TRANSFER OF POST-INERTIAL TRAINING GAINS TO FUNCTIONAL FITNESS OF PHYSICALLY ACTIVE OLDER WOMEN

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Abstract

The aims of this study were to estimate the influence of inertial training on knee extensor muscle strength and power and evaluate the effect of that training on functional fitness in physically active older women. Twenty-two physically active women ages 58-70 years were randomly divided into a training (T) and a control groups (C). The T group performed inertial training using the ITMS three times per week for five weeks. Each training session included three exercise sets involving the knee extensor muscles. The 30-second chair stand, 8-ft up-and-go, and stair climbing tests were used to estimation of functional fitness. Significant post-training increases of average force (55%) and power (62%) were noted in the T group ($p \leq 0.05$). No significant magnitudes of changes were observed in the C group. Changes in functional tests did not differ significantly between T group (2.9-5.6%) and C group (0.6-5.4%). Post-training changes on ITMS were not significantly correlated with changes in functional tests. Inertial training proposed here induced significant improvements in knee muscle strength and power in physically active older women, but the transfer of post-training gains to functional fitness was poor. It seems that the 30-second chair stand, 8-ft up-and-go, and stair climbing tests are undemanding tests for women with very good functional mobility and further study to estimate post-inertial training transfer should be done using more demanding tests for this sub-population.

Keywords: *strength training, elderly, functional tests*

Introduction

Relatively high levels of muscle strength and power facilitate maintaining independence in daily-life activities in older people, and lower body weakness has been associated with an increased incidence of falls (Hunter et al., 2004; Moxley Scarborough et al., 1999). Therefore, various strength and power methods should be applied in the elderly. One of these methods is inertial training using gravity-independent devices. During inertial exercises, repeated series of stretch–shortening cycles occur, i.e., muscle eccentric action precedes a concentric action. This eccentric–concentric coupling stimulates the body’s proprioceptors and muscle elastic properties to generate maximal force output in a minimal amount of time (Wilk et al., 1993). Inertial training induces significant improvements in elbow, shoulder, and knee muscle strength and power in young and middle-aged people (Illera-Domínguez et al., 2018, Naczk et al., 2014, 2016a, 2016b; Nunez et al., 2018, Romero-Rodriguez et al., 2011; Tesch et al., 2004). Such training also elicits significant increases in strength and power of shoulder joint muscles and power of knee extensors in older women (Brzenczek-Owczarzak et al., 2013; Onambele et al., 2008), and maximal force of elbow and knee muscles in elderly nursing home residents (Naczk et al., 2020).

Inertial training involves special devices that reduce the influence of gravitation on the skeletal system. Thus, this training method is relatively safe and can be used for muscle strength and power improvement in older people. Another factor that enhances safety is the application of tonic technique during inertial exercise. In the current study the Inertial Training and Measurement System (ITMS) was used. Software associated with ITMS enables registration of the number of cycles and the force and power developed during specific training tasks.

It is known that in older people population resistance training should be carried out to improve functional fitness and make activities of daily living more easy to perform. Activities such standing up, sitting down, stair climbing, and walking depend mainly on the strength and/or power of leg extensors (Hughes et al., 1996; Moxley Scarborough et al., 1999) and it is justified to train these muscles to increase muscles potential. However, it should be noted that the transfer of post-training gains to everyday functional tasks does not always happen in the elderly (Brandon et al., 2000; Earles et al., 2001; Skelton et al., 1995). One of the reasons of such inconsistency can be different subjects physical status and activity (Skelton et al., 1994). Unfortunately, most of authors examined functionally impaired or sedentary people and there is very little works concerning physically active older people. Therefore, it is interesting if knee extensors inertial training of high-functioning older women will improve these muscle's strength and power and functional fitness.

The aims of this study were to estimate the influence of inertial training on knee extensor muscle strength and power and evaluate the effect of ITMS training on functional *fitness* in physically active older women.

Methods

The participants were 22 physically active women ages 58–70 years (Table 1), recruited from the Third Age University. Participants were randomly divided into two groups: training (T) and control (C). The T group underwent a 5-week inertial training program, and the C group did not undergo any specific type of training. Before and during the training period, subjects regularly participated in collective physical classes (i.a. gymnastics, swimming) organized by the Third Age University in order to older people activation, but none of the women had undergone resistance training. The women were required to maintain their normal routine physical activity and diet during the training period, but it was not controlled by the researchers. All subjects were retired and they were independent in life. Before the study, all of the participants completed the Medical Outcomes Survey Short Form (SF-36) (Ware and Sherbourne, 1992). All women were postmenopausal. All participants were informed about the procedures, risks, and benefits and signed an informed written consent document. The study was performed in accordance with the Declaration of Helsinki, and it was approved by the Institutional Review Board.

Device

Training was performed with the ITMS, which was designed and constructed by an inter-university group from the Faculty of Physical Culture and the Faculty of Mechanics (Figure 1). The device wheel (19.4 kg) was not loaded with any additional weights. A detailed description of the ITMS is presented in Naczk et al. (2016a).

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

	Group	
	T (n=13)	C (n=9)
Age (years)	64.7 ± 3.1	65.8 ± 4.7
Height (cm)	156.2 ± 3.8	158.0 ± 5.2
Body mass (kg)	63.2 ± 7.5	64.9 ± 7.5
BMI	25.9 ± 2.9	26.0 ± 2.5

Abbreviations: BMI = body mass index; T = training group; C = control group

Training

Inertial training was performed three times per week (Monday, Wednesday, and Friday) for 5 weeks. Training was conducted by the same two researchers.

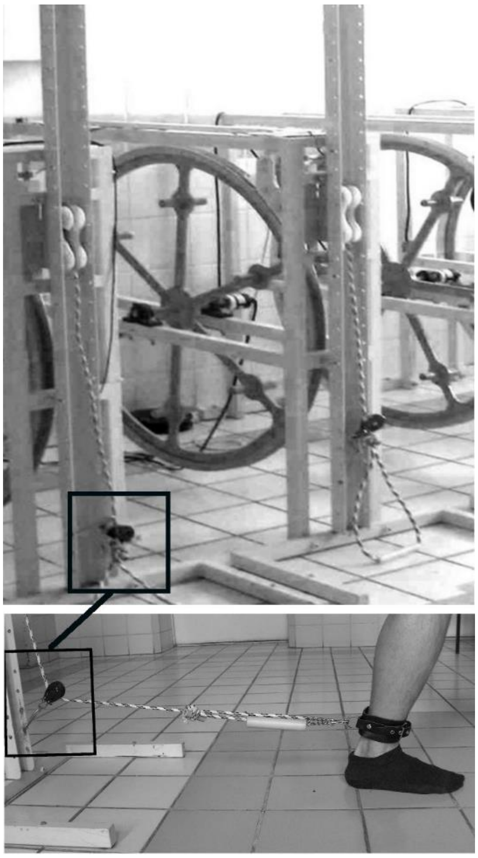

Figure 1. The Inertial Training and Measurement System (ITMS) and a way of mounting the rope to the ankle.

Each training session included exercises involving the elbow and knee flexor and extensor muscles. In this study, we focused only on the knee extensor muscles. Participants performed three sets of leg extension, with the right and left legs worked separately (without rest). A 2-minute break occurred between consecutive sets. Before the exercises, each participant sat on a bench with her back to the device and the rope above the ankle. In the starting position, the angle of the knee joint of the active leg was approximately 60 degrees. To begin exercise, participants set the flywheel in motion by straightening the knee (the range of motion was approximately 80 degrees) (Figure 2).

Figure 2. Knee extensor muscles training on the Inertial Training and Measurement System.

They performed a succession of concentric and eccentric movements (but the eccentric phase was forced only by the flywheel mass of inertia). Participants were instructed to exercise as quickly as possible during the work sets. This training regimen had a tonic character with a constant tension on the rope during transitions from concentric to eccentric muscle loading, which ensures greater joint stability in comparison with the phasic technique (Albert and Thein, 1995). Extensor muscles worked for 15 seconds per set (right and left leg, respectively), for a total work time for each leg of 45 seconds per training session. The external loads were unchanged during the training period, but the total volume of training was progressively increased by increasing the number of cycles (average increase between pre–post measurements was 2 cycles per 10 seconds). Each training session was preceded by a standardized warm-up consisting of opposite and synchronized arm swings, knee bends, push-ups by the wall, running in place for a few seconds, and a few slow cycles with the ITMS. At the end of the experiment, each woman completed a questionnaire for feedback about exercise classes.

Measurements

Force and power

Before and after the training period, testing movement pattern was similar to the training (first measurement sessions were preceded by a trial session). On the ITMS, participants performed 10-second maximal tests of the right and left legs. Measurements were done separately for each muscle group, with a 2-minute break between them. Data from the tensometer and encoder were sent to the DAQ module and saved on the computer using MAD01 software. The average values of force [N] and power [W] developed during extension of both legs together were used for further analysis.

Functional tests

Three functional tests were used before and after training. Two of them, the 30-second chair stand and 8-ft up-and-go, are part of the Fullerton Functional Fitness Test (FFT), and a detailed description of these tests was presented by Rikli and Jones (1999a). The third test was the stair climbing. A 16-stair flight (stair height = 16 cm) with handrails on both sides was used for this test. Participants were asked to climb up the stairs as fast and safely as possible and then to turn around on the top platform and walk down. If necessary, the handrails could be used on the preferred side. Performance was recorded with a stopwatch, which was stopped when both feet landed on the bottom of the flight of stairs. After a practice trial, two test trials were done, and mean values were used for further analysis.

Body composition

Before and after training, bioelectrical impedance analysis (BIA 101 Analyser, Italy) was used to evaluate muscle mass. The participants were asked to maintain a normal state of hydration before measurement. Measurements were made according to manufacturer's guidelines.

Statistical analysis

Statistical analysis was performed using R language for statistical computing (2012). Box plots with median values for the data were used to display a set of data. The differences between pre- and post-training for each group were calculated using one-sample Wilcoxon's tests. Non-parametric Wilcoxon's multiple comparisons tests with Benjamini–Hochberg's correction were used to determine the differences between relative changes in analyzed parameters noted in the training and control groups. The simple effect of training for each participant was defined as relative change (RC) in force and power between post- and pre-training measures using the following formula:

RC [%] = (*xpost*–*xpre*)/*xpre* where RC is relative change and x is the value measured before (xpre) and after (xpost) training.

For estimating the magnitude of the training effect, the effect size (ES) was determined with the one-sample Cliff's delta method (δ) (1) and the standardized mean difference (SMD) (2) using the following formulas:

(1) delta = [#(*x*>*0*) – #(*x*<*0*)] / *n* where *x* are score within group, and n is the size of the group. The cardinality symbol # indicates counting. This statistic estimates the probability that a value selected from the group is greater than 0, minus the reverse probability.

(2) SMD = [mean(*x*) / GMD] · [2 / sqrt(п)] where GMD is within group mean of absolute differences between all pairs of observations. SMD's scale is compatible with Cohen's d scale.

Lower and upper borders of 95% confidence intervals (CIs) for SMD and δ were calculated using the Monte Carlo bootstrap method. For Cliff's delta, ES magnitudes are determined between −1 and +1, where value of -1 or +1 indicates an absence of overlap between the two groups and a 0 indicates that distributions of group overlap completely. For SMD the greater the magnitude, the greater the effect size. To estimate relationships between parameters, the Spearman correlation was calculated. Median values of relative changes were taken for further analysis. The significance level was set at p ≤0.05.

Results

On the SF-36, none of women from both groups answered that her health was poor and all women answered that at that time, they had no health limitations regarding moderate activities (such as moving a table or pushing a vacuum cleaner), climbing one flight of stairs, walking more than one mile, walking one or several blocks, or bathing or dressing.

In the training group, significant post-training relative increases of average force and power developed by knee extensor muscles were noted. Moreover, relative changes in the T group significantly differed from changes in the C group (Figure 3). In the C group, changes observed after 5 weeks were not significant.

In case of functional tests, significant improvements were observed in T group in the 30-second chair stand and 8-ft up-and-go tests (Figure 4), but in relation to the C group, these differences were not significant.

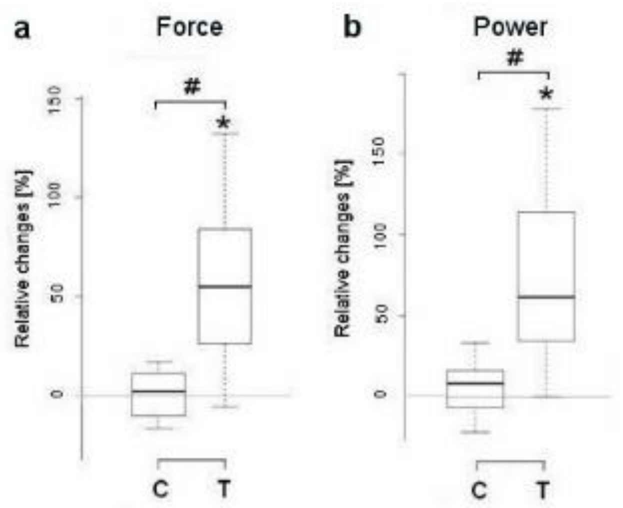

Figure 3. Post-training relative changes in average force (a) and power (b). T - training group; C - control group. *Significant post-training relative changes (p≤0.05). [#]Significant differences between relative changes in training and control group (p≤0.05).

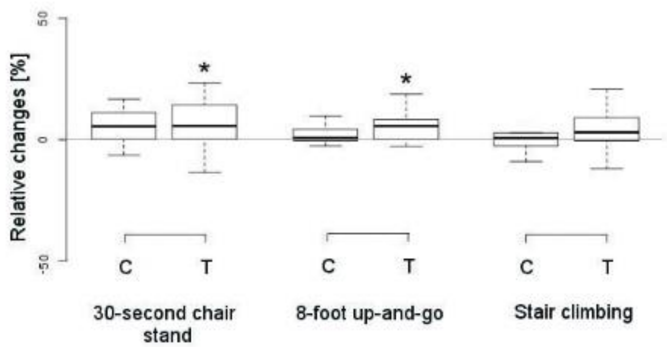

Figure 4. Post-training relative changes in functional tests. T - training group; C - control group. *Significant post-training relative changes (p≤0.05).

The effect sizes calculated from a training intervention ranged from 0.23 to 1.79 for SMD, and from 0.09 to 0.83 for δ, in relation to the C group (Table 2). Moreover, significant negative correlations between values of average force and power developed before the training, and a percentage increase of these parameters after training was observed (p≤0.05). However, RC on ITMS was not correlated with RC in functional tests.

Table 2. Training effect sizes for force and power measured on ITMS and for functional tests (in relation to control group).

	ITMS			
	SMD	CI_{min}-CI_{max}	δ	CI_{min}-CI_{max}
Force	1.78	0.74-2.72	0.83	0.00-1.00
Power	1.79	0.81-2.70	0.83	0.00-1.00
	Functional tests			
30-second chair stand	0.23	-0.89-1.31	0.09	-0.56-0.64
8-foot up-and-go	0.51	-0.65-1.46	0.28	-0.43-0.78
Stair climbing	0.46	-0.70-1.45	0.28	-0.43-0.78

; ; CImin/CImax=lower/upper border of 95% confidence interval for SMD % confidence interval for SMD and δ.

Abbreviations: SMD=one-sample standardized mean difference; δ=one-sample Cliff's dominance probability; CImin/CImax=lower/upper border of 95% confidence interval for SMD

Muscle mass, expressed in percent, increased significantly in the T group but not significantly compared to the control group ($p>0.05$). The effect sizes (in relation to the control group) were 0.46 and 0.10 for SMD and δ, respectively. Moreover, correlations between RC of muscle mass and RC of force and power measured on ITMS were not significant.

On the questionnaires about the exercise classes that the women completed at the end of the experiment, 12 women stated that they were very motivated during the exercise program and wished to continue the training. They also experienced positive effects of ITMS training such as better muscle strength (n = 8), greater muscle mass (n = 4), better coordination (n = 2), and improved walking (n = 2). Other reported benefits included improved balance (n = 1), mood (n = 1), and muscular endurance (n = 1).

Discussion

Muscle strength and power

The results showed that ITMS training induced significant increases in force and power of knee extensors (55 and 62%, respectively), measured under the same conditions as the training ($p \leq 0.05$). The training also elicited significantly greater post-training increases in average force and power in weaker women, confirming the well-known fact that adaptive changes are more pronounced in individuals with lower baseline values of measured parameters (Graves et al., 1994). Increases noted in *the current study* were greater than increases observed by *Brzenczek-Owczarzak et al. (2013) in shoulder muscles of older women (11 and 22% for torque and 28 and 34% for power of left and right arms, respectively).* However, in that study, the measurements were done in isokinetic conditions, and as the authors note, under specific inertial testing conditions, improvements would be greater. It can be confirmed by Naczk et al. (2020) study, which observed increase of elbow and knee muscles force from 37.1% to 69.1%, in older people. In another study concerning inertial training in elderly women (12 weeks on YoYo ergometers), an increase of 28% in knee extensor power was noted noted (Onambele et al., 2008). Unfortunately, other inertial studies have not been performed in older people and after 4 or 5 weeks of training the force increased by 5–39% and power by 14.5–33% for elbow or knee muscles (Albert et al., 1994; Naczk et al., 2014, 2016a; Seynnes et al., 2007; Tesch et al., 2004).

To better evaluate the overall treatment effect and improve the applicability of this research to practice, the calculation of effect sizes was done. According to Rhea's (2004) scale, which was proposed for strength training research and the training status of participants, our results indicate moderate effect sizes (expressed by SMD) in the women being measured. However, according to the scale presented by Romano et al. (2006) for a Cliff's delta, the value calculated in the current study indicates a large effect size. Unfortunately, regarding other research concerning inertial training, only Naczk et al. (2014, 2016a, 2020) presented effect sizes. In the first paper, these authors reported 1.94 and 2.50 for SMD and 0.93 and 0.86 for Cliff's delta for the maximal force and power, respectively, after ITMS training. In their second paper, ES values for percentage increases of torque were 0.84–2.03 (depending on training group) and were 0.78–1.65 for power and the last one 1.14 - 3.95. However, the calculations were done using some other formula.

Force and power improvements can be associated with muscle mass increase, but increases in muscle mass in the T group (2.2%) in this study were not significantly greater than in the C group (1.9%), despite distinctly greater increases in strength (55% in T vs 2% in C) and power (62% in T vs 9% in C). Moreover, the magnitudes of the effect sizes confirm a trivial training impact on muscle mass. These findings and the lack of significant correlation between RC of muscle mass and RC of force and power measured on ITMS agree with other authors' suggestions that in young and older people populations strength gains occurring within the first few weeks of training do not depend largely on hypertrophic factors but mainly on neural factors (Deschenes and Kraemer, 2002; Häkkinen et al., 1998; Narici et al., 1989; Seynnes et al., 2007).

Training and functional tests

Magnitudes of effect sizes (considered in relation to the C group) and non-significant differences between post-training changes in the T and C groups suggest a trivial or small transfer of ITMS training gains to functional abilities. Moreover, distinctly smaller improvements in functional tests (2.9–5.6%) than in force and power noted on ITMS and non-significant correlations between increases in ITMS parameters and changes in functional tests could indicate on poor transfer of physical benefits of ITMS training to functional performance. However, it is worthy to note that subjects in the current study were high-functioning older people in comparison to other elderly groups and it is not possible to exclude a ceiling effect in the functional tests. Before the training, our participants achieved mean scores of 23.5 repetitions in the 30-second chair-stand and 4.8 seconds in 8-ft up-and-go tests, while Rikli and Jones (1999b) reported values of 14.5 and 5.2 seconds, respectively. Elderly women examined by Pinto et al. (2014) also had worse results on the chair test (14.1 repetitions). It can not be also excluded that for a high functional fit group of subjects, the 30-second chair stand, 8-ft up-and-go and stair climbing tests might be inappropriate tool to estimate post-inertial training transfer. For sedentary and for functionally limited older people transfer of post-training gains to functional fitness measured by FFT tests was observed. Naczk et al. (2020) observed 12.8 and 40% improvements in 8-ft up-and-go and chair stand tests (respectively) in elderly nursing home residents. Pereira et al. (2012) noted significant improvements in 8-ft up-and-go and chair stand (18%) tests after a 12-week high-speed power training in sedentary women. In another older adult groups (probably sedentary, but it was not given in the text) changes in chair stand (25 and 34%) and on the 8-ft up-and-go tests (4% and 10%) after a 9-week training with elastic resistance bands were also significant (Hasegawa et al., 2014). Functionally limited people also significantly improved themselves in the chair sit-to-stand test after a 16-week exercise program with Thera-Band resistive bands (Fahlman et al., 2011). In case of other functional tests (e.g. climbing stair tests) carried out in sedentary or moderately physically active older people, positive changes in functional fitness following resistance training were also reported (Hartman et al., 2007; Ramsbottom et al., 2004). However, it should be noted that training period in all above cited studies was longer than in the current study. Transfer of post-training gains to other than training tasks after 5-weeks training was noted only in Naczk et al. study (2016a). However, these authors examined young men and changes were observed in maximal anaerobic power, countermovement and squat jumps.

Healthy high-functioning older people were rarely examined to estimate the transfer of training adaptations beyond the training exercise, but in some studies the lack of this transfer was noted (even after a longer training period). Brandon et al. (2000) pointed out that a 4-month strength training improved lower extremity strength substantially but did not improve results in walking up and down stairs and 50-ft walk tests. Earles et al. (2001) did not note improvements in functional performance after a 12-week power training although leg strength and power significantly increased. Women in Skelton et al. (1995) study did not improve their results in chair rise and stair climbing tests after 3 months of progressive resistance strength training despite the significant increase in knee extensor strength and power.

Worth noting is also the issue of the impact of different training type on post-training transfer to *functional movements.* Some authors showed that in older adults, this transfer occurred more often after functional training than after strength/power training of individual muscles (de Vreede et al., 2005; Liu et al., 2014). It cannot be excluded that the ability to perform the functional tasks is more affected by inactivity or disease than by strength or power *per se* (Skelton et al., 1994), and in the case of physically active participants, the transfer of post-training gains may be poor.

Conclusions

Inertial training proposed here induced significant improvements in knee muscle strength and power in physically active older women. Due to the fact that no injuries were occurred and training was well tolerated, it seems to be a safe method of lower limb muscles training. However, the transfer of post-training gains to functional fitness was poor. It seems that the 30-second chair stand, 8-ft up-and-go, and stair climbing tests are undemanding tests for women with very *good functional mobility and a ceiling effect* in the functional tests *can not be excluded.* The further study with using other, more demanding tests for such sub-population of women are needed.

Acknowledgments

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