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Rodrigo Fernandez-Gonzalo
Karolinska Institutet

EFFECTS OF INERTIAL SETTING ON POWER, FORCE, WORK, AND ECCENTRIC OVERLOAD DURING FLYWHEEL RESISTANCE EXERCISE IN WOMEN AND MEN

LUIS M. MARTINEZ-ARANDA[1] AND RODRIGO FERNANDEZ-GONZALO[1,2]

[1]*Muscle and Exercise Physiology Laboratory, Department of Physiology and Pharmacology, Karolinska Institutet, Stockholm, Sweden; and* [2]*Radiobiology Unit, Laboratory of Molecular and Cellular Biology, Institute for Environment, Health and Safety, Belgian Nuclear Research Center, SCK•CEN, Mol, Belgium*

ABSTRACT

Martinez-Aranda, LM and Fernandez-Gonzalo, R. Effects of inertial setting on power, force, work and eccentric overload during flywheel resistance exercise in women and men. *J Strength Cond Res* 31(6): 1653–1661, 2017—Exercise load is a key component in determining end-point adaptations to resistance exercise. Yet, there is no information regarding the use of different inertia (i.e., loads) during isoinertial flywheel resistance exercise, a very popular high-intensity training model. Thus, this study examined power, work, force, and eccentric overload produced during flywheel resistance exercise with different inertial settings in men and women. Twenty-two women ($n = 11$) and men ($n = 11$) performed unilateral (in both legs) isolated concentric (CON) and coupled CON and eccentric (ECC) exercise in a flywheel knee extension device employing 6 inertias (0.0125, 0.025, 0.0375, 0.05, 0.075, 0.1 $\mathrm{kg \cdot m^{-2}}$). Power decreased as higher inertias were used, with men showing greater ($p \leq 0.05$) decrements than women (-36 vs. -29% from lowest to highest inertia). In contrast, work increased as higher inertias were employed, independent of sex ($p \leq 0.05$; $\sim$48% from lowest to highest inertia). Women increased CON and ECC mean force (46–55%, respectively) more ($p \leq 0.05$) than men (34–50%, respectively) from the lowest to the highest inertia evaluated, although the opposite was found for peak force data (i.e., peak force increased more in men than in women as inertia was increased). Men, but not women, increased ECC overload from inertia 0.0125 to 0.0375 $\mathrm{kg \cdot m_2}$. Although estimated stretch-shorting cycle use during flywheel exercise was higher ($p \leq 0.05$) in men (6.6%) than women (4.9%), values were greater for both sexes when using low-to-medium inertias. The information gained in this study could help athletes and sport and health professionals to better understand the impact of different inertial settings on skeletal muscle responses to flywheel resistance exercise.

KEY WORDS isoinertial resistance exercise, stretch-shortening cycle, training optimization

INTRODUCTION

Flywheel iso-inertial resistance exercise (RE) was first introduced as a countermeasure for the deleterious effects of microgravity on skeletal muscle (4). Nowadays, flywheel RE is a very popular RE model in elite sports (12,13,40), rehabilitation, and injury prevention programs (2,15,32). In addition, flywheel RE has emerged as a novel conditioning routine for recreational practitioners and the aging population (5). In contrast to traditional constant-load RE where maximal activation is only required at the "sticking point" of the concentric (CON) action (26), the flywheel technology offers accommodated and unlimited resistance during coupled CON and eccentric (ECC) muscle actions using the inertia of a rotating flywheel. Consequently, the loading stimulus has been described as more optimal during flywheel RE compared with conventional RE (29). This is supported by data showing that force, power, and increases in muscle mass and neural activation are typically greater after flywheel RE than after conventional RE (14,15,21,22,28,29). For example, after 5 weeks of flywheel RE, muscle volume increased by 6 vs. 3% increment after 5 weeks of traditional weight stack training (27).

The superior adaptations induced by flywheel RE are explained, at least in part, by the maximal nature of the stimulus throughout the entire CON action and the possibility to generate even greater peaks of force during the ECC phase of the movement (i.e., ECC overload) (39). In addition, the powerful stretch reflex produced in the ECC–CON transition during flywheel RE may also play an important role explaining the robust training adaptations induced by this exercise regimen. Indeed, other training methods, such as plyometric training, use the energy stored during the ECC phase to potentiate the performance of a subsequent CON action (i.e., stretch-shortening cycle; SSC) (41). To date however,

Address correspondence to Dr. Luis M. Martinez-Aranda, luismanuel6049@gmail.com.

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the role of the SSC has not been evaluated in RE using flywheel technology.

Exercise-induced muscle adaptations (e.g., hypertrophy or power) can to some extent be manipulated toward the desired outcome by modifying exercise execution (i.e., speed) and/or load (16,24), at least in exercise routines not calling for muscular failure (25). In supporting this concept, earlier studies reported that high-load, low-speed RE boosted hypertrophic adaptations, whereas low-load, high-speed RE was found to be a better stimulus for power gains (3,33). In the particular case of flywheel RE, however, all repetitions should be performed at maximal intensity, which translates into maximal possible speed during exercise execution. Yet, there is no information regarding the impact of altering the inertia (i.e., loading stimulus) in the adaptive response to flywheel RE.

Studies using flywheel RE have typically employed flywheels with inertias ranging from 0.11 $\text{kg}\cdot\text{m}_2$ (22) to 0.036 $\text{kg}\cdot\text{m}_2$ (15). Even though all repetitions will be executed with maximal voluntary effort, lower inertia allows for more rapid muscle actions, whereas high inertia slows down the exercise execution. These differences in movement velocity will impact the power, force, and work produced during flywheel RE and may consequently influence adaptations to chronic training. Given the great amount of athletes, conditioning professionals and researchers employing this RE paradigm, studies assessing power, force, and work produced during flywheel RE using different inertias are warranted. The information gained from such studies could aid fine-tuning and personalizing flywheel RE training protocols for a wide range of populations, from elite athletes to patients suffering from various diseases.

Although RE-induced muscle adaptations occur in both women and men, there is no consensus about the different/equal magnitude of such adaptations across sexes (1,18,34,37). When employing flywheel RE, hypertrophic adaptations have been reported to be similar across sexes, yet gains in maximal strength and power at high loads may be somewhat greater from men than for women (14). Therefore, any effort to refine flywheel RE protocols should include the analysis of potential sex differences.

The main purpose of this study was to analyze force, power, work, and ECC overload generated during knee extension flywheel RE with 6 different inertias in women and men. In addition, differences in force production during coupled ECC–CON and isolated CON flywheel RE were addressed to indirectly analyze the SSC use. We hypothesized that force, power, and work would differ across sexes and inertias, and that isolated CON actions would call for lower force production than coupled ECC–CON muscle actions, underlining the importance of the SSC during flywheel RE.

METHODS

Experimental Approach to the Problem

Participants performed maximal unilateral (in both legs) isolated CON and coupled CON–ECC tests in a flywheel knee extension device using 6 different inertias, i.e., 0.0125, 0.025, 0.0375, 0.05, 0.075, 0.1 $\text{kg}\cdot\text{m}_2$. Force, power, and work produced were measured, and ECC overload calculated thereafter. In addition, force during isolated CON exercise was also assessed. Before any test using the flywheel knee extension device, participants completed 2 familiarization sessions to ensure appropriate technique during tests. All tests were preceded by a standardized warm-up and performed at the same time of the day (±1 hour). Verbal encouragement was provided by research staff during all tests. Real-time feedback on force and knee angle was provided during familiarization sessions.

Subjects

Twenty-two subjects (11 women; 32.1 ± 4.8 years, 166.2 ± 5.5 cm, 57.9 ± 7.8 kg, and 11 men; 35.4 ± 13.0 years, 177.5 ± 6.3 cm, 75.4 ± 10.4 kg) with no previous muscle joint or bone injury for the past 6 months volunteered for the study. Sample size calculations indicated that for an expected difference of 50% in power produced by men vs. women using flywheel RE (14) and a 25% difference in power generated using inertia 0.05 vs. 0.075 $\text{kg}\cdot\text{m}_2$ (23), 10 subjects per group ensured a statistical power of ~0.80. Subjects were healthy and moderately active individuals, engaged in 2–4 days per week of vigorous ($1.9 \pm 1.0\ \text{h}\cdot\text{wk}^{-1}$) or moderate ($2.0 \pm 1.5\ \text{h}\cdot\text{wk}^{-1}$) exercise. All subjects were requested to avoid strenuous activities and lower-limb RE at least 48 hours before any test. A period of >48 hours was required between test sessions. Information about the study purposes and potential risks associated with the experiments were explained to all subjects before obtaining their written informed consent to participate. The study protocol was approved by the Regional Ethical Review Board in Stockholm (#2014/2174-31/1).

Equipment

All tests were performed on a seated knee extension flywheel device (YoYo Technology Inc., Stockholm, Sweden) (39), equipped with a force sensor (100 Hz; Model 276A, K-Toyo, Korea). During coupled CON–ECC actions, by knowing the inertia used, power (during CON actions) and total work (CON + ECC) were calculated for each repetition by measuring rotational velocity with the aid of a magnetic encoder system and associated software (BlueBrain, nHance, Stockholm, Sweden). Knee joint angular position was measured using electro-goniometry (MuscleLab). Machine settings were individually accommodated for each subject during familiarization and then maintained throughout all tests. Thighs, hip, and chest were fixed to the machine using straps. For the dynamic tests, i.e., isolated CON and coupled CON–ECC tests, the flywheel knee extension device was equipped with wheels providing different inertia (load), corresponding to 0.0125, 0.025, 0.0375, 0.05, 0.075, 0.1 $\text{kg}\cdot\text{m}_2$. The order of dominant vs. nondominant leg was randomized in a counterbalance manner for all tests. The order of inertias employed during CON and CON–ECC exercise was randomized for each subject during familiarization and maintained through all tests. The mean value of 3 repetitions (2 for isometric tests) in each leg in a particular test was considered for further analysis.

Maximal Isometric Torque

Maximal unilateral isometric torque of quadriceps femoris muscle was measured in both legs at 120° knee extension. During 5 seconds, the subject was requested to push, trying to extend the knee, as hard as possible against the crossbar of the knee extension device, which had been adjusted and fixed in the desired position (i.e., 120° knee flexion). Two attempts were performed for each limb. An additional attempt was carried out if trials differed >5% for a given leg. The best score in a 1-second window defined peak isometric torque (21,22). A recovery of 2.5 minutes was allowed between tests in the same leg.

Isolated CON Flywheel Test

Unilateral isolated CON mean torque was measured in both legs in the flywheel knee extension device using the 6 inertial settings previously described. Subjects performed 1 set of 2 CON actions for each leg and inertia, with 2 minutes of recovery between legs and 4 minutes rest between tests in the same leg. Starting from a completely static position, the subject was requested to push as hard as possible from 90° knee flexion to full extension (180°). After a 10-second rest period, a second repetition was carried out.

Coupled CON–ECC Flywheel Test

Subjects performed 6 sets of 3 maximal coupled CON–ECC unilateral repetitions for both legs in the flywheel knee extension ergometer with 2-minute recovery between legs and 4-minute rest between sets in the same leg. Each set was carried out with an inertia corresponding to 0.0125, 0.025, 0.0375, 0.05, 0.075 or 0.1 $\text{kg}\cdot\text{m}_2$. After an initial, submaximal repetition to initiate the flywheel movement, the subject was instructed to push with maximal effort, and therefore as fast as possible, through the entire CON action (i.e., from 90° knee flexion to full extension). Upon reaching full extension, the flywheel strap rewound because of inertial forces, which initiated the ECC muscle action. To produce ECC overload, subjects were requested to resist gently during the first third of the ECC action and then to apply maximal breaking force to stop the movement at about 90° knee flexion (39) (Figure 1). Then, the next CON action was immediately initiated. The ECC overload was calculated in both absolute (Nm = ECC peak force − CON peak force) and relative values (ECC peak force × 100/CON peak force − 100). The SSC during flywheel RE employing different inertias was estimated as follow: (CON force during coupled CON–ECC × 100/CON force during isolated CON − 100). In addition, the coupling time between ECC and CON actions was calculated in the final 15° of the ECC phase and the initial 15° of the CON action.

Statistical Analyses

Data are presented as mean ± standard deviation (*SD*). Statistical analyses were performed using SPSS v.21 (SPSS Inc., Chicago, IL). Data distribution was examined for normality using the Shapiro–Wilk test. A reliability analysis (intraclass correlation coefficient; ICC) was carried out for all outcome measures to determine whether randomized order of the inertias had any impact on the results. Differences between dominant vs. nondominant legs in women and men were analyzed employing a 1-way ANOVA. Isometric values were analyzed using 1-way ANOVA (women vs. men). A 2-way ANOVA (inertia × sex) was used to examined work, power, CON and ECC peak and mean force values, isolated CON and ECC overload during flywheel RE. A 3-way ANOVA (inertia × action × sex) was employed to analyzed potential differences in CON force production during isolated CON vs. coupled ECC–CON actions (i.e., estimated SSC use). When significant interactions were found, simple effect tests were employed, and the false discovery rate procedure was used to compensate for multiple post hoc comparisons (11). The significance level was set at 5% ($p \leq 0.05$). Effect sizes (ES) were calculated as follow: ([mean A − mean B]/*SD* A) (31). Interpretation of the magnitude of the ES was performed as follow: <0.35, 0.35–0.8, 0.8–1.5, >1.5 for trivial, small, moderate, and large, respectively (31).

RESULTS

The reliability analysis showed no impact of the order of inertias on the data recorded, as indicated by ICC values >0.9. Preliminary analysis showed no significant differences ($p > 0.05$) between dominant vs. nondominant legs in any of the variables measured, and therefore this variable was not considered for further analysis. A significant ($p < 0.0005$) main effect of sex was found in all variables analyzed, except for ECC overload in relative values (%) (see below). Thus, men showed greater absolutes values compared with women in maximal isometric torque (211.3 ± 39.0 vs. 120.4 ± 39.9 Nm; $F = 58.3$, $p < 0.0005$) (ES = 2.33) and in all variables measured during isolated CON and CON–ECC flywheel tests ($p < 0.0005$). Given that sex differences in absolute values were so evident, they are not indicated in tables and figures unless specifically stated.

Coupled CON–ECC Flywheel RE

There was an inertia × sex interaction for power data ($F = 10.2$; $p < 0.0005$). Thus, power values in men decreased to a greater extent across the different inertias used when compared with women (Figure 2A). The percentage of power loss between the lowest and the highest inertia for men and women was 36.1% (ES = 0.97) and 29.1% (ES = 0.68), respectively. In addition, overall power values were 43.7% lower in women than in men (main effect of sex; $F = 20.9$, $p < 0.0005$).

There was no inertia × sex interaction for work output during flywheel RE. However, there was a main effect of

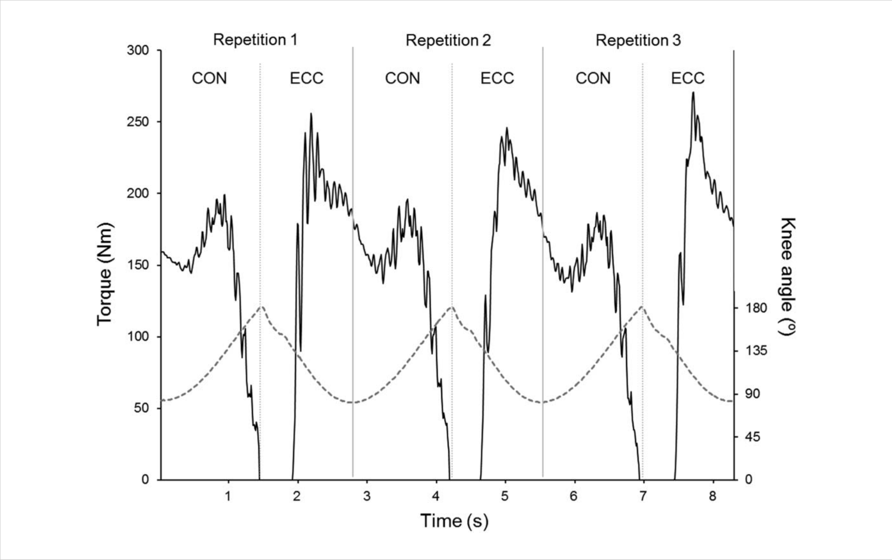

Figure 1. Example of 1 set of 3 repetitions of coupled concentric (CON) and eccentric (ECC) flywheel resistance exercise using inertia 0.075 $kg\cdot m_2$.

inertia ($F = 124.3$, $p < 0.0005$) because of greater work values in both men (ES = 1.04) and women (ES = 1.23) as inertia was increased (Figure 2B). In addition, there was a main effect of sex ($F = 24.1$, $p < 0.0005$). Thus, men produced more work than women in all inertias analyzed.

There was an inertia × sex interaction for both mean and peak force during CON and ECC actions (F range = 3.4–6.4; $p \leq 0.05$; Table 1). Thus, greater CON and ECC force values were obtained as inertia was increased (ES > 0.9 for men and women in both CON and ECC actions). Interestingly, women were able to increased CON mean force more than men in relative terms (46 vs. 34%) from the lowest to the highest inertia employed. Similarly, ECC mean force increased more in women than in men from the lowest to the 0.075 $kg\cdot m_2$ inertia (55 vs. 50%). However, increments in peak force as inertia was increased were greater in men than women for both CON (ES = 1.01 for men and 0.72 for women) and ECC actions (ES = 1.05 for men and 0.64 for women) (Table 1). Overall, men had greater peak and mean CON and ECC force values in absolute terms than women for a given inertia (main effect of sex; F range = 39.6–44.1; $p < 0.0005$). An interaction inertia × action ($F = 45.6$; $p < 0.0005$) was found for coupling time in ECC and CON actions. Thus, the time to complete the first 15° of the CON action increased more than the time employed to perform the last 15° of the ECC phase as inertia increased (Table 1) (ES = 4.71 for men and 3.60 for women in CON phase; ES = 3.71 for men and 3.33 for women in ECC phase). In addition, men had overall lower values of both ECC (16%) and CON (15%) coupling time compared with women.

During coupled CON–ECC flywheel RE, ECC actions showed higher peak force than CON actions in all inertias (inertia × action interaction; $F = 2.9$; $p = 0.015$) (see example in Figure 1), independently of sex. When analyzing this difference (i.e., ECC overload), there was an inertia × sex

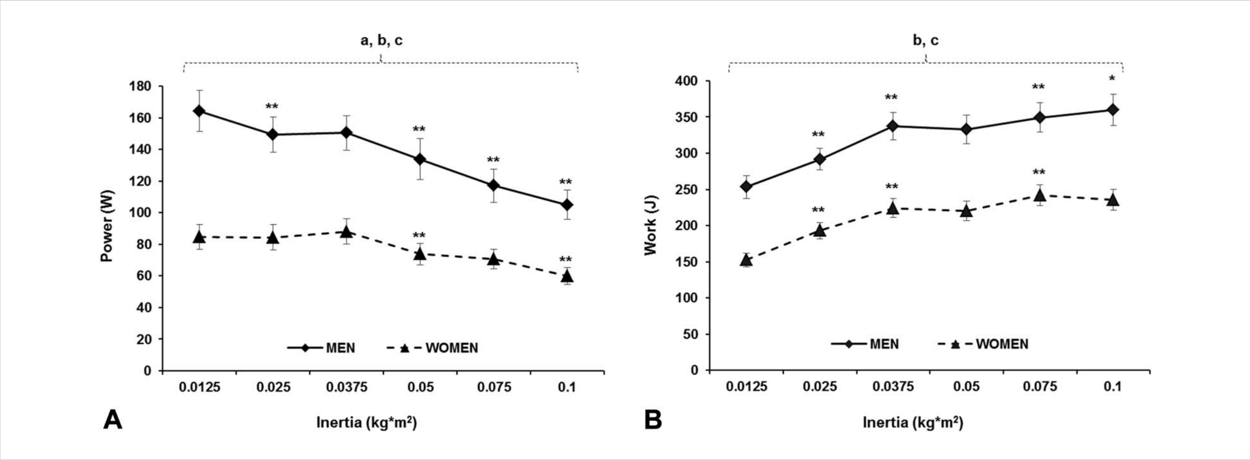

Figure 2. Power (A) and work (B) data across inertias in women and men. Significant effects ($p \leq 0.05$): a, inertia × sex interaction; b, main effect of sex; c, main effect of inertia. Significant *post hoc* differences: *($p \leq 0.05$), and **($p < 0.01$) vs. previous (lower) inertia. Data as mean ± standard error of the mean.

Table 1. Force (Nm), coupling time (s), and stretch-shortening cycle use (%) during flywheel resistance exercise employing different inertias.*†

Inertia in kg·m_2	0.0125	0.025	0.0375	0.05	0.075	0.1
CON peak‡§‖						
Men	122.0 ± 25.3	146.3 ± 31.5¶	152.5 ± 36.0¶	155.9 ± 40.2	158.2 ± 38.3	161.1 ± 38.7
Women	76.5 ± 17.6	90.9 ± 23.9¶	92.7 ± 26.0	95.3 ± 27.6	101.1 ± 30.4¶	98.3 ± 30.0
CON mean‡§‖						
Men	80.8 ± 20.5	97.3 ± 21.7¶	102.0 ± 24.6¶	104.4 ± 27.2#	107.9 ± 29.1¶	108.7 ± 29.5
Women	44.6 ± 13.9	56.5 ± 18.0¶	59.4 ± 18.5¶	61.0 ± 20.4	64.3 ± 20.6¶	65.3 ± 20.9
ECC peak‡§‖						
Men	142.9 ± 27.9	173.1 ± 35.4¶	186.8 ± 48.5¶	187.0 ± 47.8	193.2 ± 50.0	192.7 ± 47.3
Women	93.4 ± 16.0	109.5 ± 26.2¶	111.9 ± 31.0	111.6 ± 33.6	117.6 ± 34.6	114.3 ± 32.2
ECC mean‡§‖						
Men	91.0 ± 17.0	122.3 ± 25.3¶	132.8 ± 33.6¶	134.1 ± 35.2	137.2 ± 39.5	134.5 ± 36.2
Women	52.9 ± 14.3	72.1 ± 22.5¶	79.2 ± 25.6¶	78.4 ± 24.7	82.1 ± 26.5	78.4 ± 24.3
Isolated CON mean‡§‖						
Men	77.1 ± 16.3	90.1 ± 21.0¶	93.3 ± 20.0¶	98.4 ± 25.0¶	102.7 ± 26.2¶	106.0 ± 26.4¶
Women	43.4 ± 12.1	53.1 ± 15.3¶	55.6 ± 16.6#	58.3 ± 17.3#	61.9 ± 19.4¶	63.7 ± 19.9
Coupling time ECC§‖**††						
Men	0.25 ± 0.04	0.27 ± 0.04#	0.32 ± 0.06¶	0.35 ± 0.07¶	0.45 ± 0.05¶	0.51 ± 0.07¶
Women	0.30 ± 0.05	0.32 ± 0.06	0.38 ± 0.07¶	0.44 ± 0.08¶	0.52 ± 0.09¶	0.60 ± 0.09¶
Coupling time CON§‖**††						
Men	0.25 ± 0.04	0.30 ± 0.04¶	0.35 ± 0.06¶	0.40 ± 0.08¶	0.50 ± 0.06¶	0.58 ± 0.07¶
Women	0.30 ± 0.04	0.35 ± 0.06¶	0.41 ± 0.06¶	0.49 ± 0.08¶	0.58 ± 0.10¶	0.66 ± 0.10¶
SSC‖						
Men	4.4 ± 10.2	9.1 ± 13.1	9.7 ± 13.7	7.4 ± 15.5	5.6 ± 13.1	3.1 ± 15.4
Women	3.8 ± 18.6	6.5 ± 11.9	7.5 ± 12.4	4.7 ± 12.3	4.1 ± 8.3	3.1 ± 12.9

*CON = concentric; ECC = eccentric; SSC = stretch-shortening cycle expressed in relative values (FL CON mean × 100/isolated CON − 100).
†Data as mean ± *SD*.
‡Significant effects ($p \leq 0.05$): inertia × sex interaction.
§Significant effects ($p \leq 0.05$): main effect of sex.
‖Significant effects ($p \leq 0.05$): main effect of inertia.
¶Significant *post hoc* differences: $p < 0.01$ vs. immediately previous (lower) inertia.
#Significant *post hoc* differences: $p \leq 0.05$.
**Significant effects ($p \leq 0.05$): main effect of action.
††Significant effects ($p \leq 0.05$): inertia × action interaction (ECC–CON).

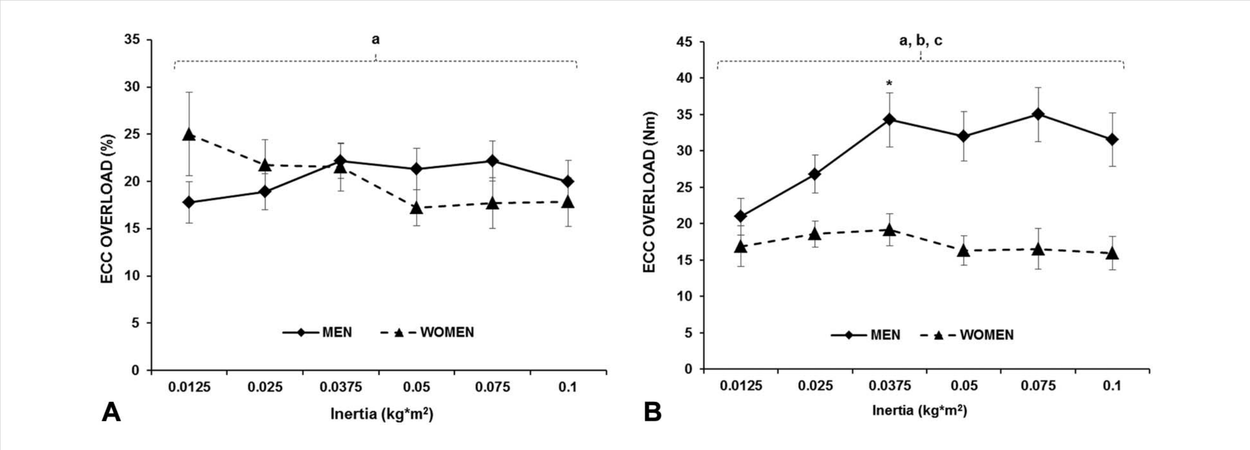

Figure 3. Eccentric (ECC) overload expressed in relative (A) and absolute (B) values across inertias in women and men. Significant effects ($p \leq 0.05$): a, inertia × sex interaction; b, main effect of sex; c, main effect of inertia. Significant *post hoc* differences: *($p < 0.01$) vs. previous (lower) inertia. Data as mean ± standard error of the mean.

interaction ($F = 2.4$; $p = 0.04$), for ECC overload (expressed as %). Thus, in relative terms (%), men tended to increase ECC overload as inertia was increased from 0.0125 to 0.0375 kg·m$_2$, whereas women showed decreased ECC overload from the lowest to the 0.05 kg·m$_2$ inertia (Figure 3A). The highest ECC overload value was 22% for men (inertia 0.0375 kg·m$_2$) and 25% for women (inertia 0.0125 kg·m$_2$) (Figure 3A). When analyzed in absolute values (i.e., Nm), there was an inertia × sex interaction ($F = 2.9$; $p \leq 0.05$) because of increased ECC overload in men from the 0.0125 to the 0.0375 kg·m$_2$ inertia (ES = 0.77). This response was not found in women, where ECC overload remained practically unchanged across inertias (Figure 3B). The highest value of ECC overload (Nm) was 35.0 Nm (inertia 0.075 kg·m$_2$) and 19.2 Nm (inertia 0.0375 kg·m$_2$) for men and women, respectively (Figure 3B).

Isolated CON and SSC Use During Flywheel RE

An interaction inertia × sex ($F = 4.0$; $p = 0.002$) was found for force produced during isolated CON action. Thus, force values increased to a greater extent in women (47%; ES = 1.02) than in men (37%; ES = 1.09) from the lowest to the highest inertia (Table 1).

There was an inertia × sex interaction ($F = 4.9$; $p < 0.0005$) for estimated SSC use during flywheel RE. Although men had overall greater values for SSC use in all inertias (except 0.1 kg·m$_2$), both sexes showed higher SSC use during exercise employing low-medium inertias (i.e., 0.025 and 0.0375 kg·m$_2$). The inertia inducing greater SSC use was 0.0375 kg·m$_2$ for both men (9.7%) and women (7.5%) (Table 1).

DISCUSSION

This study analyzed power, work, force, and ECC overload produced during knee extension flywheel RE using 6 different inertial settings. In addition, potential differences across sexes were assessed, and SSC use was estimated. In agreement with the hypothesis, there were important differences in force, power, and work across inertias used, and between men and women. We also report that performing RE using this particular technology allows for a substantial SSC use, which was maximized by using medium inertias in both sexes.

Despite the visible and evident differences in movement velocity during flywheel RE employing different inertial settings, this is the first investigation reporting the power, work, and force produced across a wide range of inertias. Given that these RE variables could affect muscle and functional adaptations to chronic training (16,24,35), the data presented here could aid in fine-tuning exercise protocols employing flywheel RE. From the existing literature, we were only able to identify 3 investigations where an inertia selection process was carried out before commencing a flywheel RE training period (12,13,40). In these studies, the inertia selection was rather simplistic, comparing the maximal power developed across 2 different inertial settings. Our results showing decreased power as inertia increased may indicate that other variables apart from power (i.e., work output) should be considered when selecting the best inertia for a particular purpose.

Across the inertial settings analyzed, power values were ~44% lower in women than in men, confirming previous reports employing traditional RE (9,20). Interestingly, power across the different inertias used was also different between men and women, with greater decrements from the lowest to the highest inertia in men than in women. These results are supported by previous investigations employing conventional RE, where sex differences in power or peak velocity between men and women were greater when light loads were employed, and differences decreased as resistance was increased (9,30). Differences in power outcome during RE as loads increase across sexes may be because of (a) a better capacity of women to maintain movement velocity as inertia increases, and/or (b) an inability of women, when compared with men, to increase movement velocity with very light inertias/loads, and/or (c) lean body mass differences across sexes. Thus, although the mechanism(s) for power differences between men and women in light vs. high inertias/loads is still unknown, it appears that sex is a variable to consider when selecting the inertia to be employed during flywheel RE. In addition, studies employing flywheel RE in women and men should take into account potential differences in muscle/lean body mass because this factor may help explaining some of the differences across sexes shown in the current study.

In line with the general understanding of the force–velocity relationship (17), force values during CON and ECC actions increased during flywheel RE because inertia increased in both men and women. Similarly, a recent study using free weights also reported greater peak force values during higher vs. lower loads (9). The authors used those data to recommend higher loads to improve force producing capacity (9). In the current study, the relative increments in peak CON and ECC force were greater in men when compared with women as inertia was increased. In contrast, women increased CON and ECC mean force more than men in relative terms, from the lowest to the highest inertia. Therefore, our data indicate that men and women may respond differently to inertia increments, with men relying more on short and explosive moments of great force production (increased peak force), whereas women rather produce lower peak forces but they are able to maintain force levels for a longer period within the muscle action (increased mean force). The different response across sexes in the coupling time of both ECC and CON actions is another indication of the more explosive capacity of men compared with women. These data seem to be supported by previous research showing sex differences in skeletal muscle structure (i.e., greater area of type I, slow, fatigue-resistant fibers in women than men vs. greater type II, fast-explosive fibers in men compared with women) (36). In addition, the fact that men increased peak force more than women because inertia/load was higher could explain, at least partly, the greater gains in maximal force and peak power at high loads in men than women previously reported after flywheel RE (14).

The ECC overload that can be produced during flywheel RE is a critical feature of the exercise model that has been used to partly explain the greater muscle adaptations induced by this exercise paradigm when compared with conventional RE (27–29). Our results indicate that ECC overload can be generated during knee extension flywheel RE in all inertias analyzed, ranging from 17 to 25% (i.e., 17–25% more peak force production during ECC compared with CON), which confirms previous reports from our laboratory (14). Given the greater capacity of the muscle to produce force during ECC vs. CON actions (19,38), it seems ECC overload is critical to offer an appropriate stimulus to maximize neural drive and muscle use (7). The current data indicate that men have a greater capacity than women to generate ECC overload during flywheel RE. In women, the greater ECC overload in relative terms occurred at the lightest inertia employed (i.e., highest velocity), which confirms results from earlier research showing women produced significantly more ECC force, relative to CON, than men only at very high movement velocities (8).

The SSC is often described as the ability to store energy during the ECC muscle action to potentiate the subsequent CON action (6). In a recent study, we inferred that flywheel RE training could emphasize the stretch reflex and the SSC use, which would boost neural adaptations after a period of training (15). The current results showed lower force in isolated CON compared with force during the CON phase in coupled ECC–CON muscle actions. Although this has been described before using traditional RE models (10), our results are the first indicating significant SSC use during flywheel RE. Thus, the inertia 0.0375 $\mathrm{kg \cdot m_2}$ showed the highest (estimated) SSC use independent of sex. The particular benefits that may be associated with such strategy, and the magnitude of potential differences with other RE modes, remain to be investigated.

In summary, this study assessed power, work, peak and mean CON and ECC force, ECC overload, and the SSC use during knee extension flywheel RE in men and women using 6 different inertial settings. Power decreased because higher inertias were used and more so in men than in women. In contrast, work increased because higher inertias were employed independently of sex. Women increased CON and ECC mean force more than men as greater inertias were used. Yet, peak force increments were higher in men than in women as inertia increased. Although men increased ECC overload from inertia 0.0125 to 0.0375 $\mathrm{kg \cdot m_2}$, ECC overload was rather constant across the inertias analyzed in women. Men produced slightly higher SSC than women, yet values were greater for both sexes when using low-to-medium inertias. The information gained by this study highlights that manipulating the inertial setting during flywheel RE will modify the stimulus imposed on the muscles. Future training studies are necessary to elucidate whether differences in inertial settings translate into different flywheel RE-induced muscle adaptations.

PRACTICAL APPLICATIONS

Isoinertial flywheel resistance exercise is a time-effective method to increase force, power, and muscle mass. Given the extensive use of this training paradigm in elite sports, rehabilitation and clinical settings, and among recreational practitioners, we believe that current results will help designing and fine-tuning new training programs employing flywheel RE. Indeed, this is the first study describing the impact of inertia (i.e., load) on RE variables that could influence end-point training adaptations. Considering the power, work, ECC overload, and SSC use data, the inertia of 0.0375 $kg \cdot m_2$ seems as an appropriate choice for general conditioning purposes in both women and men. In contrast, athletes looking for explosive adaptations may use lower inertias calling for a shorter ECC–CON coupling time and greater power production, whereas practitioners pursuing greater work output during RE should employ higher inertias. In addition, modifying the inertial setting during flywheel RE may affect women and men differently in terms of force and power produced, and ECC overload achieved.

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