EQOL Journal (2019) 11(1): 29-36

ORIGINAL ARTICLE

Influence of inertial resistance squat exercise protocol based on novel exercise intensity determination on physical fitness of older adult women

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Received: 28th March, 2019
Accepted: 19th May, 2019
DOI: 10.31382/eqol.190604

Abstract

The aim of the study was to examine practical implications and actual effects of the 8-week progressive resistance exercise protocol with the custom-made inertial device on sit-to-stand, 6-MWT, functional reach, up-and-go test results and Rate of Perceived exertion (RPE) among older adult women (age 65-74). Thirty-seven healthy volunteers were randomly assigned to the control group (n = 11) and to two exercise – inertial (n = 12) and traditional (n = 14) – groups.

The participants performed hip belt squats on the inertial device and kettlebell squats, respectively. Exercise intensity was relatively adjusted using mass moment of inertia (MMI) of the cylindrical weight and %1RM. Time under tension was equalized between groups by the type of the exercise executed. Tests were performed before and after the intervention. Moreover, RPE was monitored after each exercise set. We used two-way repeated measures ANOVA to assess exercise-related differences in test results and to assess intensity-related differences in RPE.

The Senior Fitness Test results significantly differed in pre and post measurements, regardless of the group. A significant time x group interaction was only found in Sit-to-stand test results. RPE results significantly varied from each other across intensities. Statistically different results among groups were only found at the highest intensity (70%).

The results indicate that inertial resistance exercise using the novel exercise intensity determination on the inertial device is a useful and less strenuous alternative to traditional resistance exercise among older adult women while performing squats.

Keywords inertia • sarcopenia • sit-to-stand • flywheel • overload.

Introduction

Processes of aging, of which the leading factor is sarcopenia, cause on the one hand decreased physical and functional abilities (Narici & Maganaris, 2006), whereas on the other hand they cause the increase in getting some age-related diseases and acute injuries (Ebner, Sliziuk, Scherbakov, & Sandek, 2015). Due to reduced relative strength, the body gets tired more quickly, and, consequently, balance, speed, agility and cardiovascular endurance deteriorates. By implementing resitance exercise, older adults can expand their maximum strength and power, which consequently keeps or even improves their physical and functional abilities, and personal independence (Hazell, Kenno, & Jakobi, 2007; Häkkinen, Alen, Kallinen, Newton, & Kraemer,

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2000) which was also discovered in some studies concerning inertial devices (Onambele, Maganaris, Mian, Tam, Rejc, McEwan, & Narici, 2008).

Inertial load presents a new trend in resistance exercise possibilities. The effects of this type of resistance exercise on muscle hypertrophy and strength were shown to be more "robust" than those gained from weightlifting protocols (Petré, Wernstål, & Mattsson, 2018). In contrast to weightlifting, the angular momentum (AM) of a wheel, which is created in the concentric part of a muscle contraction on an inertial device, causes episodes of increased muscle activation and produces higher mechanical forces in the eccentric part of contraction (approximately 25% compared to the concentric part). This phenomenom is known as "eccentric overload" (Norrbrand, Pozzo, & Tesch, 2010).

Numerous studies have established that eccentric contractions can maximize the force exerted and the work performed by muscles, are associated with a greater mechanical efficiency, can attenuate the mechanical effects of impact forces, and enhance the tissue damage associated with exercise. The neural commands controlling eccentric contractions are unique. Eccentric contractions require lower levels of voluntary activation by the nervous system to achieve a given muscle force due to differences involving recruitment order, discharge rate and recruitment threshold of motor units in comparison to concentric contractions. A common human-movement strategy is to combine eccentric and concentric contractions into a sequence known as the stretch-shorten (SSC) cycle. The SSC involves an initial eccentric contraction that is followed immediately by a concentric contraction. The prevalence of this movement strategy can probably be attributed to several factors, such as its ability to maximize performance, to enhance mechanical efficiency, and to attenuate impact forces (Duchateau & Baudry, 2013; Enoka, 1996). Consequantly, the concept of "eccentric overload", which can be easily achieved using inertial devices, increases the efficiency of exercising, taking advantage of all the positive effects of eccentric contraction (Maroto-Izquierdo, García-López, Fernandez-Gonzalo, Moreira, González-Gallego, & de Paz, 2017).

Firstly, the purpose of this research was to examine a progressive resistance exercise protocol using a custom-made squat inertial device, intended for older adult women, which was, as opposed to some other studies, based upon novel relative exercise intensity determination. Furthermore, the purpose of the research was to examine the effects of the inertial device exercise protocol compared to the traditional weight-based one among older adult women's physical abilities – namely the strength of leg extensor muscles, agility, balance and cardiovascular endurance – and the RPE during the execution of the exercise.

Method

The research included 44 healthy older adult women (65-74 yo). Each participant voluntarily provided written consent before participating. They were all occupants of a health care center from Črnomelj (Southeastern Slovenia). During the study, the dropout rate was 7 (16%) and all the participants stated personal reasons as its cause. Therefore, only 37 participants were included in the final analysis (table 1). The participants had no experience in doing strength exercises before, but they had been physically active performing their housework and various chores. The entire experiment was conducted in accordance with the Helsinki-Tokyo Declaration. The study was approved in advance by the Sports Ethic Committee, at the Faculty of Sport (Slovenia).

Procedure and equipment

Before the exercise program, the participants were asked to fill in the PAR-Q Questionnaire (The Physical Activity Readiness Questionnaire for Everyone, 2018). They were also warned about the possible complications during the study and informed that they were free to quit the research at any time. The participants were randomly divided into three groups (Table 1). Before and after the exercise protocol, modified Senior Fitness Test (SFT) battery was used to assess physical and functional abilities. Testing battery included the six-minute walk test (6-MWT), the chair stand test, the timed up-and-go test (Rikli & Jones, 2013) and, additionally, the functional forward reach test (Singh, Pillai, Tan, Tai, & Shahar, 2015). Apart from SFTs in the traditional group, we additionally measured squat 1RM with the intention to relatively adjust the intensity, while in the inertial group we measured the maximum ability of a squat pull using the squat inertial device (inertial repetition maximum). The intensity of exercise was also monitored after each exercise set using the 15-level Borg's scale of perceived exertion (Morishita, Yamauchi, Fujisawa, & Domen, 2013).

Table 1. Basic characteristics of the study participants; values are Mean±SD

	Control (N= 11)	Traditional (N=14)	Inertial (N=12)
Variable	Mean±SD	Mean±SD	Mean±SD
Age (years)	67.3±4.5	71.6±6.4	68.8±6.4
BMI (kg/m^2)	29.9±5.3	25.6±4.7	24.8±4.1

Exercise intervention

Throughout eight weeks of resistance protocol the participants performed hip belt squats (Figure 1) as a part of the standardized exercise unit. In the group executing inertial exercise the custom-made inertial device for squats was used, with relatively adjusted exercise intensity using mass moment of inertia (MMI) of the cylindrical weight. In the group that carried out the traditional exercise, kettlebell weights were used that were held with both hands and adducted between the thighs while performing a squat.

Figure 1. Training belt for attaching the load to the pelvis

Table 2 presents the progressive load in strength exercise for the older adults who carried out the traditional weight training and inertial squat device training. The intensity of exercise on the inertial device was determined with the percentage of its maximum AM that had been previously specified with the baseline measurements of maximum ability of pull from a squat position (inertial repetition maximum). Compared to the studies that have been carried out in this field so far (Norrbrand, 2008; Tesch et al., 2017) and with the intention of comparing exercise effects of inertial and traditional load, the velocity of the repetitions between exercise groups (Carroll et al., 2018) was standardized by executing fluent concentric squats during which the concentric and eccentric part of the exercise lasted one second.

Table 2. Resistance exercise protocol for older adult women with free weights and on the inertial squat device

Week	%1RM[1] % inertial 1RM[2]	Series	Repetitions	Rest period	RPE (6-20)
1 IN	40	3	15-22	90"	12-14
2 IN	50	2	12-15		12-14
3	60	2	12-15		14-16
4	60	3	12-15		14-16
5	60	4	12-15		14-16
6	70	2	10-12		14-16
7	70	3	10-12		14-16
8	70	4	10-12		14-16

Legend: IN – induction week, %1RM – repetition maximum, 1 – traditional group, 2 – inertial group, RPE – rate of perceived exertion

Measurements of inertial repetition maximum using the inertial squat device

Just as we indirectly carried out the measurements of the maximum load during a single repetition with kettlebell weights for all individuals to relatively adjust their exercise intensity (Brzycki, 1993), we also measured the maximum ability of the pull of the cylindrical weight from squat to rotation on the inertial device. Maximum angular velocity (ωmax) was measured with the use of custom-written software, Slot-Type Optocoupler Speed Measuring Sensor and a fifty-tooth plastic ring that was attached to the rotation axis. The software and device were validated beforehand (Spudić, Pori, Cvitkovič, Smajla, & Ferligoj, 2018). The weight MMI (Jweight) – together with the axis MMI (Jaxis) was used to calculate the maximum AM (Γmax) which is produced for each participant when lifting. Taking into consideration the maximum AM and calculated data about the constant velocity of lifting the load with fluent concentric repetitions, the percentage of the rotation quantity of AM was relatively adjusted for each individual.

By adjusting all the cylindrical weights to an equal diameter and determine the execution of exercise repetition by slow concentric-eccentric repetitions ($\omega 1$), we were able to regulate the relative intensity of exercise. Mass of the weight was relatively adjusted using the equation $m=p*((2*\Gamma max-2\omega 1*Jaxis)/(r^2*\omega 1))$. In equation, the percentage of the maximum pull ability, also percentage of the maximum quantity of AM (% of inertial 1RM) in presented by 'p'; maximum quantity of AM measured at inertial 1RM is marked by 'Γmax'; the MMI of axis of rotation is defined by 'Jaxis'; radius of a cylindrical weights in standed by 'r' and the calculated angular velocity per second during slow concentric-eccentric repetitions is denoted by '$\omega 1$'.

Statistical Analysis

The descriptive analysis was performed using measures of central tendency (means±SD). The variables were tested for normality with the Shapiro-Wilk test ($p>0.05$; normality assumed). The baseline differences between the groups (control, traditional, inertial) were tested with a one-way ANOVA. Homoscedasticity was analyzed with the Levene's test ($p>0.05$; equal variances).

We used a two-way repeated measures ANOVA (time x groups; time: pre vs. post; group: control vs. traditional vs. inertial) to assess exercise-related differences in results based on tests performed by the groups and to assess intensity-related differences in results based on RPE (Borg's scale) (groups x intensity; group: inertial vs. traditional; intensity: 40 vs. 50 vs. 60 vs. 70%). Sphericity was analysed with the Mauchly's test ($p>0.05$; sphericity assumed). Post-hoc tests were performed using a Bonferroni adjustment to assess training-related and intensity-related changes within groups. In addition, paired sample t-test was performed to determine differences in RPE at different intensities among training groups. Cohen's d-effect sizes were estimated to compare the magnitude of exercise response, with ≤0.20 representing a small effect, 0.50 representing a medium effect, and ≥0.80 representing a large effect (Cohen, 1988). The statistical analyses were performed using IBM SPSS Statistics 25 and Microsoft Office Excel 2013. The limit for significance was set at $p<0.05$.

Results

Prior to the exercise protocol there were no statistically significant differences in mean results of the functional reach test ($F=0.781$, $p=0.466$), up-and-go test ($F=0.380$, $p=0.687$), 6-MWT test ($F=0.270$, $p=0.765$) and sit-to-stand test ($F=0.270$, $p=0.765$) across different training groups (control, traditional, inertial) (Table 3).

Table 3. Test results pre and post the exercise intervention

	Control (N=11)			Traditional (N=14)			Inertial (N=12)		
Variable	Initial	Final	ES	Initial	Final	ES	Initial	Final	ES
Functional reach	33±6.2	31.8±4.8	-0.22	32.3±6	33.4±6.3	0.18	34.9±3.3	35.5±5.6	0.13
Sit-to-stand	15.6±2.8	15.7±3.1	0.03	16.5±3.1	19.2±3.2	0.86	16.7±4.8	19.5±4.4*	0.61
Up-and-go	5.4±1.6	5.5±1.4	0.07	5.7 ±1.2	5.3 ±0.9	-0.38	5.3±1.0	4.9±0.8	-0.44
6-MWT	565±125	617±151	0.38	581±93	672±120	0.85	593±134	653±121	0.47

Legend: Values are expressed as mean ± standard deviation. N – number of units, ES – effect size, 6-MWT – six-minute walk test, * – significantly different from Control and initial, p<0.05

Significant time x group interaction (F=4.530, p=0.018) was only found in sit-to-stand test results. The results in sit-to-stand test in the three groups significantly differed in pre and post measurements. Pairwise comparisons for the main effect of time – corrected using a Bonferroni adjustment – reflect significant differences between the control and the inertial group, but not between the control and the traditional one, neither between the traditional and the inertial group (p>0.05) (Table 3). There was a significant main effect of time found across test results of up-and-go (F=9.026, p=0.013), 6-MWT (F=19.720, p=0.001) and sit-to-stand test (F=18.217, p=0.002). The results significantly differed in pre and post measurements, regardless of the group. In functional reach test results, there was no main effect of time found (F=3.927, p=0.312). There were also no main effects of the exercise group found across all test results (p>0.05).

According to the RPE results, no interaction (groups x intensity; Greenhouse-Geisser=2.141, p=0.116) or main effect of group (Greenhouse-Geisser=2.300, p=0.160) were found. There was a significant main effect of intensity (Greenhouse-Geisser=52.202, p=0.000) found. The results of RPE considerably differed between exercise intensities (40 vs. 50 vs. 60 vs. 70%). Pairwise comparisons – again corrected using a Bonferroni adjustment – reflect that results, regardless of the group, were all significantly different from each other (p>0.05) (Figure 2). Moreover, despite tendency of higher values in traditional groups, paired samples t-test showed statistically significant difference between inertial and traditional group only at 70% exercise intensity (t=4.457, p=0.046) (Figure 2).

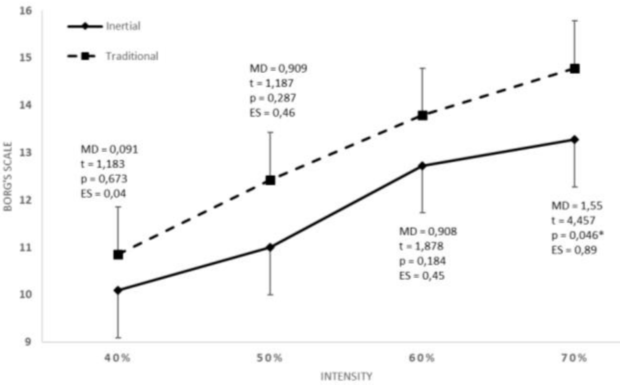

Figure 2. Mean values and standard deviations of rate of perceived exertion (Borg's scale, 6-20), gathered after corresponding exercise session intensity. MD – mean difference between training groups, t – t-test statistics, p – statistical significance, ES – effect size, * – p<0.05

Discussion

The aim of the study was to examine practical implications and actual effects of a progressive resistance exercise protocol using a custom-made squat inertial device for older adult women. It was based on novel measuring of the inertial repetition maximum using the device for each of the participants and upon standardized time of repetition executions. In this manner, the effects of the inertial device exercise protocol for performing squats were compared to the traditional resistance exercise with weights and to a control group. We measured older adult women's physical abilities, namely the strength of leg extensor muscles, agility, balance, cardiovascular endurance and RPE - using Borg's scale of perceived exertion.

The main finding of our study was that 8 weeks of inertial resistance exercise caused a significant 16% improvement in sit-to-stand test in older adult women. In the inertial and the traditional group, we have also shown a trend of improvement of the other SFT components, although the results were not statistically different compared to the control group. This was in concordance with some previous findings, which state that resistance exercise extends the distance covered in 6-MWT, rate of oxygen consumption (VO2max), improves the speed of walking, the ability to change direction during walking (timed up-and-go test) (Cadore, Rodriguez-Manas, Sinclair, & Maroto-Izquierdo, 2013); however, they were in disconcordance with shown improvements in some parameters of balance (Lee & Park, 2013; Onambele et al., 2008). Results could be related to the fact that the study lasted only 8 weeks and to the execution of hip belt squats that unburden the spine and might alter posterior kinetic chain involvement and proximo-distal joint sequencing, respectively (Wade, Lichtwark, & Farris, 2018). Furthermore, a significant difference between the measurement results in the sit-to-stand test that, as opposed to the other tests, can be attributed to a specific motoric pattern that appears during executing a squat and in the sit-to-stand test. This is due to two similar kinematic and kinetic motions that take place during both motion techniques and cause similar electromyographical muscle responses (Flanagan, Salem, Wang, Sanker, & Greendale, 2003). A larger, but not statistically significant effect of the exercise protocol on the sit-to-stand test results was detected when using the inertial squat device.

Although technique was attentively controlled, the results could be a consequence of the deviation in the repetition execution due to untrained individuals (Norrbrand et al., 2008). The timing of switching between the concentric and eccentric phases of contraction is crucial in executing repetitions correctly. The beginning of the active deceleration of the downward motion in the eccentric phase of squatting using the device also causes the development of higher force in the specific amplitude of a knee angle, with which the force-length ratio and functionality of the muscles involved are influenced. Norrbrand, Fluckey, Pozzo and Tesch (2008) also established that a higher force in the eccentric part is developed because the time in executing eccentric contraction repetitions using an inertial device is shorter than in performing concentric contractions. What in turn means that to gain the sequences of development of higher forces in the eccentric part of repetitions we need to actively decelerate the weight in a shorter amount of time than we spend moving the weight into rotation in the concentric part of the exercise. With an intention of balancing the intensity of exercise between the two experimental groups, we specified the way of executing exercise repetitions with slow concentric repetitions, in which the eccentric and concentric part lasted one second. The time under tension was equalized, but the main concept of inertial exercise (eccentric overload) might be violated. The concept of achieving the eccentric overload in submaximal repetition execution though has to be explored. Even though we did not entirely take full advantage of the potential of executing exercise repetitions using the developed inertial device, the exercise performed on it had similar or even more positive effects (sit-to-stand test) than the traditional squat exercise with free weights. Relative adjustment of MMI of cylindrical weight to definite velocity of repetitions that was tested in the research with initial inertial repetition maximum proved useful and is worth further research.

Comparable studies have shown that inertial resistance exercise during which a higher MMI is used and subsequently lower velocities and higher force production are developed significantly affect hypertrophy and muscle strength, while a lower MMI with higher velocities and lower force production (fast repetitions and less force produced) significantly influences the development of muscle power (Naczk, Naczk, Brzenczek-Owczarzak, Arlet, & Adach, 2016; Sabido, Hernández-Davó, & Pereyra-Gerber, 2017). Performing slow exercise repetitions affected the development of muscle power to a smaller extent in both groups, thus the test results of the functional tests were not significantly better. There is now research suggesting that muscle power is more closely associated with the performance of everyday activities than muscle strength is (Hazell, et al., 2007). The type of repetition execution and the manipulation of the MMI and, consequently, the velocity of exercise repetitions using inertial devices influences the adjustment of muscles during exercise (Martinez-Aranda & Fernandez-Gonzalo, 2017). We conclude that for power development and improving physical and functional abilities it is better to prescribe exercises using an inertial device with faster repetitions of adequate intensity (e.g. at peak power output).

The monitored values of RPE after each set of exercise were slightly lower at a certain exercise intensity in the inertial group compared to the traditional group. There was a significant difference at 70% intensity, so one could argue that inertial resistance exercise, which provides similar strength improvement over 8-week resistance training protocol, acts less demanding or strenuous at higher intensities in comparison to traditional weight-lifting resistance exercise. Structural viscoelastic mechanisms may make a greater contribution to force enhancement in the muscles of older adults compared to those of younger age. A relatively greater maintenance of eccentric strength shows that force production among elderly relies more on passive structural properties of muscles (Power, Herzog, & Rice, 2014). So lower values of RPE could be an effect of leaning on passive contractile elements in muscles during force production in eccentric contraction, which also causes less energy consumption and less exertion (Herzog, 2018). In this manner, with inertial load and the type of contractions used, we optimized the capability of producing muscle force among elderly.

In conclusion, the inertial squat device and the novel exercise intensity determination proved to be a practical and effective alternative to a traditional resistance exercise including squats, for older adult women. The applicability of the inertial exercise protocol enables an efficient alternative in resistance exercise among older adults. Moreover, in relationship to a traditional type of resistance exercise, it enables a comparable achievement of exercise objectives with less exertion. In general, resistance exercise improves health parameters; moreover, improvements in leg extensor muscle strength also positively influence elderly's independence, balance and consequently prevents falls and fractures. By implementing short-term and secure exercise on the inertial device, we can be more economically efficient in improving quality of life among the elderly.

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How to cite this article:

APA:	Spudić, D., Hadžić, V., Vodičar, J., Carruthers, J., & Pori, P. (2019). Influence of inertial resistance squat exercise protocol based on novel exercise intensity determination on physical fitness of older adult women. *Exercise and Quality of Life, 11*(1), 29-36. doi:10.31382/eqol.190604
MLA:	Spudić, Darjan, et al. "Influence of inertial resistance squat exercise protocol based on novel exercise intensity determination on physical fitness of older adult women." *Exercise and Quality of Life* 11.1 (2019): 29-36.
Chicago:	Spudić, Darjan, Vedran Hadžić, Janez Vodičar, Jamie Carruthers, and Primož Pori. "Influence of inertial resistance squat exercise protocol based on novel exercise intensity determination on physical fitness of older adult women." *Exercise and Quality of Life* 11, no. 1 (2019): 29-36.