and upper-body maximal strength was assessed using one-repetition concentric maximum (1RM) actions in a leg press (1RM_{LE}), leg extension (1RM_{LE}) and in a bench-press (1RM_{BP}) position, respectively.
Specific warm-up was allowed consisting of 1 set of 5 repetitions at 40–60% of the perceived maximum. Separate attempts were performed to determine the one repetition maximum until the subject was unable to extend the leg and arm muscles to the required position. The intra-class correlation coefficient (ICC) for 1RM<sub>LP</sub>, 1RM<sub>LE</sub> and 1RM<sub>BP</sub> was 0.94, 0.95 and 0.93, respectively.

**HIGH-SPEED STRENGTH TRAINING**

The subjects included in the S group were asked to report to the training facility three times per week for 8 weeks, on nonconsecutive days. Each training session included 2 exercises for the leg extensor muscles (leg extension and leg press) and 1 exercise for the arm extensor muscles (the bench press) and finished with abdominal crunches and trunk extensors. An interval period of at least 2 min was permitted between sets and between exercises. During the first 2 week of the training period, the subjects trained with loads of 40–50% of the individual 1RM, 10-12 repetitions per set, and 3-4 sets of each exercise, and progressively increase to 75% of 1RM, 3 sets by 4–6 reps. Subjects were performing all exercises at high velocity, with instructions to do them “as fast as you can”.

**COMBINED STRENGTH AND STEP AEROBICS TRAINING**

The training protocol for the step aerobics group (SE) consisted of 3 sessions per week, 45 to 60 minutes per session for 8 weeks with the same certified instructor. The aerobic component within the training program included 30 minutes of cardiovascular exercises using a step platform. Each session included 10 minutes of warm-up and 20 minutes of step aerobics training. In the first 2 weeks of exercise, participants were initiated to the basic movements and choreography with continuous movement of legs and alternating movement of the arms (bicep curls and lateral raises at shoulder level and above the head) simultaneously with the selected steps. Exercise included movements of conventional basic step; “V”; “A”; “L”; turn step (right and left lead); alternating knee-lift, leg up and down; alternating kicks and lateral lunge. The aerobic session started with a work heart rate (HR) of 40-50% HR (1-3<sup>th</sup> week), increasing progressively to 50-70% HR (4-6<sup>th</sup> week),

---

**Table I.**—Physical characteristics of the control (C), strength (S) and combined endurance and strength (SE) training groups at baseline and after 8 weeks of training.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group</th>
<th>T1 ±σ</th>
<th>T2 ±σ</th>
<th>(T1-T2) P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>C (n=12)</td>
<td>59.0±7.2</td>
<td>59.1±7.2</td>
<td>0.877</td>
</tr>
<tr>
<td></td>
<td>S (n=13)</td>
<td>61.0±9.3</td>
<td>61.1±9.3</td>
<td>0.979</td>
</tr>
<tr>
<td></td>
<td>SE (n=11)</td>
<td>58.3±8.1</td>
<td>58.4±8.1</td>
<td>0.879</td>
</tr>
<tr>
<td>Body Mass (kg)</td>
<td>C</td>
<td>72.7±12.9</td>
<td>72.8±13.3</td>
<td>0.667</td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>66.8±12.0</td>
<td>67.2±11.3</td>
<td>0.413</td>
</tr>
<tr>
<td></td>
<td>SE</td>
<td>63.8±7.8</td>
<td>65.8±7.9</td>
<td>0.336</td>
</tr>
<tr>
<td>Total Standing Height (m)</td>
<td>C</td>
<td>1.56±0.08</td>
<td>1.56±0.07</td>
<td>0.989</td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>1.56±0.06</td>
<td>1.56±0.07</td>
<td>0.786</td>
</tr>
<tr>
<td></td>
<td>SE</td>
<td>1.57±0.04</td>
<td>1.57±0.03</td>
<td>0.765</td>
</tr>
<tr>
<td>BMI (kg·m⁻²)</td>
<td>C</td>
<td>29.5±4.8</td>
<td>29.6±5.0</td>
<td>0.696</td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>27.3±4.7</td>
<td>27.4±4.4</td>
<td>0.836</td>
</tr>
<tr>
<td></td>
<td>SE</td>
<td>27.8±3.7</td>
<td>26.3±3.6</td>
<td>0.016</td>
</tr>
<tr>
<td>WC (cm)</td>
<td>C</td>
<td>86.1±5.9</td>
<td>87.6±7.0&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.106</td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>83.9±9.9</td>
<td>84.1±10.1&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.733</td>
</tr>
<tr>
<td></td>
<td>SE</td>
<td>83.0±5.08</td>
<td>80.5±5.6</td>
<td>0.005</td>
</tr>
</tbody>
</table>

P (T1-T2)- P value between 2<sup>nd</sup> and 1<sup>st</sup> moment; BMI = body mass index. a weight-to-height ratio calculated by dividing one’s weight in kilograms by the square of one’s height in meters; C – Control Group. S – resistance training group. SE - combined endurance and strength training; ±Significant changes (P<0.05) between the groups; *P<0.05.C significantly different from S; †P<0.05.C significantly different from SE; ‡P<0.05. S significantly different from SE.
and then to 70-85% HR (7-8th week). The perceived exertion was 11 to 13 (6 to 20 point, Borg scale). Heart rate reserve was determined by the Karvonen formula.19 HR monitoring equipment (Accurex plus, Polar Electro Oy, Finland) was used to monitor and keep records during exercise. Music was selected to increase work heart rate and the cadence of the sessions was between 120 and 128 foot-strikes per minute. Then, subjects performed the same resistance exercise prescription applied to the S group. Each training session was closely supervised and monitored by two researchers, specialized in physiology and in aerobic-dance instruction to direct and assist each subject towards achieving the appropriate work rates and loads.

Statistical analysis

The Kolmogorov–Smirnov test was used to evaluate the normality of the distribution of the variables. The intra-individual reproducibility of the measurements was assessed by the intraclass correlation coefficient (ICC). Descriptive statistics (mean±SD) were calculated for all variables. To assess any differences among the three groups’ initial anthropometry or performance variables a one-way analysis of variance (ANOVA) was used. When significant differences were found, Tukey’s post-hoc test was used to identify which groups differed among them.

For the variables that did not pass the normality test, Kruskall-Wallis test and Dunn’s post-hoc test were used. Two-way ANOVA with repeated measures (groups x moments) was used to assess the training related effects. To establish statistical significance, a P<0.05 criterion was used. All data were analyzed using SPSS 17.0.

Results

At baseline evaluation, no significant differences (P>0.05) were observed between the exercise and control groups in any of the studied variables. From pre- to post-training period, the S group significantly increased (P<0.001) their dynamic strength performance in 1RM_{BP} (116.7%), 1RM_{LE} (71.0%) and 1RM_{LP}(80.7%), whereas the SE group also significant increased maximal strength performance but only in lower limbs (1RM_{LE}: 35.7% and 1RM_{LP}: 42.4%, P<0.001 respectively and 1RM_{BP}: 13.6%, P=0.266). No significant changes were observed for the C group (Table II). No significant changes (P>0.05) in height or body mass were observed (Table I) between the first (T1) and the second evaluation (T2) in all the groups. However, BMI showed a significant decrease between T1 and T2 only in SE group (-5.6%, P=0.016). Likewise, significant decreases (P<0.05) were observed only in the SE group for WC by -3% (-2.5 cm, P=0.005) (S: +0.2% and C: +1.7%, P=0.106 and P=0.733, respectively) (Table II).

Discussion

The primary findings of the present study demonstrated that 8 weeks of strength training alone is an effective way to enhance maximal dynamic strength with only two exercises of resistance training for upper and lower extremities per session. Additionally, combined step aerobics exercise and strength training was not effective in increase maximal strength in upper limbs but induced significant improvements in the body composition, mirrored here by the reduction in waist circumference.

Significant improvements in maximal dynamic strength in upper body extremity performed by bench press exercise were only observed in the S group. This suggests a positive effect of strength training on...
upper-extremity in women. Our findings agree with previous studies that used bench press exercise. Therefore, both S and SE training groups significantly improved lower-extremity strength (1RM_{LE}: 42.4-80.7% and 1RM_{LE}: 35.7-71%). Our results are comparable with recent studies on previously untrained women after 8-24 weeks of strength training.

As results achieved were greater in magnitude in bench press exercise it may indicate differential changes in activity patterns between upper and lower muscles and perhaps lesser strength in the arms compared to the legs. Moreover, the alternating movement of the arms during step workout could also cause greater weariness at the end of the aerobic training session, and, consequently, induce declines in muscle performance and self-motivation to perform the rest of the strength exercises. Thus, as the present study demonstrated, strength training alone is more favorable to increase muscular performance in upper extremity in women.

Relatively to body composition, there were significant changes in BMI and in waist circumference only in SE group. This can be partially explained by the efficacy of the combined training. Since step aerobic exercise does not appear to significantly prevent the age-related decrease in muscle mass and strength in the older population, the decreased that we observed may be explained by the loss of some fat mass. Previous studies on age-dependent height have suggested that an incorrect overestimation of adiposity may induce a false BMI by more than 2.5 kg/m² in women across aging, being a weak predictive indicator of obesity particularly in populations of short stature as the Portuguese. Nevertheless, as the accumulation of intra-abdominal fat seems to persist even without significant body mass changes, weight losses may be necessary, especially when the optimization of the musculoskeletal function in aging is essential. Results of the present study indicate that baseline WC values are above the threshold value for the European women (80 cm), which suggests an increased risk of cardiovascular disease. The present study has shown that combined training may potentially countering the age-related increase in abdominal fat (-2.5 cm) in older women and emphasizes the importance of concomitant training-induced changes in body composition in the prevention and treatment of metabolic risk factors. Ours results also contribute to a novel finding in the prescription of exercise especially to older obese individuals – aerobic workout using step platforms may have a better effect in mobilization of the major muscles groups in upper limbs, leading to better physical condition and also providing greater effects in weight loss.

Some studies related to the effects of step aerobics training on body mass and body fat percentage have failed to find any significant changes, although, as our study verified, strength training after step aerobics session may be essential to improve body composition. Thereafter, strength stimulus in combined training may help explain the additional beneficial outcome of muscular improvement in lower and upper extremities.

The first limitation constraint of the present study was that the fat and lean mass was not measured because BMI and waist circumference cannot predict total body composition. Also Karvonen formula was used to evaluate heart rate for older adults but this have some constraints in this population, in future studies different protocols should be used. A second limitation is that the level of functional capacity and balance of the participants were not measured. With this mind, further research with step aerobics training or multicomponent training should be developed in order to determine if this type of exercise could be applicable to older persons with balance problems or low functional fitness.

Conclusions
As a means of evaluating the specificity of each type of training proposed here, it seems that combined training can be a useful working tool for health and sports professionals, contributing to a better way of prolonging functional independence and quality of life in older adults.

Practical applications
Step aerobics training can be considered an effective exercise modality to prevent the loss of muscular performance and its associated consequences. Understanding the nature of combined or multicomponent training may help choreographers and professionals in sport science to develop exercise combinations that are more useful and helpful to increase strength in older people and to prevent the age-related changes in body composition.
**COMBINED STRENGTH AND STEP AEROBICS TRAINING**

**PEREIRA**

**References**


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**Conflicts of interest.**—The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

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Chronic effect of the combinations of resistance exercises with static stretching exercises on flexibility levels in trained men

C. L. Bastos 2, J. Vilaça-Alves 1,2, V. M. Reis 1,2, G. B. Tavares 3, T. M. Gomes 3, J. Novaes 3

Aim. Aim of the study was to investigate the effects of eight weeks of strength training, conducted with and without static stretching exercises (before and between sets of resistance exercises) on the flexibility in trained men.

Methods. Thirty subjects were randomly divided in three experimental groups: static stretching before resistance exercises (SSBRE); static stretching between sets of resistance exercises (SSBSRE); and strength training without static stretching (ST).

Results. A 3 (groups) X 2 (time) ANCOVA was performed and did not show any significant difference for the comparisons between the groups. For the analysis within groups, the results showed significant changes, between measurements times on the range of motion only on the horizontal adduction of the shoulder (20.12%, 12.46% and -8.56%, SSBRE, SSBSRE and ST, respectively), horizontal flexion with the knee joint flexed (8.04%, 2.39% and 6.35%, SSBRE, SSBSRE and ST, respectively) and medial rotation of the hip (0.48%, 28.30% and 8.79%, SSBRE, SSBSRE and ST, respectively). No significant interactions were observed between measurements times and groups.

Conclusion. Based on the present results, the flexibility of trained men increases on some shoulder movements with the use of SSBRE and SSBSRE and increases on some hip joint movements independently of the experimental protocols used.

Key Words: Resistance training - Muscle stretching exercises - Range of motion.

Muscle strength and flexibility are fundamental for a good physical and skeletal muscle function, contributing for the preservation of healthy muscles and joints, and a better quality of life.1

Therefore, both motor capacities should necessarily be included within any supervised training program.1

Performing stretching exercises alone seems to provoke significant chronic effects on strength performance.2,3 Kokkonen et al.3 observed increases up to 31% on the performance of the 1RM tests, after performing static stretching for eight weeks. On the other hand, Rees et al.2 using proprioceptive neuromuscular facilitation (PNF) stretching technique, observed increases on the maximal isometric strength (26%) and on the rate of force development (25%) for the plantar flexors muscles. Conversely, LaRoche et al.4 using static and dynamic stretching exercises, observed minimal increases on the peak torque of the extensor muscles of the hip, but not significantly different from those of the control group who had not perform any exercise for four weeks.

Studies with elderly of both genders have shown that the execution of isolated strength training (ST) causes significant increases on the flexibility of several joints. Barbosa et al.5 observed increases of nearly 13% in sedentary elderly when performing the sit and reach test after 10 weeks of ST. Similar results have been found by Fatouros et al.6 who observed significant increases on the flexibility, rang-
ing from 3% to 28%, in sedentary elderly men after 16 weeks of ST performed with different intensities.

However, the results of the studies, which used participants from different age groups, tended to be inconsistent. Monteiro et al.7 investigated the effects of resistance exercises (RE) on the flexibility in sedentary middle-aged women (35 to 39 years-old). The movements of the shoulder horizontal adduction, the flexion and extension of the trunk and the hip presented significant increases (37.3%, 146.2%, 135.6% and 15.4%, respectively) after 10 weeks of ST. Santos et al.8 observed that two orders of RE execution, the alternated segment and the agonist-antagonist orders, tended to promote identical increases (P<0.05) on the articular range of motion in sedentary women. While analysing the effects of RE, performed either alone or combined with stretching exercises, Simação et al.9 observed significant increases on all flexibility assessment comparisons, and concluded that the execution of RE alone caused significant increases on the flexibility. However, Nóbrega et al.10 have not observed significant differences in sedentary young people’s joint range of motion after 12 weeks of RE executed in an isolated manner. However, significant increases were observed in the flexibility specific training group (+33%; P<0.001) and in the flexibility and ST combined training group (+18%; P<0.001).

Ress et al.2 suggested that an increase on strength after the chronic execution of stretching exercises can occur through increases in the myotendinous unity, as a result of high mechanical stresses on the tendons and muscles. This mechanical stress contributes to changes in the collagen’s structure and promotes the hypertrophic process. However, the mechanisms responsible for the increase on flexibility as a consequence of chronic ST are not clarified in the literature. The possibility that has been proposed for such adaptation is based on the increase in the tendon and ligament’s tension in addition to the muscular strength increases and the muscle contractility that enable a wider joint range of motion.11

Even though some evidence has provided support for the chronic influence of ST on different joint’s flexibility, the chronic effect of the combinations in different moments of RE with static stretching exercises (SSE) in the same sessions, in trained adults, has not yet been investigated.

Therefore, the aim of the present study was to investigate the effects of eight weeks of ST performed in an isolated manner and combined with SSE (before and between sets of RE) on the flexibility of trained men.

### Materials and methods

#### Participants

Thirty male and physically active adults volunteered to participate in this study. The characteristics of the subjects are displayed in Table I. The inclusion criteria of this study were: A) to be physically active with at least one year of experience on the strength and flexibility exercises suggested on the study, with a frequency of four times a week; B) to not have any functional limitation that could influence the ST or the flexibility or the 8RM tests performance; and C) to not have/report any medical condition that could influence the tests’ results. The Ethical Committee of Research of the Clinical Hospital Gaspar Viana, Belém do Pará/Brasil approved this study with the process number 133/2010.

#### Experimental design

The present study was a longitudinal, randomized experiment with three groups that aimed to deter-

<table>
<thead>
<tr>
<th>Group</th>
<th>Variable</th>
<th>Mean±SD</th>
<th>P (SW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SBST</td>
<td>Age (years)</td>
<td>29.80±3.55</td>
<td>0.121</td>
</tr>
<tr>
<td></td>
<td>Body mass (kg)</td>
<td>78.97±7.19</td>
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</tr>
<tr>
<td></td>
<td>Height (m)</td>
<td>1.77±0.05</td>
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<tr>
<td></td>
<td>BMI (kg/m²)</td>
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<tr>
<td>SDST</td>
<td>Age (years)</td>
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</tr>
<tr>
<td></td>
<td>Body mass (kg)</td>
<td>72.39±10.23</td>
<td>0.883</td>
</tr>
<tr>
<td></td>
<td>Height (m)</td>
<td>1.70±0.06</td>
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<tr>
<td></td>
<td>BMI (kg/m²)</td>
<td>24.86±2.60</td>
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</tr>
<tr>
<td>ST</td>
<td>Age (years)</td>
<td>29.90±2.88</td>
<td>0.824</td>
</tr>
<tr>
<td></td>
<td>Body mass (kg)</td>
<td>85.05±8.75</td>
<td>0.198</td>
</tr>
<tr>
<td></td>
<td>Height (m)</td>
<td>1.74±0.06</td>
<td>0.800</td>
</tr>
<tr>
<td></td>
<td>BMI (kg/m²)</td>
<td>28.06±2.04</td>
<td>0.053</td>
</tr>
</tbody>
</table>

SD: standard deviation; BMI: Body Mass Index; P value (SW) Shapiro-Wilk normality test; SSST: static stretching before resistance exercises; SSBSRE: static stretching between sets of resistance exercises; ST: strength training without static stretching.
mine the effects of different ST programs on joint range of motion, in trained men. The intervention period of the study lasted for eight weeks, involving the execution of ST sessions in an isolated manner or combined with SSE. Before starting the training sessions, the recruited subjects (N.=30) were randomly divided in the following experimental groups: SSE before the RE (SSBRE; N.=10), who performed the static stretching protocol (SSP) for each primary motor muscle of the RE sequence in the beginning of each ST session; SSE between each set of RE (SSBSRE; N.=10), who performed the SSP before each exercise of the ST sequence; Strength Training (ST; N.=10): execution of the resistance exercises sequence without performing any type of SSE.

The initial strength and flexibility levels were measured 48 and 72 hours (test and retest) before the beginning of the training period. After the eight training weeks, the same tests were repeated in order to verify the effects of each experimental condition on the dependent variables.

**Strength training program**

The subjects performed ST for eight weeks, with a weekly frequency of three sessions, with a 48-hours interval between them, for a total of 24 sessions. The subjects performed vertical chest press (VCP); wide grip front lat pull-down (WGFLP); seated leg extension (SLE); seated leg curl (SLC); barbell curl biceps (BCB); triceps pushdown on the pulley (TPP); abdominal crunch (AC); and lumbar extensions (LE). Selected exercises were chosen in order to create a proper balance on the muscular development. Thus, agonist and antagonist training methods were used. In each RE, four sets of 8 to 10 maximal repetitions were performed with 90-second rest interval between sets. Abdominal crunch and lumbar extensions were performed for 15 and 20 repetitions per set, respectively. The training loads were adjusted to 8RM and gradually increased every time the subjects were able to perform 10RM in every set of each exercise. These changes were done until the minor limit of repetitions (8RM) was achieved.

**Static stretching protocol**

The stretching exercises were executed accordingly with the RE performed, using the static method. It was used one set for each SSE before RE by the SSBRE group and between each set by the SSBSRE. The SSE was performed while maintaining the position to a mild discomfort for 30 seconds. Static stretching was performed for the horizontal shoulder flexors and extensors, the knee flexors and extensors, the elbow, and the hip extensors (Figure 1).

**Flexibility measures**

The flexibility measurements were done using a goniometry technique (angular tests), in accordance
EFFECT OF RESISTANCE EXERCISES WITH STATIC STRETCHING EXERCISES ON FLEXIBILITY

BASTOS

Table II.—Articular range of motion values on all the experimental situations.

<table>
<thead>
<tr>
<th></th>
<th>SSBRE</th>
<th>SSBSRE</th>
<th>ST</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
<td>Pre</td>
</tr>
<tr>
<td>SE</td>
<td>61.20±16.94</td>
<td>69.90±13.00</td>
<td>59.80±13.05</td>
</tr>
<tr>
<td>SABD</td>
<td>174.00±17.91</td>
<td>187.30±6.57</td>
<td>170.90±9.47</td>
</tr>
<tr>
<td>HABS</td>
<td>32.30±12.35</td>
<td>38.80±15.77</td>
<td>34.50±8.02</td>
</tr>
<tr>
<td>HADS</td>
<td>100.20±17.80</td>
<td>118.60±9.22</td>
<td>99.20±19.61</td>
</tr>
<tr>
<td>LRS</td>
<td>75.20±21.10</td>
<td>93.40±5.17</td>
<td>80.50±7.28</td>
</tr>
<tr>
<td>MRS</td>
<td>59.10±14.36</td>
<td>64.80±13.54</td>
<td>62.60±14.97</td>
</tr>
<tr>
<td>EF</td>
<td>130.50±9.40</td>
<td>136.10±7.62</td>
<td>130.20±13.01</td>
</tr>
<tr>
<td>HFKF</td>
<td>109.50±8.72</td>
<td>118.30±7.44</td>
<td>113.20±11.41</td>
</tr>
<tr>
<td>HFKE</td>
<td>81.00±16.32</td>
<td>82.50±12.45</td>
<td>83.20±12.51</td>
</tr>
<tr>
<td>HE</td>
<td>23.90±11.64</td>
<td>26.90±5.88</td>
<td>24.40±8.46</td>
</tr>
<tr>
<td>HABD</td>
<td>42.50±13.09</td>
<td>49.00±11.62</td>
<td>37.70±7.21</td>
</tr>
<tr>
<td>LRH</td>
<td>34.80±8.78</td>
<td>37.90±8.94</td>
<td>30.20±7.54</td>
</tr>
<tr>
<td>MRH</td>
<td>41.40±8.51</td>
<td>41.60±9.43</td>
<td>31.10±6.03</td>
</tr>
<tr>
<td>KF</td>
<td>126.70±5.83</td>
<td>130.10±7.69</td>
<td>121.30±9.57</td>
</tr>
</tbody>
</table>

† P<0.01; ‡ P<0.05; N: without significance differences; M: effect moment; MxG: interaction moment group; G: differences between groups; JRM: joint range of motion; SSBRE: static stretching before resistance exercises group; SSBSRE: static stretching between sets of resistance exercises group; ST: performing resistance exercises without stretching exercises; SE: shoulder extension; SABD: shoulder abduction; HAB: horizontal adduction of the shoulder; LRS: lateral rotation of the shoulder; MRS: middle rotation of the shoulder; EF: elbow flexion; HFKF: hip flexion with knee flexed; HFKE: hip flexion with the knee on extension; HE: hip extension; HABD: hip abduction; LRH: lateral rotation of the hip; MRH: medial rotation of the hip; KF: knee flexion.

with the Norkin and White protocol, assessing a maximum amplitude of eight articular movements: 1) shoulder joint flexion; 2) shoulder joint extension; 3) shoulder joint horizontal abduction; 4) shoulder joint horizontal adduction; 5) trunk flexion; 6) trunk extension; 6) hips joint flexion; and 7) knee joint extension. With the exception of the trunk movements, all measures were collected in the right side. An experienced specialist measured the joint range motion with a 360° goniometer (Lafayette Goniometer Set, Sammons Preston Rolyan 7514, USA).

Statistical analysis

The data was processed by the SPSS 19.0 for Mac and presented as mean and standard deviation. Shapiro-Wilk, Levene and Mauchly’s tests were used in order to check, respectively, the normality, homogeneity and sphericity of the sample’s data variances. The intraclass correlation coefficient (ICC) was used to measure the repeatability on the strength tests (8RM) and the flexibility (goniometry). A 3 (groups) X 2 (time) repeated measures ANCOVA was performed with body mass and height as covariates. The significance level was established in 5%.

Results

All the flexibility and strength measures collected at the pre-test showed an excellent repeatability, with the ICC values varying between 0.90 and 0.98, respectively.

The analysis of variance did not show significant differences between groups. With respect to the within-groups analysis, results showed significant changes (P<0.05) in HABS (F=802.596; P=0.026; ηp²=0.183), HFKF (F=1478.968; P<0.001; ηp²=0.512) and MRH (F=297.253; P=0.041; ηp²=0.157) articular movements when compared with the before and after measurements times (Table II). In all these joints the range of motion increased between the pre and post-tests, with exception on HABS, for the ST group, who decrease 8.56%. It was not observed any significant interaction between measurements times and groups.

Discussion

The aim of this study was to examine the effects of eight weeks of ST performed in an isolated manner.

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or combined with static stretching exercises (before and between the RE sets) on the flexibility levels in trained men. Based on the obtained data, we could observe that only one movement for the shoulder joint (HABS) was positively affected by SSBRE and SSBSRE interventions and negatively by ST. Also, only two movements of the hip joint (HFKF and MRH) were positively affected by all the training protocols. The present results confirm previous studies,\textsuperscript{5-7,15} that showed that performing isolated ST could also promote significant increases on the joint range of motion performance.

Nevertheless, the present data does not confirm what has been previously reported by Nóbrega et al.,\textsuperscript{10} who have investigated the effect of 12 weeks of isolated ST, flexibility training, and the combination of both, on the joint range of motion in untrained subjects. These authors concluded that isolated ST didn’t promoted increases on any joint range of motion. According to them, in order to increase the joint range of motion, specific stretching exercises are needed. Nevertheless, the present study demonstrated that isolated ST promoted significant increases on the joint range of motion for the HFKF (6.35\%) and for MRH (8.79\%). The different stretching tests used on the studies may partly explain the different results obtained. More specifically, Nóbrega et al.,\textsuperscript{10} measured the flexibility by using the Flexitest, which is an extremely subjective test where a slight interpretation change could lead to different results on the evaluation within and between subjects. On the present study, flexibility was measured through angular goniometry tests, in accordance with the Norkin and White\textsuperscript{15} protocol, on which all the movements were executed on maximum range of motion. Also, on the present study, the participants were trained men and in Nóbrega et al.,\textsuperscript{10} study they were sedentary of both sexes. These differences may influence the different results observed between the present and Nóbrega et al.,\textsuperscript{10} study.

Barbosa et al.,\textsuperscript{5} observed significant increases in the sit-and-reach performance on elderly patients, attending a cardiac rehabilitation program, after ten weeks of ST. The average increase was 4 cm (1.6 inch) when the before and after measurements times were compared. On the present study, however, without significance difference, an increase of 46.12\% on the HE movement was observed. The no significance differences observed on this movement, on the present study, may be caused by the differences between groups on the baseline values of body mass and height.

Monteiro et al.,\textsuperscript{7} investigated the effects of 10 weeks of ST performed on a circuit method in middle-aged sedentary women and observed significant increases on the flexibility for the trunk, hips, and shoulder joints. Increases of 37.3\% for the HADS and 23.6\% for the HE were found. On the present study increases of 17.82\% for the HADS and 46.12\% for the HE were observed but without statistical significance. These differences may be explained by the different ST methods applied and the differences in baselines values mentioned before. While Monteiro et al.,\textsuperscript{7} used a circuit training method, the present study used a multi sets of RE with agonist/antagonist order method for each joint. Furthermore, the different levels of trainability of the participants may have also influenced the outcome results.

This investigation results are in accordance with the ones found by Fatouros et al.,\textsuperscript{16} on which eight subjects performed 16 weeks of ST. As in the present study, these authors verified significant increases (P<0.05) for the hip flexion movement. Nonetheless, it is important to underline that, on that particular study,\textsuperscript{16} the duration of the ST was two times longer, which may suggest that the increases on the flexibility levels observed in a larger number of movements by Fatouros et al.,\textsuperscript{16} may be due to the higher intervention period and, therefore, the bigger stretching volume.

Santos et al.,\textsuperscript{8} were the first to analyse if moderately intense ST improved sedentary women’s flexibility. The participants were divided in 3 groups: the agonist/antagonist group (AA), the alternating segment group (AS) and the control group (CG). Both groups (AA and AS) considerably increased their strength and flexibility during the intervention, when compared with the CG (P<0.05). The AS group increased their strength and flexibility more than the AA group (P<0.05), in all the measures. In brief, this study showed that sedentary young women’s flexibility could be improved after 8 weeks of resisted exercise.

After 16 weeks of training, Simão et al.,\textsuperscript{9} analysed the flexibility and strength gains in 80 sedentary women randomly divided in four groups: strength (N.=20), strength and flexibility (N.=20), flexibility (N.=20) and control group (N.=20). Flexibility was
assessed using the sit-and-reach test and strength was measured using the 10RM tests for the leg press and horizontal chest press exercises. Results showed that all experimental groups demonstrated significant improvements when compared to the baseline and the control group, although no difference was found between these three groups. In short terms, the authors demonstrated that the RE contributes to the improvement and maintenance of flexibility without including any type of stretching, but RE and stretching can be prescribed together in order to obtain better results.

The intensity of the ST is a determining factor for the flexibility increases on different joints, as a result of this exercise. Fatouros et al.\(^6\) aimed to investigate the effect of manipulating the resistance exercise intensity in 58 elderly divided in three groups: low (40% of the 1RM), moderate (60% of the 1RM) and high intensity (80% of the 1RM). The intervention time was 24 weeks. Based on the obtained results, percentage increases in the different joints flexibility depended on the exercise intensity. The low intensity group had a lower range of increase on flexibility (3-12%), when compared with the moderate and high intensity groups (6 to 22% and 8 to 28%, respectively). The authors observed significant increases in the movement range on the sit-and-reach test, and on the goniometry for the elbow flexion, the knee flexion, the shoulder flexion, the shoulder extension, the hip flexion and extension. No significant change was shown for the hip adduction, the hip abduction, or the shoulder adduction. Both the present study and Fatouros et al.'s\(^6\) study showed that ST could increase the range of motion during the hip flexion.

The physiological mechanisms that can be responsible for the increase on flexibility as a result of ST are not well understood, but several hypothesis have been suggested: 1) ST increases the tensile strength of the tendons and ligaments, increasing their mass and contractility, allowing for a higher movement range;\(^{11}\) 2) ST may increase the collagen’s turnover tax in different structures of the musculoskeletal system. Since the synthesis and degradation tax of the collagen fibers can be changed by physical activity, as a consequence of the increase of the mechanical stress applied along the longitudinal axis of the fibers, it is observed a decrease on the formation of cross-bridges, as it is evidenced on animals’ models. The decrease on the quantity of cross-bridges, especially on the tendon, allows a better deformation of this structure (extensibility), reducing this way the chances of rupture, in addition to easing the transmission of the force generated by the muscles to the bones, which would lead to an increase in the movement range.\(^{17}\) Moreover, a better force transmission, linked with specific ST adaptations, such as the increase of the capacity of generating muscular strength by the trained muscles and the reduction on the movement antagonistic muscles co-activation, can cause an increase on the movement range when this is performed actively.

The principal limitations of this study were the number of the participants, the differences at baseline on the body mass and height and the duration of the intervention’s programs. We propose the application of the same study design in more participants and longer intervention periods with homogeneous anthropometric characteristics.

**Conclusions**

In summary, the execution of all the experimental protocols caused significant increases on few joints movement’s flexibility in trained men, with the exception of HABS movement, in the ST group, that showed a significant decrease. The comparisons between the groups showed no significant differences between the executions of ST in an isolated manner or combined with SSE.

**References**


Conflicts of interest.—The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

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Effects of 24 weeks of strength training or hydrogymnastics on bone mineral density in postmenopausal women

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H. FURTADO 4,5, R. MENDES 1,3, V. M. REIS 1,3

Aim. The aim of this study was to investigate and compare the effects of 24 weeks of strength training or hydrogymnastics on bone mineral density in postmenopausal women.

Methods. Thirty one elderly women (66.9±6.1 years old) volunteered to participate in 24 weeks of supervised exercise, performed on three non-consecutive days a week. Participants were allocated into two groups according to their preferences: strength training (ST, N=14) and hydrogymnastics (HG, N=17). The bone mineral densities (BMD) at the femoral neck (FN) and lumbar spine (L1 to L4) were assessed at baseline and after 24 weeks of exercise.

Results. BMD levels at the femoral neck and lumbar spine significantly increased in the ST group (4.25% and 5.59%, respectively; P=0.001) and maintained (0.02% and 0.37%, respectively; P>0.05) in the HG group, with no differences between groups after 24 weeks of exercise (P>0.05).

Conclusion. These findings indicate that 24 weeks of strength training are effective in moderately increasing BMD at the femoral neck and lumbar spine in postmenopausal women, while the same period of hydrogymnastics tended to maintain these BMD-related levels. However, 24 weeks of exercise intervention were not sufficient to identify differences between exercise groups.

Key words: Exercise - Bone density - Women - Osteoporosis, postmenopausal.

The reduction of the bone mineral density (BMD) associated with a menopausal condition (i.e., osteopenia) has been recognized as an important public health issue that affects an increasingly number of aged women, since it can act as a precursor condition of osteoporosis. Although a reduction of bone mass is observable from the middle adulthood in some areas with a larger amount of trabecular bone, a drastic decline in BMD and a deteriorated bone micro-architecture occurs mainly in women aged over 55 years and/or entering the menopause.1 The osteoporosis condition associated with a physical functional decline is a risk factor of age-related fractures caused by falls, which are consequently linked to loss of autonomy, lower quality of life and elevated morbidity and mortality rates.2

Available evidence has suggested that physical activity is a nonpharmacological intervention that plays a crucial role in the prevention of osteoporosis,3-5 which may be explained by the fact that the extra tendons tension on the bone structure appears to be an important stimulus to osteogenesis,6,7 and an important determinant of BMD maintenance or increase.1,8-10 Those suggestions have been confirmed by longitudinal intervention studies that found positive exercise-related effects on BMD among men and women, especially when accompanied by exercise-induced changes in fitness.11,12

However, the type/mode and length of the exercise intervention needed to promote an adequate tension
in the bone structure still remains undetermined. More precisely, the controversy may be associated with the type and level of tension promoted by the different physical activities. For example, exercise effects can be caused by gravitational and reaction forces such as on walking, running and dancing or by muscular contractions such as swimming. Moreover, different types/modes of exercise may include weight-bearing (e.g., aerobics, strength training and individual/team sports) or non/minimal weight-bearing activities (e.g., swimming, hydrogymnastics and cycling). Regarding the length of the exercise intervention, some studies have suggested that physiologically significant improvements in BMD are only observable after a prolonged intervention period (i.e., one year). However, more recently, Marques et al. demonstrated that 8 months of ST were sufficient to increase the BMD at the trochanter and total hip of older women, and also suggested that this mode of exercise was more effective than aerobic exercise for inducing favourable changes in BMD. Given the above evidence and taking into consideration that the bone remodelling process/cycle takes approximately 4 to 6 months to complete in the adult skeleton, it is of great interest to investigate if lower length exercise interventions based on different mechanical loadings provide sufficient stimulus to increase BMD in postmenopausal women.

Therefore, the main purpose of the present study was to investigate and compare the effects of 24 weeks of ST or hydrogymnastics on bone mineral density in postmenopausal women.

### Materials and methods

#### Participants

Thirty-one, Caucasian, postmenopausal elderly women, with 66.9±6.1 years old, 73.70±10.38 kg of body mass and 155.10±10.05 cm height were assigned into two groups, according to their preferences and willingness to participate in a long-term intervention: strength training (ST, N.=14) and hydrogymnastics (HG, N.=17). All participants fulfilled the following inclusion criteria: living independently in the community, aged 55 or above, postmenopausal status, being without contraindications to physical activity and not reporting history of regular structured exercise. By the end of study, all participants attained more than 85% of the exercise sessions. The procedures were designed according to the Helsinki Declaration and were approved by the Institutional Research Ethics Committee (Table I).

<table>
<thead>
<tr>
<th>Procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prior to the baseline measurements, all participants were informed of the aims of the study/intervention and provided a signed informed consent. A PAR-Q questionnaire and a medical and exercise history questionnaires were also administered and completed at this moment. Anthropometric measures were recorded in light clothing through the use of a portable stadiometer (Sanny®, model ES2030, Brazil) with a precision of 0.1 cm and a portable scale (Tanita®, model BF-562, Japan) with a precision of 0.1 kg. The resting heart rate of women in the HG group was measured by palpating the radial pulse for 60 seconds, after being quietly sat during five minutes. On the other hand, the one repetition maximum (1-RM) tests of exercises using additional weights were performed based on the Knutzen et al. recommendations. Participants completed two weeks of familiarization with the equipment, prior to the strength testing, and were advised regarding the execution of proper technique. Participants of both groups were instructed not to change their nutrition and social practices during the 24 weeks of intervention.</td>
</tr>
</tbody>
</table>

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### Table I.—Mean±SD of bone mineral density (BMD) levels in the Strength Training and Hydrogymnastics groups at baseline and after 24 weeks of exercise.

<table>
<thead>
<tr>
<th></th>
<th>Strength Training</th>
<th>Hydrogymnastics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Baseline</td>
<td>After 24 weeks</td>
</tr>
<tr>
<td>Femoral neck (g/cm²)</td>
<td>0.880±0.12</td>
<td>0.917±0.13</td>
</tr>
<tr>
<td>Lumbar spine (g/cm²)</td>
<td>0.836±0.11</td>
<td>0.883±0.10</td>
</tr>
</tbody>
</table>
Bone mineral density assessment

Bone densitometry was conducted using a Discovery Wi (Hologic Inc., Bedford, MA, USA) dual-energy X-ray absorptiometer, and measurements were taken at the left femoral neck and the first four lumbar vertebrae (L1-L4) of the spine (anteroposterior plane). BMD results were calculated by dividing the bone mineral content by the bone area, and expressed in g/cm². DXA calibration was executed according to the manufacturer’s specifications. All scans were performed by the same certified technician for each participant at baseline and after 24 weeks.

Exercise programs

Both exercise prescription and programming were planned in order to promote the functional fitness and designed according to recent guidelines for the geriatric population. Exercise classes were conducted three times per week on alternate days, with each session lasting for about 45 minutes, including warm-up and cool down. Exercise programs were conducted by certified and experienced fitness instructors.

Each session of the ST group began with a 5-10 minute cardiovascular warm-up, followed by resistance training exercises and ending with a 5-10 minute stretch/cool down. During the first 12 weeks, women performed the following exercises: squats with dumbbells, rowing with dumbbells, leg curl, vertical chest press, leg standing calf raise with dumbbell, dumbbells shoulder press, biceps curl with dumbbells, seated dumbbell triceps extension, abdominal crunch and lumbar extensions. During the first two weeks of the ST, a higher emphasis was placed on the proper and safe execution of each exercise. During the training period, women were required to perform three sets of the first eight exercises previously mentioned: 10 repetitions with a load of 70% of 1-RM (1st day), 8 repetitions with a load of 80% of 1-RM (2nd day) and 12 repetitions with a load of 60% of 1-RM (3rd day). With respect to the abdominal and lumbar extensions exercises, women performed three sets of 20 repetitions. There were 1 minute rest periods between all exercises and 3 minutes rest periods between sets. The weight load was increased by 5% every 3 weeks. During the second phase of the intervention (13-24th weeks), the ST program included exercises that replicated possible/typical daily activities and needs. During this period, women performed the following exercises: wall squat, chair squat, wall push-ups, raising a 1 kg weight from the ground and placing it on 1.6 meter high shelf, stair climbing and descending, a simulated car entry and exit, carrying grocery-like bags with a total of 3 kg for a distance of 5 meters, abdominal crunch and lumbar extensions. Women performed three sets of 30 seconds for each one of the first seven exercises. For the abdominal and lumbar extensions exercises, women were required to perform three sets of 30 repetitions each. The rest periods and weight load increase (in exercises using additional weights) adopted in the first phase were maintained during the second phase of the intervention.

Regarding the HG, each session included 10 min of stretching and warm-up, 30 min of shallow water endurance-type exercises and 5 min of cool-down/relaxation, at a public indoor swimming pool with a water depth of 1.20-1.40 m and a water temperature of 30.5 °C. The training zone was individually determined using the heart rate reserve as determined by the Karvonen formula. On each session, 4 women were randomly selected to wear heart rate monitoring equipment (Polar®, model FT1, Finland) and were instructed to attain 70 to 80% of their work heart rate. The pace of the exercises was determined by appropriate synchronous music selected by the certified fitness instructor. During the first 12 weeks, the cardio workout consisted of consecutive bouts of a combination of movements, such as forward, backward and side walking, kicking, knee up, twisting, shoulders’ adduction/abduction, elbow flexion, and squats. During the second phase of the intervention (week 13 to week 24), the main component of the classes also included the use of aqua gloves and flotation devices, and the practice of waterpower workouts in chest-deep water.

Statistical analysis

The data was processed by the SPSS 21.0 for Mac and presented as mean±SD. Two way (groups x moments) repeated measures ANOVA was performed to investigate the exercise related effects. Partial eta-squared values ($\eta^2_p$) were reported as measures of effect size according to the following rule of thumb: small (>0.01), medium (>0.06) and large (>0.14). Shapiro-Wilk, Levene and Mauchly’s tests were
used in order to check, respectively, the normality, homogeneity and sphericity of the sample’s data variances when performing the ANOVA, and none of the assumptions was violated. Percent changes (Δ%) from baseline to week 24 were calculated through the differences in the scores. Follow-up paired t tests were conducted to compare pre and posttest difference scores for each group separately. The significance level was established at 5%.

Results

At baseline, there were no between-group significant differences in BMD at the femoral neck (P=0.624) and lumbar spine (P=0.140).

For the BMD at the femoral neck, the repeated measures ANOVA revealed a significant effect for the interaction between groups and time (F=5.52; P=0.026; η²=0.16) and the main effect of time (F=5.63; P=0.025; η²=0.16), but not for the main effect of groups (F=0.00; P=0.998; η²=0.00). Follow-up paired t tests revealed that the BMD levels at the femoral neck significantly increased (4.25%; P=0.001) in the ST group and maintained (0.02%; P=0.989) in the HG group.

Regarding the BMD at the lumbar spine, the repeated measures ANOVA revealed a significant effect for the groups-time interaction (F=11.31; P=0.002; η²=0.28) and the main effect of time (F=15.00; P=0.001; η²=0.34), but not for the main effect of groups (F=0.97; P=0.333; η²=0.03). Follow-up paired t tests revealed that the BMD levels at the lumbar spine significantly increased (5.59%; P=0.001) in the ST group and maintained (0.37%; P=0.678) in the HG group.

Discussion

The data of the present study showed that ST was an effective exercise intervention in improving the BMD in 24 weeks in postmenopausal elderly women. These findings support those referenced by Bemben and Fetters, suggesting that ST contributes to the overload of clinically important body sites (spine, hip, wrist) while also giving the extra skeletal benefits of improving muscular strength and balance, which are associated with a reduced risk for falls. Walls et al. indicated on their meta-analysis study that ST programs tend to prevent or reverse bone mass loss by almost 1% per year in the lumbar spine and femoral neck, when compared with the control groups, which is of great significance from a clinical point of view, since the risk ratio for hip fracture increases with a reduction of one standard deviation in BMD in elderly women.

The significant changes in BMD in the ST group may be related to the extra tension of the tendons on the bones structures that promote the osteogenesis. On the other hand, in the aquatic environment, the effect of thrust on an immersed body tends to reduce this extra tension who is an important stimulus to osteogenesis. Another aspect to be considered is that the eccentric muscle contractions are lowered or even null in water environment. The lack of these types of muscle actions causes less tension of the tendons on the bone, when compared with the same movement performed in land. Consequently, it has been suggested that intense/high impact exercise programs are needed to increase bone mineral density in postmenopausal women, preferably weighed against other popular and applicable exercise programs such as aerobic classes, Tai Chi, and walking, which appear to be easier to adhere to, but are less effective on the osteoporosis prevention in this geriatric population.

On the other hand, Rotstein et al., observed significant differences in the BMD at the lumbar spine of postmenopausal women who performed hydrogymnastics for 7 months, with a weekly frequency of three times, but not in the femoral neck. The depth of the pool may be one of the factors that could help explain these results. On the present study and in Rotstein et al., a 1.40m of depth was used. This depth allows a fewer interference of thrust on the upper limbs, which have muscles with insertions in the lumbar spine and consequently a higher tension on these structures. This fact may be one of the possible reasons why in the HG group, on the present study, the BMD in the lumbar spine did not change.

Kemper et al., did not observed significant differences in the BMD at the femoral neck and lumbar spine, after 24 weeks, either in the group that
performed ST or in the group that performed swimming. The results observed by Kemper et al., 6 are not in accordance with the present study on the ST. This fact may be related with the methodology of the ST. In the Kemper et al. 6 study, the load was increased every four weeks in all exercises, while in the present study, there was an increment of 5% of the initial 1RM load, every three weeks. However, in the study performed by Korpelainen et al., 26 no significant difference was observed in the BMD of the femur bone, between and within exercise and control groups, after 30 weeks of exercise intervention, even in the exercise group which performed high intensity exercises. The possible reason may be related with the fact that these exercise sessions were performed at home without specialist supervision. This fact probably promoted a low control of the load and intensities of the exercises and sessions. The load is an important factor to promote tension on the tendon muscle structure. The use of a load of about 80% of 1RM or more with a partial range of motion appears to be beneficial on the promotion of the osteogenesis. 27, 28

On the other hand, the period comprised between 12 to 24 weeks of ST, on the present study, it was used a combination of traditional ST exercises with activities that simulated daily life functions. These exercises involved muscle groups that were part of the femoral neck and lumbar spine structures and were performed with fast movements for 30 seconds. Stengel et al. 29 used ST exercises that also involved fast movements and also observed positive effects on the BMD in postmenopausal women. The use of this methodology may promote a higher tension of the tendons in bones structures, and thereby promote the osteogenesis. Therefore, the length of 24 weeks of the ST program alongside an average load of about 80% of the 1RM, or more, with a partial range of motion, using concentric and eccentric muscle actions performed with fast movements, seems to provide an effective methodology for promoting BMD levels at some body sites.

Some limitations of the present study should be acknowledged. Firstly, it was not possible to recruit an adequate control group to be followed with no alteration in exercise practices. Secondly, and although women were instructed to maintain their nutrition routines, no assessment of dietary supplement intakes was performed throughout the study.

Conclusions

In conclusion, the present findings indicate that 24 weeks of strength training are effective in moderately increasing BMD at the femoral neck and lumbar spine in postmenopausal women, while the same period of hydrogymnastics tended to maintain these BMD-related levels. However, 24 weeks of exercise intervention were not sufficient to identify differences between exercise groups.

References


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Conflicts of interest.—The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

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Psychological responses to resistance training in middle-aged and older women

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H. FURTADO 3, 4, D. OLIVEIRA 1, 2, F. J. AIDAR 1, 2, F. SAAVEDRA 1, 2

Aim. The aim of the present study was to investigate the effects of resistance training on selected psychological variables (perception of health status, body satisfaction, life satisfaction, and depression) in elderly women.

Methods. A total of 14 women, aged 55 years and above (M=63.36, SD=4.47), volunteered to participate in a 24 weeks supervised exercise intervention, three times a week on alternate days. During the first 12 weeks, women performed sets of calisthenics and weight-lifting exercises with dumbbells. During the second phase of the intervention (13-24th weeks), the strength training program also included sets of possible/typical daily living activities/tasks and needs (e.g., raising and placing weights on high shelves, stair climbing and descending, simulated car entry and exit, and carrying grocery-like bags). Measures were assessed at baseline, after 12 and 24 weeks.

Results. Within-subjects analysis indicated no significant differences between baseline and week 12 scores. Between week 12 and week 24, significant differences were found in the perceived health status (P=0.046) and depression scores (P=0.041), but not in body satisfaction and satisfaction with life.

Conclusion. These results indicate that resistance training promotes significant improvements in the perceived health status and reductions in depressive symptoms, and suggest that resistance exercises based upon the middle-aged and older women’s daily living tasks/demands and needs may be a more efficacious and beneficial type of exercise for their well-being.

Key words: Resistance training - Mental health - Women - Activities of daily living - Longitudinal studies.

The beneficial effects of regular physical activity (e.g., unstructured daily activities such as walking, jogging, and cycling) and exercise participation on the physical, social and mental health of elderly individuals are well documented.1-5 Although much of this evidence has been based on aerobic-based activities or exercise programs, the recent guidelines for older adults recommended by the American College of Sports Medicine (ACSM) and the American Heart Association (AHA) have placed additional emphasis on muscle-strengthening activities, with the aim of promoting and maintaining health and physical independence.6

However, despite this evidence and recommendations, epidemiological research indicates that a considerable number of elderly individuals is not regularly involved in physical activity or fails to achieve the international recommendations.6-9 From a public health perspective, this is problematic since a large percentage of this population has at least one chronic disease and represents the highest proportion of health care use.10 Moreover, loss of independence and reduced well-being related to impaired functioning are one of the most distressing factors associated with the aging process.11

Nevertheless, the available descriptive evidence
suggests that, besides walking and jogging, weight-lifting or strength training are among the most preferred and practiced exercises by middle-aged and older adults, although the prevalence rate for resistance exercise is lower than average young adult participation levels. Albeit available data on gender specific participation is scarce, one may assume a lower proportion of female participants.

Within the physical activity and well-being literature in older adults, a great extent of available studies has reported results without separating men and women. At the same time, of the 36 intervention studies these authors reviewed, only seven were performed with women only. Research shows that women have higher life expectancies, higher rates of morbidity, and report more mental health problems (e.g., depression), lower levels of perceived health status and life satisfaction, which in turn may lead to higher and more costly medical care services.

Given this evidence, more research is warranted to investigate the psychological responses of this geriatric population to a supervised progressive strength training program. In order to provide further insight into the plausible effects of resistance training in middle-aged and older women, different conditions/means of resistance were prescribed and incorporated into the two phases of the long-term intervention (1-12th weeks and 13-24th weeks). Usually, most of the strength training programs for women suggest the use of free weights such as dumbbells and ankle cuff weights or elastic bands and body weight as the means of resistance. Given the specific nature of adaptation to exercise and the need for maintaining muscle mass and muscular strength in this period of life, one may advocate for an exercise prescription that also includes possible/typical daily living activities/demands and needs (e.g., raising and placing weights on high shelves, stair climbing and descending, simulated car entry and exit, and carrying grocery-like bags), which represent increasingly difficult daily motor tasks during the aging process.

Therefore, the present study aimed to investigate the effects of resistance training on selected psychological variables (perception of health status, body satisfaction, life satisfaction and depression) in elderly women. More specifically, changes in the outcome measures were analyzed after the first (1-12th weeks) and the second phase (13-24th weeks) of the exercise intervention.

Materials and methods

Participants

Initially, a total of fifteen middle-aged and older women volunteered to participate in the present longitudinal intervention study. However, since one participant moved away to a different country, only fourteen women (N.=14) completed all of the assessments and were then analyzed. Participants ranged in age from 55 to 69 years (M=63.36, SD=4.47). At baseline, 78.6% of the women were married or de facto and 21.4% were widowed or divorced. The women’s mean height and body mass values were 1.55±0.06 m and 67.91±7.94 kg, respectively, and the body mass index (BMI) was 28.24±2.76 kg/m². Women were eligible to participate in the study, providing they met the following inclusion criteria: age 55 or above, postmenopausal status, absence of diagnosed neurodegenerative or neuromuscular disorders, nonexistence of medical contraindications to physical activity, and not having participated in any structured exercise program in the two-year period previous the present study. Participants were recruited in a northern coastline region of Portugal, and invited to participate in the exercise program through local community advertising, namely in newspapers and in socio-cultural organizations for seniors. No sample size was determined at the beginning of the study.

Instruments

Self-reported health status was assessed using a single item question that asked women to rate their health status using a 10-point scale ranging from 1 (very poor) to 10 (excellent). Body satisfaction was evaluated by one question (“How satisfied are you with your body/appearance?”) using a 10-point response scale (1: very dissatisfied to 10: very satisfied). Satisfaction with life was measured using the self-report measure developed by Diener et al., which contains 5 items responded on a 7-point scale ranging from 1 (strongly disagree) to 7 (strongly agree). The range of possible scale scores is from 7 to 35. In the present study, Cronbach alpha values varied between 0.79 and 0.84. To assess scores of depression symptoms, the Beck Depression Inventory (BDI), originally developed by Beck et al., was used. The BDI consists of 21 symptoms rated on a 4-point se-
During the first 12 weeks, women performed the following ten exercises: squats with dumbbells, rowing with dumbbells, leg curl, vertical chest press, leg standing calf raise with dumbbell, dumbbells shoulder press, biceps curl with dumbbells, seated dumbbell triceps extension, abdominal crunch and lumbar extensions. A higher emphasis was placed on the proper and safe execution of each exercise during the initial phase of the strength training (about two weeks). For the first eight exercises, women were required to perform three sets of repetitions as follows: 10 repetitions with a load of 70% of 1-RM (1st day), 8 repetitions with a load of 80% of 1-RM (2nd day) and 12 repetitions with a load of 60% of 1-RM (3rd day). For the abdominal and lumbar extensions exercises, women were required to perform three sets of 20 repetitions. Interval periods of at least 1 and 3 minutes were assured between exercises and sets, respectively. The weight load was increased by 5% every 3 weeks.

During the second phase of the intervention (13-24th weeks), the resistance training program was designed towards possible/typical daily living activities and needs. During this period, women performed the following exercises: wall squat, chair squat, wall push-ups, raising a 1 kg weight from the ground and placing it on 1.6 meter high shelves, stair climbing and descending, a simulated car entry and exit, carrying grocery-like bags with a total of 3 kg for a distance of 5 meters, abdominal crunch and lumbar extensions. For the first seven exercises, women were required to perform three sets of 30 seconds for each exercise. For the abdominal and lumbar extensions exercises, women were required to perform three sets of 30 repetitions each. The previous interval periods and weight load increase were maintained during this phase. Participants’ overall adherence rate was higher than 85%.

Statistical analysis

Descriptive statistics of data were presented as mean (M) and standard deviation (SD). Percent changes (Δ%) from baseline to week 12 and from week 12 to week 24 were calculated from the differences in the scores. Skewness and kurtosis coefficients were computed for univariate normality analyses purposes, and all values were within ±2. The internal consistency of the measured scales
was estimated using the Cronbach’s alpha. Within-subjects ANOVAs were performed to investigate exercise-related changes in the outcome measures over time. Post-hoc tests with Bonferroni adjustment for multiple comparisons were used to identify pairwise differences. Partial eta-squared values ($\eta_p^2$) were reported as measures of effect size, with values higher than 0.01, 0.06 and 0.14 representing small, medium, and large effects, respectively.\textsuperscript{19} The level of significance in this study was set at $P<0.05$. All statistical analyses were conducted by using SPSS (version 16.0, SPSS Inc., Chicago, USA).

Results

The descriptive results of the outcome measures at the three assessment moments are shown in Table I. Mauchly’s test of sphericity indicated that the assumption of sphericity was not violated for these data ($P>0.05$). The repeated measures ANOVA revealed a large significant effect of time on perception of health status ($F_{(2,26)}=4.73, P=0.018, \eta_p^2=0.27$) and on depression scores ($F_{(2,26)}=4.90, P=0.016, \eta_p^2=0.27$), but not on body satisfaction ($F_{(2,26)}=1.04, P=0.368, \eta_p^2=0.07$) and satisfaction with life ($F_{(2,26)}=1.16, P=0.331, \eta_p^2=0.08$). Pairwise comparisons indicated no significant differences between baseline and week 12’s scores. Between week 13 and week 24, results indicated significant improvements in the perceived health status (+15.13%, $P=0.046$) and reductions in the depression scores (−17.95%, $P=0.041$).

Discussion

The aim of the present study was to investigate the effects of resistance training on selected psychological variables (perception of health status, body satisfaction, life satisfaction and depression) in elderly women. The main findings of the present study were that: i) 24 weeks of supervised resistance training promoted beneficial changes in health perception and depressive symptoms scores and ii) significant changes in these outcome measures were only found in the second phase (13–24th weeks) of the intervention.

Although accumulated research has demonstrated a link between physical activity and diverse psychological benefits, available evidence on the specific effects of nonaerobic modes of exercise, especially among older people, is limited and has provided mixed findings. While some meta-analytic findings have supported the superiority of aerobic exercise, others have provided a larger effect size for anaerobic/resistance training \textsuperscript{1} or similar positive effects.\textsuperscript{3, 21, 22} In addition, one other meta-analysis showed no significant effect of resistance training on mood improvement.\textsuperscript{23} In light of this, the present study’s findings provide evidence to support the effectiveness of 24-weeks of supervised resistance training in improving psychological outcomes.

The descriptive results of the outcome measures at baseline, after 12 weeks and after 24 weeks of resistance training are presented in Table I.

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>After 12 weeks</th>
<th>After 24 weeks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perception of health status</td>
<td>6.43±1.78</td>
<td>7.07±1.69</td>
<td>8.14±1.46</td>
</tr>
<tr>
<td>Body satisfaction</td>
<td>8.00±1.92</td>
<td>7.93±1.00</td>
<td>8.50±1.40</td>
</tr>
<tr>
<td>Satisfaction with life</td>
<td>28.21±7.59</td>
<td>29.36±4.33</td>
<td>30.50±4.83</td>
</tr>
<tr>
<td>Depression</td>
<td>21.71±7.31</td>
<td>21.50±5.63</td>
<td>17.64±3.18</td>
</tr>
</tbody>
</table>

Table I.—Descriptive results ($M\pm SD$) of the outcome measures at baseline, after 12 weeks and after 24 weeks of resistance training.
elderly since age-related loss of functional capacity, autonomy and independence are usually associated with a poorer mental health status.\(^2, 11, 30\)

As a result, at least two factors may help explain the observed beneficial effects of resistance training among this geriatric population. First, muscle-strengthening activities might provide the necessary stimulus to improve daily functioning.\(^1, 6\) and, consequently, promote an overall well-being improvement.\(^3\) Secondly, perceived improvements in the functional capacity have been proven to provide a mastery experience among this population, enhancing their physical self-efficacy, which in turn leads to improved mood.\(^3, 29, 31\) This argument receives additional support from the fact that significant improvements were only found in the second phase of the intervention, which emphasized possible/typical daily living activities/tasks that are increasingly more difficult to perform during the aging process. Furthermore, this evidence suggests the need to include an informational component in similar programs for middle-aged and older adults that provides detailed testing, comprehensible explanations and feedback on physical function improvement.\(^28\)

On the other hand, the absence of resistance training effects on body satisfaction and life satisfaction scores may be explained by the relatively high values obtained at the baseline assessment, which may have resulted in a ceiling effect and, therefore, reduced the sensitivity of these general, non-domain specific, measures to identify significant changes during the intervention.\(^3\)

However, when interpreting the findings of the current study, some limitations should be considered. Firstly, the reduced size of the sample obtained may have lead to an underestimation of the intervention effects. Secondly, the sequence of the intervention phases may have affected the changes in the outcome measures. Therefore, future research should investigate if an exercise order/intervention phase effect mediates the psychological responses to resistance training among middle-aged and older women. Thirdly, in order to overcome the absence of an adequate control group and the quasi-experimental design of the present study, future research is needed to evaluate the effectiveness of this exercise mode in older adults using randomized controlled trial designs and controlling for other possible influential factors (e.g., living alone).

Conclusions

In summary, our results indicate that 24 weeks of resistance training promotes significant improvements in the perceived health status and reductions in depressive symptoms in middle-aged and older women. Moreover, the findings of the present study suggest that resistance exercises based upon this population’s daily living tasks/demands and needs may be a more efficacious and beneficial type of exercise for their well-being. Therefore, it is recommended that future research and intervention efforts should give emphasis to the weight training based on daily motor tasks and needs, which has demonstrated to improve mental health and appears to be (more) appreciated by middle-aged and elderly women. Based on the evidence of the present study, one also suggests that this means of resistance exercise may contribute to a more practical dissemination and acceptability of this training modality among the female geriatric population.

References


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Conflicts of interest.—The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

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