Spudić Darjan [1]*
Cvitkovič Robert [2]
Pori Primož [1]

FLYWHEEL LOW-ROW RESISTANCE EXERCISE AMONG OLDER ADULT WOMEN: A RANDOMIZED CONTROLLED TRIAL

VPLIV INERCIJSKE VADBE NA MOČ ROK PRI STAROSTNICAH: RANDOMIZIRANA KONTROLNA ŠTUDIJA

ABSTRACT

The purpose of our study was to examine the practical application of the progressive resistance exercise protocol among older adult women using a custom-made low-row flywheel (FW) device. The objective was to compare the effects of the FW device exercise protocol to the traditional gravity-based (GB) one, with regards to older adult women's physical abilities, i.e. shoulder mobility, upper body low-row strength, velocity, power and, lastly, trunk extensor endurance. Fourty healthy older adult women (old: 66 ± 5 years; height: 1,62 m; weight: 73,7 kg; body mass index: 28 ± 6 kg/m^2) were randomly assigned to the FW low-row or Pulley low-row group. They underwent eight weeks of resistance exercise. We used a two-way ANOVA for repeated measures and standardized effect sizes (ES) comparison to assess exercise-related differences within and between groups. The results showed significant improvement of resistance exercise parameters during the eight-week resistance exercise protocol, regardless of the group. Moreover, we found no statistically important inter-group differences in improvement of shoulder mobility, upper body strength, velocity, power and trunk extensor endurance. Nevertheless, the highest ES in favour of FW low-row group was found when comparing the eccentric peak power changes. We have demonstrated that FW load could be as effective and useful as GB pulley row-row resistance exercise modality. Further research is required, where the concept of the eccentric overload and muscle power enhancement with the use of FW devices for older adult population should be utilized.

Keywords: isoinertial, eccentric, elderly, yo-yo, overload

[1]University of Ljubljana, Faculty of Sport, Slovenia
[2]University of Ljubljana, Faculty of Computer and Information Science, Slovenia
Corresponding author:*

IZVLEČEK

Namen raziskave je bil preveriti praktično uporabnost namensko izdelane inercijske naprave za izvedbo horizontalnega potega pri starostnicah. Glavni cilj je bil preveriti razlike v učinkih med dvema osemtedenskima protokoloma vadbe za moč - na inercijski napravi in škripcu - in sicer v gibljivosti ramenskega obroča, največji sposobnosti proizvajanja mehanske sile, moči in hitrosti pri vertikalnemu potegu ter vzdržljivosti v moči mišic iztegovalk trupa. V raziskavo je bilo vključenih šestdeset starostnic (starost: 66 ± 5 let; višina: 1,62 m; masa: 73,7 kg; indeks telesne mase: 28 ± 6 kg/m^2), ki so bile naključno razporejene v dve vadbeni skupini (vadba z inercijsko napravo in vadba na škripcu). Za ugotavljanje razlik v napredku med vadbenima skupinama smo uporabili dvostransko analizo variace za ponovljene meritve in primerjavo indeksa velikosti učinka. Po osmih tednih smo v obeh skupinah ugotovili statistično značilno izboljšanje gibljivosti ramenskega obroča, največje sposobnosti proizvajanja mehanske sile, moči in hitrosti pri horizontalnem potegu ter vzdržljivosti v moči mišic iztegovalk trupa, vendar med skupinama razlik v izboljšanju ni bilo. Največjo moč učinka v prid inercijski skupini smo ugotovili v sposobnostih proizvajanja največje mehanske moči v ekscentričnem delu horizontalnega potega na inercijski napravi. Inercijsko breme se je izkazalo za učinkovito in varno za uporabo pri starostnicah. V prihodnje bi bilo smiselno preveriti učinke vadbenih protokolov na inercijski napravi, ki bi upoštevali koncept ekscentrične preobremenitve in bi bili usmerjeni v izboljšanje mehanske moči mišic pri starostnikih.

Ključne besede: izoinercija, ekscentrika, starostniki, jo-jo, preobremenitev

Spudić Darjan, University of Ljubljana, Ljubljana, Slovenia. E-mail: darjan.spudic@fsp.uni-lj.si

INTRODUCTION

The aging process involves numerous physiological and morphological changes in skeletal muscles, which are related to declines in physical, functional abilities and increases in susceptibility to age-related diseases and acute injuries (Ebner, Sliziuk, Scherbakov, & Sandek, 2015). Due to the reduced relative strength, the body gets tired more quickly. Moreover, balance, speed, agility and cardiovascular endurance deteriorate as well. Strength training has been proven to improve cardiovascular health, to combat sarcopenia, to reverse the loss of muscle mass and muscle strength, to combat frailty and falling incidences and overall extends personal independence (Hakkinen, Alen, Kallinen, Newton, & Kraemer, 2000; Hazell, Kenno, & Jakobi, 2007). Benefits regarding strength and power training for older population have also been documented in literature concerning flywheel (FW) devices (Kowalchuk & Butcher, 2019).

FW load presents a new trend in resistance exercise (RE) modalities. The main difference between the FW and the gravity-based (GB) load is that FW load does not have a constant gravitational component. While using FW devices, the resistance is proportionate only to the angular acceleration of the rotating FW. Power and force can vary depending on the tempo of the execution, even with the same FW load used. By controlling the execution technique (delaying the braking action in the first part of the eccentric phase), these devices enable one to reach an eccentric overload, i.e. the difference between eccentric peak force and concentric peak force (Martinez-Aranda & Fernandez-Gonzalo, 2017). Numerous studies have established that eccentric contractions a) maximize the force exerted and the work performed by muscles, b) are associated with greater mechanical efficiency, c) attenuate the mechanical effects of impact forces, and d) enhance tissue damage associated with exercise (Enoka, 1996). Moreover, 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 in comparison to concentric contractions due to differences involving recruitment order, discharge rate and recruitment threshold of motor units (Duchateau & Baudry, 2013; Enoka, 1996). Consequently, the concept of “eccentric overload”, which can be easily achieved using FW devices, may increase the efficiency of exercising, taking advantage of all the positive effects of the eccentric contraction (Maroto-Izquierdo et al., 2017).

FW resistance exercise was shown to be effective in developing muscular hypertrophy, maximal strength, power and improving functional performance in the vertical and horizontal plain movements (Maroto-Izquierdo et al., 2017; Nuñez Sanchez & Villarreal, 2017; Petré, Wernstål, & Mattsson, 2018). In addition, the eccentric overload training resulted in several significant benefits in elderly population – it improved balance (Onambélé et al., 2008; Sañudo et al., 2019), muscle strength and power (Bruseghini et al., 2015; Tesch, Fernandez-Gonzalo, & Lundberg, 2017), muscle cross-sectional area (Bruseghini et al., 2015) and some functional abilities, measured using sit-to-stand (Sañudo et al., 2019), 6-minute walk test, functional reach test and up-and-go test (Sañudo et al., 2019; Spudić, Hadžić, Vodičar, Carruthers, & Pori, 2019). Further studies are required to examine the optimal method to introduce FW training to older adult population as well as its protocols in order to confirm and optimize the benefits (Kowalchuk & Butcher, 2019; Spudić, Hadžić, et al., 2019).

Despite the increasing popularity of resistance training FW devices, only two studies (Onambélé et al., 2008; Spudić, Hadžić, et al., 2019) compared FW resistance exercise training to GB training methods among older adults. Also, early research of the FW as a resistance training modality was mostly limited to either leg pressing or knee extension exercises. While the quality of life among older adults is determined by their independence while doing chores, upper-extremities functionality seems important as well (Candow & Chilibeck, 2005; Metter, Conwit, Tobin, & Fozard, 1997).

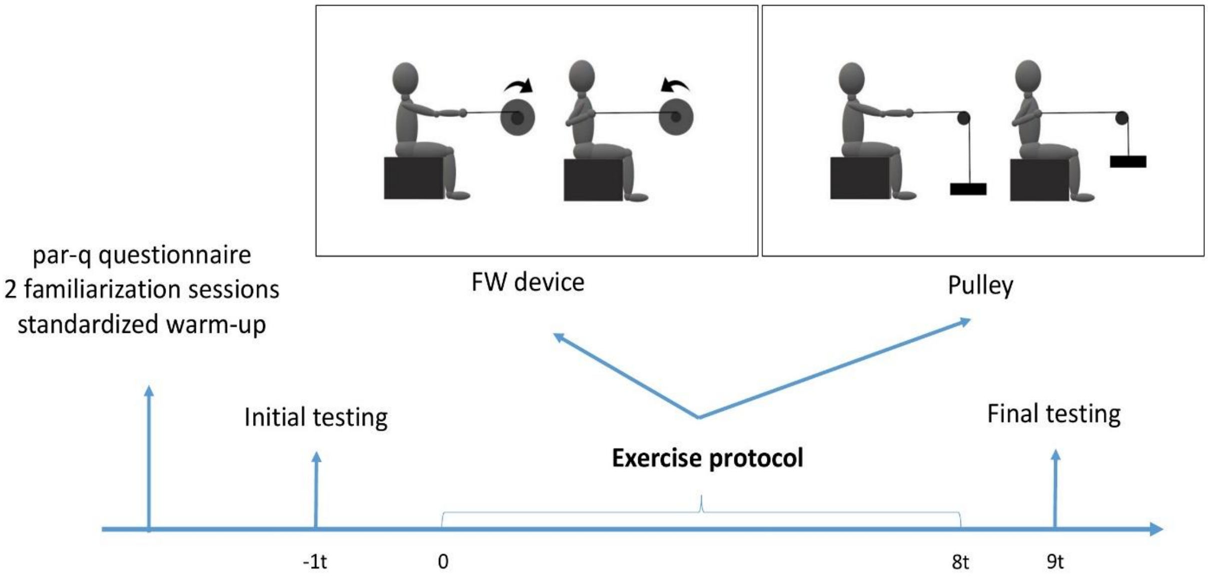
Firstly, the purpose of our study was to examine a practical application of a custom-made low-row FW device and, also, to compare the effects of the FW device exercise protocol to the traditional weight-stack one, with regards to older adult women's physical abilities: shoulder mobility, upper body strength, velocity, power and, lastly, trunk extensor endurance. Protocol was, as opposed to some other studies, based upon a relative exercise FW load determination. Our hypothesis was that the FW group would achieve greater improvements in muscle strength, velocity, power and endurance related parameters due to the utilization of eccentric overload and all the positive effects of muscle loading during eccentric contraction. The results are expected to lead to the optimization of the FW resistance exercise protocols among the older adult population.

METHODS

Study design

The study was designed as a parallel-group randomized controlled trial with testing sessions that were separated by ten weeks' time (Fig. 1). The study was approved by the Sports Ethic Committee at the Faculty of Sport, University of Ljubljana, Slovenia, in accordance with the Declaration of Helsinki (no: 2019-1267).

Figure 1. Sequence of the study protocol



Participants

The research was conducted among healthy older adult women. They were all the occupants of the Črnomelj health care centre (Southeastern Slovenia). The participants were regularly physically active, performing housework and various chores. They were also familiar with resistance exercises – they attended group exercise sessions, twice a week in the past year before the study has begun. The exclusion criteria were: shoulder injuries, chronic diseases, neuromuscular disorders, the history of lower back pain or acute injuries in the past 6 months that could in anyway negatively influence the maximal low-row exercise execution or study attendance due to a decline in the health status. Before the exercise program, the participants were asked to fill in the PAR-Q Questionnaire (Bredin, Gledhill, Jamnik, & Warburton, 2013).

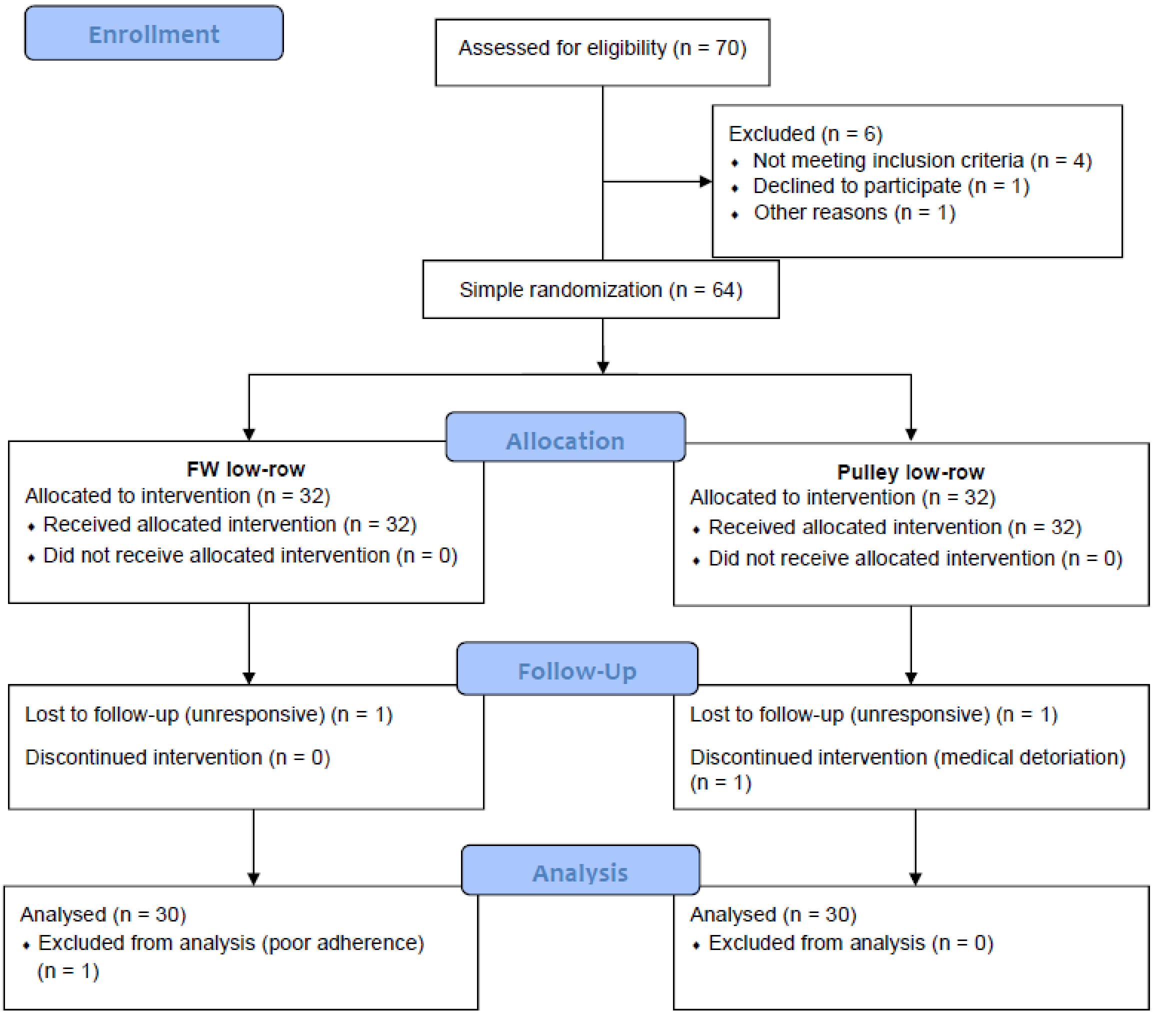
Moreover, the health status was ad-hoc approved by a general practitioner. They were also warned about the possible complications during the study and informed that they were free to withdraw the research at any time. To estimate the sample size we used a G*Power Sample size calculator (Faul, Erdfelder, Lang, & Buchner, 2007). We calculated the required number of participants when β = 0,20; α = 0,05; number of groups = 2 and effect size (ES) = 0,8. The ES was based on the differences in the primary outcome measure, i.e. power output improvement between the FW-based and GB load resistance exercise groups, found in the meta-analysis of Maroto-Izquierdo et al. (2017). This calculation required six participants to be tested in each group. The flow of the participants through the study is presented in Fig. 2. Due to a large response to study participation and the consideration of participants dropping out, we recruited 70 participants in total (Fig. 2). The main characteristics of the participants who completed both testing sessions are shown in Table I.

Table 1. Characteristics of the participants.

Group	**n**	**Age (years)**	**Body height (m)**	**Body mass (kg)**	**BMI (kg/m^2)**
FW	30	69,8 ± 18,0	1,61 ± 0,16	73,0 ± 14,5	27,3 ± 5,8
Pulley	30	65,7 ± 4,8	1,63 ± 0,57	74,3 ± 14,6	27,9 ± 5,8

N – number of the participants; FW – flywheel low-row group; Pulley – pulley low-row group; data are presented as means ± standard deviations

Figure 2. Flow diagram of participants through the trial



Study outcomes

The primary outcome measure was concentric peak power (Con. Peak P; W) produced during FW low-row repetition maximum test. The FW device and acquisition system used in this research has shown adequate criterion validity and good-to-excellent test-retest reliability (ICC = 0,773– 0,948) of the mechanical parameters (Spudić, Kambič, Cvitkovič, & Pori, 2020). Additionally, eccentric peak power (Ecc. Peak P, W), concentric peak force (Con. Peak F; N), eccentric peak force (Ecc. Peak F; N), average velocity (m/s), shoulder mobility (cm), plate tapping test result (s), Sorrensen's test time (s), over head sitting throw length (cm), biceps curl 1RM (kg) and low-row 1RM were measured (kg).

Randomization process

The participants were divided into two groups by a simple randomization process, i.e. the FW low-row (n = 32) and the Pulley low-row (n = 32), respectively (Table 1). Randomization was performed by a member of the research team, who was not directly involved in the recruitment or assessment of the participants, using a computer-generated random allocation data processing program and a 1:1 ratio (FW vs. Pulley).

Procedures and equipment

Two weeks before the initial testing, two familiarization sessions were performed (Sabido, Hernández-Davó, & Pereyra-Gerber, 2018). The sessions included familiarization with both tests and low-row exercise execution, respectively. Before and after the exercise program, a modified testing battery was used. It was selected based on the assessment of trunk and upper extremities physical abilities. The tests were executed in a single testing unit in the following sequence: shoulder mobility test, over head medicine ball throw, fifty stroke plate tapping test, FW low-row repetition maximum test (Spudić, Hadžić, et al., 2019), indirect pulley low-row one repetition maximum test (1RM), Sørensen‘s test, indirect biceps curl 1RM test and hand grip strength test.

The shoulder mobility test was performed following instructions of Cook et al. (2014), to assess bilateral and reciprocal shoulder range of motion, combining internal rotation with adduction of one shoulder and external rotation with abduction of the other. The test also requires normal scapular mobility and thoracic spine extension (Mitchell, Johnson, Vehrs, Feland, & Hilton, 2016). Two repetitions were performed with each arm. Bilateral overhead medicine ball throw was selected to test upper body power. The participants sat on a chair, holding a 3 kg medicine ball between their hands. They were instructed to throw the ball from the resting position, which was on the thighs, backwards over the head – as fast and far as possible. A countermovement was not allowed. The distance from the position of the chair to the ball drop mark was measured in cm. Three repetitions were performed, with 30 s rest in-between. The stroke-plate tapping test was selected to assess the speed and coordination of upper limb movement. Three discs (20 cm diameter) were drawn on the table. The two discs were placed with their centres 60 cm apart. The third disc was placed equidistantly between both discs. The non-dominanr hand was placed on the middle disc. The subject moved the dominant hand left and right between the discs over the hand in the middle as quickly as possible. This action was repeated for 25 full cycles (50 taps), starting with hands crossed. The test was performed two times. The time taken to complete 25 cycles was recorded. FW low-row repetition maximum test was selected to assess the maximum ability of the horizontal low-row pull of the FW. The test was performed in the sitting position with legs stabilized. FW device with high FW load (mass moment of inertia; 0.2 kg·m2) was mounted on the wall bars. The participants were instructed to accelerate the FW and stabilize the pulling amplitude within first two repetitions - the following three repetitions were executed with maximal effort and post-hoc analysed. The strength-related parameters were measured with a custom-written software, Slot-Type Optocoupler Speed Measuring Sensor and a 35-tooth plastic ring that was attached to the FW shaft. The software and device were validated beforehand (Spudić et al., 2020). We indirectly carried out the measurements of low-row 1RM with weight-stack, lifted from the floor with shifting the rope orientation from vertical to horizontal using a custom-made pulley device with linear bearings system. We adhered to the principle that the weight assigned to the participants allowed a performance of maximum ten repetitions (Brzycki, 1993). The exercise amplitude was relatively adjusted in both cases with a marker on the pulling rope. The timed-measured Sørensen‘s test (Moreau, Green, Johnson, & Susan, 2001) was used to assess the endurance of the trunk extensor muscles. The participants were lying prone on the table with the upper edge of the iliac crest in alignment with the edge of the table. Lower body was fixed to the table by two straps (around the pelvis and ankles); the arms were folded across the chest. The participant had to isometrically maintain the upper body in a horizontal position while the time was recorded. The horizontal position was determined using an elastic band stretched horizontally in contralateral orientation, one cm under the anterior part of the participant's shoulders. Afterwards, we performed indirect measurements of the biceps curl 1RM. The test was done in a sitting position and using dumbells. The biceps curl exercise amplitude was carefully monitored. Using a manual hydraulic hand-held dynamometer (Jamar 5030J1, Patterson Medical, Brookfield) maximum isometric strength of the hand and forearm muscles were assessed (Amaral, Amaral, Monteiro, Vasconcellos, & Portela, 2019). The test was performed in a sitting position, with an arm at the right angle and an elbow by the side of the body. The handle of the dynamometer was adjusted, so the base of the handle rested on the first metacarpal (heel of the palm), while the pulling handle rested on the middle of the four fingers. The maximal isometric contraction was maintained for 5 seconds under loud verbal encouragement. Two repetitions with 30 second rest period were performed with each hand.

Exercise protocol

Throughout the eight-week resistance protocol the participants performed a low-row exercise as part of the standardized exercise unit. In the group executing the FW exercise, a custom-made FW device was used. In the group that carried out the GB weight-stack exercise, a custom-made pulley device with linear bearings system was used. The resistance exercise load was relatively adjusted using the mass moment of inertia of the FW and the mass of the load, respectively. The exercise variables (intensity, volume, rest periods, frequency) followed current recommendations (Ratamess et al., 2009) for healthy older adults and were equalized between groups (Table 2).

Table 2. Characteristics of the resistance exercise protocol for older adult women

Week	Load (%)	Sets*Repetitions	Rest period	RPE (6-20)
1 IN	40	3*15		12-14
2 IN	50	2*15		12-14
3	60	2*12		14-16
4	60	3*12	90"	14-16
5	60	4*12		14-16
6	70	2*10		14-16
7	70	3*10		14-16
8	70	4*10		14-16

IN - induction week; Load (%) – percent of the maximum angular momentum (FW group) or 1RM (weight-stack group); RPE - rate of perceived exertion; exercise was performed twice a week

Table 2 presents the progressive loading of resistance exercise for older adults. Compared to the studies that have been carried out in this field so far and with the intention of comparing exercise effects of FW and weight-stack load, the velocity (Carroll et al., 2018) of the exercise execution and consequently the time under tension were equalized between groups.

Data processing

Depending on the number of test repetitions, the average of several consecutive trials was calculated to get trustworthy results. Signals from the FW acquisition system were recorded at 200 Hz, interpolated (1000 Hz) and smoothed using a low-pass filter. Parameters followed the fundamental Newton’s laws and were calculated as follows: $v=(2\pi\alpha)\cdot r=\omega\cdot r$; $F=(J\cdot\alpha)/r$ and $P=F\cdot v$ for each elementary time segment (1 ms) (Spudić et al., 2020). Peak parameters were obtained as maximum value within a 10 ms moving window average. The FW mass moment of inertia (Jweight) – together with the FW shaft mass moment of inertia (Jshaft) was used to calculate the maximum angular momentum (Γmax) which was produced for each participant performing maximal low-row pull with FW device. We took into consideration the Γmax and then calculated data about the constant velocity of lifting the load with fluent concentric repetitions. Concentric and eccentric phases of the low-row pull were determined to last 1 second each. When the velocity was determined, that gave us a basis to relatively adjust angular momentum when performing low-row repetitions for each individual. Moreover, by adjusting all the FW to an equal diameter, mass of the FW was relatively adjusted using the equation m=p*((2*Γmax-2ω1*Jshaft)/(r2*ω1). In equation, the percentage of the maximum pull ability, also the percentage of the maximum provided angular momentum in presented by 'p'; maximum angular momentum measured at initial state is marked by 'Γmax'; the mass moment of inertia for the FW shaft is defined by 'Jshaft'; 'r' stands for the radius of a FW and the calculated angular velocity per second during slow concentric-eccentric repetitions is denoted by 'ω1'. In addition, the predicted 1RM weight was calculated following the equation 1RM=load mass/(1,0278-0,0278* number of reps to exhaustion) (Brzycki, 1993).

Statistical Analysis

The descriptive analysis was performed using measures of central tendency (mean ± standard deviation). The variables were tested for normality with the Shapiro-Wilk test ($p > 0,05$; normality assumed). We used a two-way repeated measures ANOVA (time x groups; time: pre vs. post; group: FW vs. Pulley) to assess exercise-related differences in results based on the tests performed by the groups. Sphericity was analysed with the Mauchly's test ($p > 0,05$; sphericity assumed). Within- and between-group differences in testing parameters were additionally assessed using standardized effect sizes (ES). The magnitudes of the changes were interpreted using values denoted as trivial (< 0,20), small (0,20-0,59), moderate (0,60-1,19), large (1,20-2,00) and extremely large (>2,00) (Batterham & Hopkins, 2006; Hopkins, Marshall, Batterham, & Hanin, 2009). Thresholds for practical importance were derived using a distribution-based approach, where the smallest worthwhile difference was derived by multiplying within- or between-athlete standard deviation (SD) for a given test by 0,2. The probability that improvement of the parameters within or between groups actually existed was assessed via magnitude-based qualitative inference (Batterham & Hopkins, 2006). Qualitative inferences were based on the quantitative chances of benefit outlined by Hopkins, Marshall, Batterham, & Hanin (2009). Quantitative chances are the percentage chances which state that an observed effect is practicaly positive/trivial/negative; e.g. (40/40/20%), which means an effect has a 40% chance of being positive, a 40% chance of being trivial and a 20% chance of being negative. Probabilities that differences were higher than, lower than, or similar to the smallest worthwhile difference within or between groups were evaluated qualitatively as: possibly (25-74.9%), likely (75-94.9%), very likely (95%-99.5%) and most (extremely) likely (>99.5%) (Batterham & Hopkins, 2006) using a custom-written excel spreadsheet. The statistical analyses were performed using IBM SPSS Statistics 25. The limit for significance was set at p < 0,05.

RESULTS

There were no complications during relative load adjustment and exercise execution among elderly women. FW device has shown to be practical in the organizational sense. Mean ± SD values for all parameters pre and post exercise protocol are shown for both groups, along with the qualitative inferences for within-group changes (Table 3).

Table 3. Test results pre- and post- 8-week exercise intervention

	Pulley (n = 30)					Flywheel (n = 30)				
Parameter	**Pre (mean ± SD)**	**Post (mean ± SD)**	**ES (90% CI)**	**Inference and Probability**		**Pre (mean ± SD)**	**Post (mean ± SD)**	**ES (90% CI)**	**Inference and Probability**	
Hand grip test L (kg)	27,7 ± 6,6	29,0 ± 3,6	0,24 (0,09-0,40)	↑ small	possibly	29,8 ± 5,56	29,6 ± 5,5	-0,04 (-0,19-0,12)	↓ trivial	unclear
Hand grip test R (kg)	29,8 ± 4,6	30,1 ± 3,8	0,07 (-0,08-0,23)	↑ trivial	unclear	29,7 ± 5,7	29,5 ± 5,2	-0,04 (-0,19-0,12)	↓ trivial	unclear
Shoulder mobility test L (cm)	-0,7 ± 7,8	-0,9 ± 7,3	0,03 (0,13-0,18)	↑ trivial	unclear	4,5 ± 10,6	3,1 ± 10,0	0,14 (-0,02-0,29)	↑ trivial	possibly
Shoulder mobility test R (cm)	7,2 ± 12,1	4,3 ± 9,3*	0,27 (0,11-0,42)	↑ small	possibly	8,7 ± 11,1	6,5 ± 12,0	0,19 (0,04-0,35)	↑ trivial	small
Plate tapping test (s)	12,8 ± 1,0	12,5 ± 1,5*	0,24 (0,08-0,3)	↑ small	possibly	13,23 ± 1,71	12,5 ± 1,6*	0,44 (0,28-0,60)	↑ small	likely
Sorrensen's test (s)	49,5 ± 31,2	55,0 ± 35,9*	0,16 (0,01-0,32)	↑ trivial	possibly	47,5 ± 31,1	66,5 ± 53,8*	0,43 (0,28-0,59)	↑ small	likely
Over head throw test (cm)	247,2 ± 59,1	265,8 ± 43,4*	0,36 (0,20-0,51)	↑ small	likely	245,0 ± 60,3	274,0 ± 52,9*	0,51 (0,35-0,67)	↑ small	very likely
Biceps curl 1RM L (kg)	10,0 ± 1,6	11,0 ± 2,6*	0,46 (0,31-0,62)	↑ small	very likely	10,0 ± 1,4	10,9 ± 1,8*	0,56 (0,40-0,72)	↑ moderate	most likely
Biceps curl 1RM R (kg)	9,9 ± 1,1	12,3 ± 5,4*	0,62 (0,46-0,77)	↑ moderate	very likely	10,1 ± 1,7	11,5 ± 2,8*	0,60 (0,45-0,76)	↑ moderate	most likely
Low-row 1RM (kg)	42,9 ± 12,8	45,9 ± 11,9*	0,24 (0,09-0,40)	↑ small	possibly	43,2 ± 11,6	47,0 ± 13,0*	0,31 (0,15-0,46)	↑ small	possibly
Velocity (m/s)	0,72 ± 0,08	0,75 ± 0,09*	0,35 (0,20-0,51)	↑ small	likely	0,75 ± 0,06	0,78 ± 0,07*	0,46 (0,30-0,62)	↑ small	likely
Con. peak F (N)	433,1 ± 62,1	488,1 ± 56,5*	0,93 (0,76-1,09)	↑ moderate	most likely	449,5 ± 58,64	521,3 ± 70,1*	1,11 (0,94-1,28)	↑ moderate	most likely
Ecc. peak F (N)	502,7 ± 79,1	554,5 ± 78,3*	0,66 (0,50-0,82)	↑ moderate	most likely	515,7 ± 67,2	572,7 ± 71,0*	0,82 (0,66-0,99)	↑ moderate	most likely
Con. peak P (W)	316,0 ± 66,9	369 ± 68,3*	0,78 (0,62-0,94)	↑ moderate	most likely	337,2 ± 56,5	409,0 ± 83,3*	1,01 (0,84-1,17)	↑ moderate	most likely
Ecc. peak P (W)	400,1 ± 108,0	451,1 ± 99,7*	0,49 (0,33-0,65)	↑ small	very likely	420,8 ± 90,8	517,2 ± 113,1*	0,94 (0,78-1,10)	↑ moderate	most likely

n - number of the participants; L – left arm; R – right arm; v – velocity; con – concentric; ecc – eccentric; F – force; P - power; * - significant pre-post difference; ES – effect size; CI – confidence interval; ↑ - positive effect; ↓ - negative effect; qualitative inferences quantification - trivial (<0,20), small (0,20-0,59), moderate (0,60-1,19), large (1,20-2,00) and extremely large (>2,00); magnitude of the observed value - possibly, 25-74,9%; likely, 75-94,9%; very likely, 95-99,5%; most (extremely) likely, > 99.5; data are expressed as mean ± standard deviation

The results showed no significant time x group interaction effects. There was a significant main effect of time (p < 0.05) found across the parameters, namely in shoulder mobility for right arm (F = 7,359; p < 0,05), tapping test (F = 13,624, p < 0,05), Sorrensen's test (F = 5,009, p < 0,05), over head sitting throw (F = 10,244, p < 0,05), biceps curl 1RM left and right hand (F = 31,125, p < 0,05; F = 14,501, p < p < 0,05), low-row 1RM (F = 19,502, p < 0,05), velocity (F = 14,003, p < 0,05), Con. Peak F (F = 84,428, p < 0,05), Ecc. Peak F (F = 33,878, p < 0,05), Con. Peak P (F = 68,992, p < 0,05) and Ecc. Peak P (F = 39,266, p < 0,05). However, we found no significant exercise group main effect in measured parameters. The Pulley and FW groups showed trivial to moderate within-group changes of the observed parameters.

Figure 3. Forest plot of the standardized differences between groups following the two exercise protocols

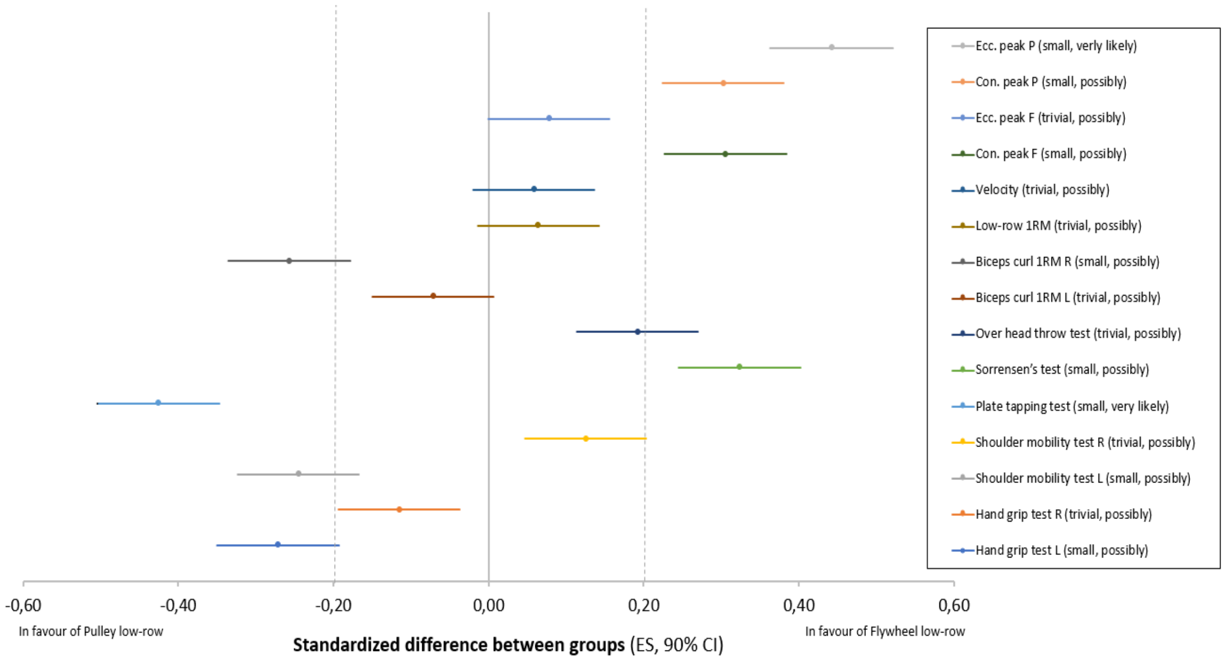


Fig. 3 shows standardized between-groups differences following the two exercise protocols along with the qualitative inferences and quantitative chances of benefit in favour of one of the groups. The highest standardized difference in favour of FW low-row group was found when comparing the Ecc. Peak P. The magnitude of Ecc. Peak P difference was small, and the change was very likely to be higher than the smallest worthwhile difference - determing the practical importance of the results.

DISCUSSION

The purpose of our study was to examine a practical application of a custom-made low-row FW device and to assess differences in the level of adaptation between two progressive resistance exercise protocols, i.e. FW low-row and GB pulley low-row, respectively. The FW protocol was, as opposed to some other studies, based upon relative exercise FW load determination. The results show practical usability of the FW low-row device. We assessed no inter-group differences in improvement of the shoulder mobility, upper body strength, velocity, power and trunk extensor endurance. In contrary – only when analyzing ES - we found favourable Ecc. Peak P adaptations of the FW low-row group. Our assumption of greater improvements of muscle strength, velocity, power and endurance related parameters in favour of FW low-row group was, therefore, rejected. Whatsoever, the results are an indication of a significant improvement of resistance exercise parameters after the eight-week resistance exercise protocol, regardless of the resistance exercise modality selected.

The five key benefits of using eccentric training on an older adult population include the increase of force and power production, decreased metabolic demand (metabolic efficiency), decreased cardiovascular demand, increased muscular adaptations as well as the fact that the eccentric strength is preserved (Kowalchuk & Butcher, 2019). Traditional methods using GB load, i.e. free-weights, weight-stack or weight machines can improve and maintain strength and power but are limited in their ability to provide constant muscle tension and high levels of muscle activation throughout the braking (eccentric) phase of lifting. With FW devices, training may overcome these limitations and has shown to result in potent adaptations in both young and older adults (Fisher et al., n.d.; Maroto-Izquierdo et al., 2017; Nuñez Sanchez & Villarreal, 2017; Petré et al., 2018; Tesch et al., 2017; Vicens-Bordas, Esteve, Fort-Vanmeerhaeghe, Bandholm, & Thorborg, 2018). Nevertheless, methods of producing eccentric overload among older adults are limited from a practical perspective.

Additionally, it has been shown that lower extremities strength and power improvements among older adults positively influence balance (Onambélé et al., 2008) and postural stability (Sañudo et al., 2019) and may, therefore, be useful in prevention of falls. In our study, we expected that upper extremities strength and power improvements during low-row exercise would also have a positive influence on other, non-task-specific functional abilities, such as trunk extensor endurance as well as speed and coordination of upper limb movement. Low-row exercise using pulley or FW device showed to be equally effective in endurance training of the trunk extensors, which is an important factor in occurrence of lower back pain (Moffroid, 1997). Moreover, the ability to perform activities of daily living could have been positively affected by improving upper limb coordination and speed. Both low-row resistance exercise protocols have shown a positive transfer of strength and power improvements to the functional tasks among older adult women.

In contemporary literature regarding FW resistance exercise, the type of exercise execution was determined as follows: the first two or three repetitions were performed with the intention to accelerate the FW, and the following were performed with maximal effort. The participants were instructed to perform the concentric phase as fast as possible while delaying the braking action in the first third of the eccentric phase. Loud verbal encouragement was given to the participants during all testing and exercise sessions. We have evaluated that maximal engagement in exercise execution for older adult women carries a higher risk of injury. Therefore, a submaximal type of exercise execution was implemented. By delaying the braking action in the first part of the braking phase, even with submaximal concentric contractions, eccentric overload could be reached. Submaximal loading in eccentric contractions and its adaptations is a matter of debate (Gault & Willems, 2013; Nosaka & Newton, 2002) and should be researched further using FW load.

Limitations and strengths

There are several limitations to the present study, which need to be addressed. Due to gender differences in adaptations to resistance exercise (Boit et al., 2016; Lundberg, García-Gutiérrez, Mandić, Lilja, & Fernandez-Gonzalo, 2019) and gender differences in reaching the eccentric overload when using low, medium or high FW loads (Martinez-Aranda & Fernandez-Gonzalo, 2017), the study was conducted only on older adult women. The generalizability of the results to the male population is therefore questioned and should be further assessed. The main reason for not finding any differences seems to be the submaximal exercise execution in the FW group, with which we could have violated the main concept of the FW resistance exercise - eccentric overload. It seems that using submaximal exercise execution, the eccentric contraction's mechanical and neural properties were not fully utilized. Our intention to relatively adjust the FW load was based on the initial measurement of the Γmax, from which we selected a high absolute FW load with the intention to assess the Γmax a participant could provide. In the meantime, a study comparing different FW loads (Spudić, Pori, & Cvitkovič, 2019) showed a progressive linear relationship between the incremental FW loading conditions and Γmax observed. Therefore, our relative adjustment in the FW group could have been biased because the maximal strength and velocity abilities are individually conditioned. The Γmax in our study might not be assessed due to absolute FW load selection (i.e. 0.2 kg·m2). In past research, velocity measurements were suggested as a useful tool for intensity prescription (Carroll et al., 2018) when discovering significant linear regression equations for velocity parameters during incremental FW loading. Consequently, we suggest that, in future research, more attention should be paid to the F-v relationship as described by Samozino et al. (2014), whose principle should be transferred to FW conditions. Individual`s F-v profile may be a useful tool for FW resistance exercise intensity prescription and assessing exercise adaptations. Last, but not least - an insignificant difference between groups might be a consequence of a sample size too small, especially due to a high inter-participant variability of the results. Despite the fact that previous studies comparing FW to GB exercise modalities included 7 (Norrbrand, Fluckey, Pozzo, & Tesch, 2008), 8 (Lundberg et al., 2019) or 12 (Onambélé et al., 2008) participants in each group.

CONCLUSION

In conclusion, we surmise that when employing the two resistance exercise protocols for either FW or weight-stack pulley low-row exercise, the two training modalities generally result in similar improvements of shoulder mobility, upper body strength, velocity, power and trunk extensor endurance. We found favourable Ecc. Peak P adaptations of the FW low-row group, only when analyzing ES. The FW low-row device has been proven to be practical for older adult women. The results are likely to lead to the optimization of the FW load resistance protocols among older adults, while we have shown that the FW load could be an equally effective and useful resistance exercise modality. Further investigation is required, especially regarding the potential of FW devices in muscle power enhancement in an older adult population.

Acknowledgment

The authors would like to thank all the participants for their efforts during the study.

Declaration of Conflicting Interests

The authors declare that they have no conflict of interest derived from the outcomes of this study. This study did not receive any funding.

REFERECES

Amaral, C. A., Amaral, T. L. M., Monteiro, G. T. R., Vasconcellos, M. T. L., & Portela, M. C. (2019). Hand grip strength: Reference values for adults and elderly people of Rio Branco, Acre, Brazil. *PLoS ONE*, 14(1), 1–13. https://doi.org/10.1371/journal.pone.0211452

Batterham, A. M., & Hopkins, W. G. (2006). Making Meaningful Inferences About Magnitudes. International *Journal of Sports Physiology and Performance*, 1, 50–57. https://doi.org/10.1123/ijspp.1.1.50

Boit, M. Da, Sibson, R., Meakin, J. R., Aspden, R. M., Thies, F., Mangoni, A. A., & Gray, S. R. (2016). Sex differences in the response to resistance exercise training in older people. *Physiological reports*, 4, 1–8. https://doi.org/10.14814/phy2.12834

Bredin, S. S. D., Gledhill, N., Jamnik, V. K., & Warburton, D. E. R. (2013). PAR-Q+ and ePARmed-X+ New risk stratification and physical activity clearance strategy for physicians and patients alike. Journal of *Electron Spectroscopy and Related Phenomena*, 59(3), 273–277. https://doi.org/10.1016/0368-2048(92)80003-Q

Bruseghini, P., Calabria, E., Tam, E., Milanese, C., Oliboni, E., Pezzato, A., … Capelli, C. (2015). Effects of eight weeks of aerobic interval training and of isoinertial resistance training on risk factors of cardiometabolic diseases and exercise capacity in healthy elderly subjects. *Oncotarget*, 6(19), 16998–17015.

Brzycki, M. (1993). Strength Testing—Predicting a One-Rep Max from Reps-to-Fatigue. *Journal of Physical Education, Recreation & Dance*, 64(1), 88–90. https://doi.org/10.1080/07303084.1993.10606684

Candow, D. G., & Chilibeck, P. D. (2005). Differences in size, strength, and power of upper and lower body muscle groups in young and older men. *Journals of Gerontology - Series A Biological Sciences and Medical Sciences*, 60(2), 148–156. https://doi.org/10.1093/gerona/60.2.148

Carroll, K. M., Wagle, J. P., Sato, K., Christopher B. Taber, N. Y., Bingham, G. E., & Stone, M. H. (2018). Characterising overload in inertial flywheel devices for use in exercise training. *Sports Biomechanics*, 18(4), 1–12. https://doi.org//doi.org/10.1080/14763141.2018.1433715

Cook, G., Burton, L., Hoogenboom, B. J., & Voight, M. (2014). Functional movement screening: the use of fundamental movements as an assessment of function-part 2. *International Journal of Sports Physical Therapy*, 9(4), 549–54963.

Duchateau, J., & Baudry, S. (2013). Insights into the neural control of eccentric contractions. *Journal of Applied Physiology*, 116(11), 1418–1425. https://doi.org/10.1152/japplphysiol.00002.2013

Ebner, N., Sliziuk, V., Scherbakov, N., & Sandek, A. (2015). Muscle wasting in ageing and chronic illness. *ESC Heart Failure*, 2(2), 58–68. https://doi.org/10.1002/ehf2.12033

Enoka, R. M. (1996). Eccentric contractions require unique activation strategies by the nervous system. *Journal of Applied Physiology*, 81(6), 2339–2346. https://doi.org/10.1152/jappl.1996.81.6.2339

Faul, F., Erdfelder, E., Lang, A. G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, 39(2), 175–191. https://doi.org/10.3758/BF03193146

Fisher, J. P., Ravalli, S., Carlson, L., Bridgeman, L. A., Roggio, F., Scuderi, S., … Musumeci, G. (2020). Utility and Advantages of the Eccentric Training through the Isoinertial System. *The "Journal of Functional Morphology and Kinesiology" Journal Club Series*, https://doi.org/10.3390/jfmk5010006

Gault, M. L., & Willems, M. E. T. (2013). Aging, functional capacity and eccentric exercise training. *Aging and Disease*, 4(6), 351–363. https://doi.org/10.14336/AD.2013.0400351

Hakkinen, K., Alen, M., Kallinen, M., Newton, R. U., & Kraemer, W. J. (2000). Neuromuscular adaptation during prolonged strength training, detraining and re-strength-training in middle-aged and elderly people. *European Journal of Applied Physiology*, 83(1), 51–62. https://doi.org/10.1007/s004210000248

Hazell, T., Kenno, K., & Jakobi, J. (2007). Functional benefit of power training for older adults. *Journal of Aging and Physical Activity*, 15(3), 349–359. https://doi.org/10.1123/japa.15.3.349

Hopkins, W., Marshall, S., Batterham, A., & Hanin, J. (2009). Progressive Statistics for Studies in Sports Medicine and Exercise Science. *Med. Sci. Sports Exerc*., 41(1), 3–12. https://doi.org/10.1249/MSS.0b013e31818cb278

Kowalchuk, K., & Butcher, S. (2019). Eccentric Overload Flywheel Training in Older Adults. *Journal of Functional Morphology and Kinesiology*, 4(3), 61. https://doi.org/10.3390/jfmk4030061

Lundberg, T. R., García-Gutiérrez, M. T., Mandić, M., Lilja, M., & Fernandez-Gonzalo, R. (2019). Regional and muscle-specific adaptations in knee extensor hypertrophy using flywheel vs. conventional weight-stack resistance exercise. *Applied Physiology, Nutrition, and Metabolism*, 1–27. https://doi.org/10.1139/apnm-2018-0774

Maroto-Izquierdo, S., García-López, D., Fernandez-Gonzalo, R., Moreira, O. C., González-Gallego, J., & Paz, J. A. (2017). Skeletal muscle functional and structural adaptations after eccentric overload flywheel resistance training: a systematic review and meta-analysis. *Journal of Science and Medicine in Sport*, 20(10), 943–951. https://doi.org/10.1016/j.jsams.2017.03.004

Martinez-Aranda, L. M., & Fernandez-Gonzalo, R. (2017). Effects of inertial setting on power, force, work, and eccentric overload during flywheel resistance exercise in women and men. *Journal of Strength and Conditioning Research*, 31(6), 1653–1661. https://doi.org/10.1519/JSC.0000000000001635

Metter, E. J., Conwit, R., Tobin, J., & Fozard, J. L. (1997). Age-Associated Loss of Power and Strength in the Upper Extremities in Women and Men. Journal of Gerontology: *BIOLOGICAL SCIENCES*, 52(5), 267–276.

Mitchell, U. H., Johnson, A. W., Vehrs, P. R., Feland, J. B., & Hilton, S. C. (2016). Performance on the Functional Movement Screen in older active adults. *Journal of Sport and Health Science*, 5(1), 119–125. https://doi.org/10.1016/j.jshs.2015.04.006

Moffroid, M. T. (1997). Endurance of trunk muscles in persons with chronic low back pain: assessment, performance, training. *Journal of Rehabilitation Research and Development*, 34(4), 440–447.

Moreau, C. E., Green, B. N., Johnson, C. D., & Susan, R. (2001). Isometric Back Extension Endurance Tests : A Review of the Literature. *Journal of manipulative and physiological therapeutics*, 24(2), 110–122. https://doi.org/10.1067/mmt.2001.112563

Norrbrand, L., Fluckey, J. D., Pozzo, M., & Tesch, P. A. (2008). Resistance training using eccentric overload induces early adaptations in skeletal muscle size. *Eur J Appl Physiol*, 102, 271–281. https://doi.org/10.1007/s00421-007-0583-8

Nosaka, K., & Newton, M. (2002). Difference in the magnitude of muscle damage between maximal and submaximal eccentric loading. *Journal of Strength and Conditioning Research*, 16(2), 202–208. https://doi.org/10.1519/1533-4287(2002)016<0202:DITMOM>2.0.CO;2

Nuñez Sanchez, F. J., & Villarreal, E. S. (2017). Does flywheel paradigm training improve muscle volume and force? A meta-analysis. *Journal of Strength and Conditioning Research*, 31(11), 3177–3186. https://doi.org/10.1519/JSC.0000000000002095

Onambélé, G. L., Maganaris, C. N., Mian, O. S., Tam, E., Rejc, E., McEwan, I. M., & Narici, M. V. (2008). Neuromuscular and balance responses to flywheel inertial versus weight training in older persons. *Journal of Biomechanics*, 41(15), 3133–3138. https://doi.org/10.1016/j.jbiomech.2008.09.004

Petré, H., Wernstål, F., & Mattsson, C. M. (2018). Effects of Flywheel Training on Strength-Related Variables: a Meta-analysis. *Sports Medicine*, 4(55), 1–15. https://doi.org/10.1186/s40798-018-0169-5

Ratamess, N. A., Alvar, B. A., Evetoch, T. K., Housh, T. J., Ben Kibler, W., Kraemer, W. J., … American college of sports medicine. (2009). Progression Models in Resistance Training for Healthy Adults. *Medicine & Science in Sports & Exercise*, 41(3), 687–708. https://doi.org/10.1249/MSS.0b013e3181915670

Sabido, R., Hernández-Davó, J. L., & Pereyra-Gerber, G. (2018). Influence of Different Inertial Loads on Basic Training Variables During the Flywheel Squat Exercise. *International Journal of Sports Physiology and Performance*, 13(4), 482–489.

Samozino, Edouard, P., Sangnier, S., Brughelli, M., Gimenez, P., & Morin, J. B. (2014). Force-velocity profile: Imbalance determination and effect on lower limb ballistic performance. *International Journal of Sports Medicine*, 35(6), 505–510. https://doi.org/10.1055/s-0033-1354382

Sañudo, B., González-Navarrete, Á., Álvarez-Barbosa, F., de Hoyo, M., Del Pozo, J., & Rogers, M. E. (2019). Effect of Flywheel Resistance Training on Balance Performance in Older Adults. A Randomized Controlled Trial. *Journal of Sports Science & Medicine*, 18(2), 344–350.

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. *EQOL Journal*, 11(1), 29–36. https://doi.org/10.31382/eqol.190604

Spudić, D., Kambič, T., Cvitkovič, R., & Pori, P. (2020). Reproducibility and criterion validity of data derived from a flywheel resistance exercise system. *Isokinetics and Exercise Science*, 28, 129–137. https://doi.org/10.3233/ies-194169

Spudić, D., Pori, P., & Cvitkovič, R. (2019). Vpliv velikosti inercijskega bremena na nekatere spremenljivke vadbe za moč. *Šport : Revija Za Teoretična in Praktična Vprašanja Športa*, 67(3/4), 177–184.

Tesch, P. A., Fernandez-Gonzalo, R., & Lundberg, T. R. (2017). Clinical applications of iso-inertial, eccentric-overload (YoYoTM) resistance exercise. *Frontiers in Physiology*, 8(241), 1–16. https://doi.org/10.3389/fphys.2017.00241

Vicens-Bordas, J., Esteve, E., Fort-Vanmeerhaeghe, A., Bandholm, T., & Thorborg, K. (2018). Is inertial flywheel resistance training superior to gravity-dependent resistance training in improving muscle strength? A systematic review with meta-analyses. *Journal of Science and Medicine in Sport*, 21(1), 75–83. https://doi.org/10.1016/j.jsams.2017.10.006