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Article

The Relationship between Bodyweight, Maximum and Relative Strength, and Power Variables during Flywheel Inertial Training

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Abstract: The main aim of this study was to examine the relationship between body weight, absolute and relative strength and power variables in a flywheel Romanian deadlift. A secondary aim was to assess the inter-day reliability of a novel power assessment protocol previously used to determine the inertial load that produced the maximum power output in Flywheel Inertia Training. Ten physically active males took part in this study. Participants had some experience with flywheel devices, but all had a minimum of 24 months of traditional resistance training experience. The first testing session consisted of three sets of 10 repetitions with a different inertial load for each set (0.050, 0.075, and 1.00 kg·m^2). Each set's first and second repetitions were used to build momentum and were excluded from data analysis. The order of inertial load used in each trial was standardized for all participants: first, 0.050 kg·m^2, second, 0.075 kg·m^2, and last, 0.100 kg·m^2. The secondary testing session followed the same procedure as the first. No statistically significant (p < 0.05) effect was found between any of the variables in the correlation analysis. There were large positive correlations between the 1 repetition max flywheel Romanian deadlift and peak concentric power, relative strength, and peak concentric and eccentric peak powers. Both body weight and relative strength showed moderate negative correlations with % eccentric overload, whereas moderate positive correlations were observed between 1RM and peak eccentric power. Both concentric power and eccentric power showed excellent reliability, while the reliability for % eccentric overload ranged from poor to excellent depending on the inertial load. In conclusion, this study shows that a protocol to assess the maximum power output has excellent reliability for both ECC and CON power and may be used in future flywheel training. The results also showed that body weight, maximum strength, and relative strength were not largely related to power variables. An individualized approach to flywheel training is required.

Keywords: flywheel inertia training; inertial load; maximum power output; eccentric overload; relative strength

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1. Introduction

Flywheel devices (FD) were first designed to support the maintenance of skeletal muscle mass in astronauts during exposure to non-gravity environments during space travel [1]. Flywheels or inertial devices provide resistance through the inertia generated by the rotating flywheels [2]. During the concentric (CON) phase, the exerted force unwinds a strap attached to the shaft of the device, which then begins to rotate the flywheel. The strap rewinds when the CON action is finished, and the user must resist the device by performing a braking eccentric (ECC) muscular action [3], which can generate an ECC overload (i.e., greater ECC than CON force production) [4–6]. With studies reporting benefits such as increased electromyographic activity [7], improved sprint performance, change of direction, jump performance [5,8], and positive hypertrophic adaptations [4], this training modality appears to be a viable alternative to traditional resistance training.

When prescribing flywheel training, several variables, such as the exercise utilized, the level of the participant's experience, the inertial load used, and the power variable chosen for the analysis, are all important and must be considered [9]. These variables have recently received attention and have been discussed in the literature. Previous studies have investigated the effects of inertial loads in different exercises such as the flywheel squat [10], leg curl [11], and Romanian deadlift [12] with medium-to-high loads advised to maximize ECC overload, whereas lighter loads have been shown to be more suitable for peak power production. The number of training sessions required to obtain stable and reliable results as well as the number of exercise repetitions, with various inertial loads required to maintain CON and ECC peak power, have both been previously explored [10], with 2–3 sessions being advised depending on the exercise being used. It is commonly acknowledged that previous experience with FD may modify the training stimulus [13].

The relative strength of an individual is another variable that needs to be considered. Various studies have provided some measure of the absolute strength of included participants [6,14–16], but few studies have provided relative strength measures [10]. To achieve ECC overload, stronger individuals may require higher CON velocities or larger inertial loads during flywheel training. However, weaker individuals may attain an ECC overload at various inertial loads owing to their limited capacity to tolerate and produce significant ECC forces [17]. Studies evaluating individual characteristics and their interaction with flywheel training are warranted, given the large number of strength and conditioning specialists and researchers currently using this training modality. Such research could aid in the fine-tuning and individualization of flywheel training protocols.

To the best of the author's knowledge, no study has investigated the effects of relative strength on power variables in flywheel training. Therefore, the main aim of this study was to examine the relationship between body weight and the absolute and relative strength and power variables in a flywheel Romanian deadlift exercise. A secondary aim was to assess the inter-day reliability of a novel power assessment protocol previously used [9] to determine which inertial load produced the maximum power output using an FD. Such an assessment has been used previously to assess which inertial load produces maximum power output in both a flywheel squat [5,9,18] and leg curl [5] exercises, but not in hip extension exercises such as a Romanian deadlift.

2. Materials and Methods

2.1. Participants

Ten physically active males (Table 1) participated in this study. Participants had some experience with FD, but all had a minimum of 24 months of traditional resistance training experience. The participants did not perform resistance training 48 h before any testing or familiarization sessions. To be included in the study, participants had to complete all the familiarization and test sessions and not have suffered any injuries in the three months leading up to the assessment. The participants were informed of the research objectives, participated voluntarily, and could withdraw from the study at any time. Written informed consent was obtained from all participants. The study adhered to the guidelines of the Declaration of Helsinki (2013) and was approved by the Institute of Technology Carlow (Code: C00232530).

Table 1. Participant descriptive data (mean ± SD).

	Age (Years)	**Height (cm)**	**Mass (kg)**	**1RM (kg)**	**Relative (kg/Mass)**
Participants	24 ± 2.5	176.7 ± 7.7	82.2 ± 11.4	126.4 ± 23.9	1.53 ± 0.2

2.2. Methods and Materials

This research analyzed the power output from several trials in the flywheel Romanian deadlift. Participants attended two familiarization sessions, which were advised to stabilize their values when using FD [19]. Participants were also instructed on both the flywheel and traditional Romanian deadlift techniques. Each participant took part in two separate testing sessions. The initial testing session and last familiarization session were separated by 72 h to avoid the effects of muscular fatigue and the delayed onset of muscle soreness. An active warm-up of 15 min preceded all tests. Five minutes of low-intensity jogging was followed by dynamic stretching of the gluteal, hamstrings, adductors, quadriceps, and gastrocnemius muscles, followed by a set of eight submaximal Romanian deadlift repetitions on the FD (kBox 3, Exxentric, AB TM, Bromma, Sweden) at 0.050 kg·m^2.

The first testing session consisted of three sets of ten repetitions with different inertial loads for each set (0.050, 0.075, and 1.00 kg·m^2). The first and second repetitions of each set were used to build momentum and were excluded from the data analysis. The order of inertial load used in each trial was standardized for all participants: first, 0.050 kg·m^2, second, 0.075 kg·m^2, and last, 0.100 kg·m^2. An adequate (4 min) inter-set rest period was provided to enable sufficient recovery and cessation of fatigue. The same procedure was followed in the secondary testing session.

When performing the exercise, the participants stood on the FD directly over the drive belt while holding the handlebar attached to the drive belt strap (Figure 1). Participants were instructed to flex their hips while keeping their knees stationary until their hips were at 90° and their trunk was parallel to the floor. To begin the CON phase of the lift, participants were instructed to extend their hips with maximum effort. Once full extension was reached, the participants flexed the hips again and attempted to stop the flywheel using a braking action, the ECC phase of the lift. This movement was repeated for the desired number of repetitions. The participants were instructed not to shrug their shoulders at complete hip extension, and ankle extension was not permitted. The participants were instructed to perform the CON phase as quickly as possible, resist the inertial force softly throughout the first third of the ECC action, and stop the movement at the end of the range of motion with maximal effort. Verbal encouragement was provided to the participants during all sessions. During all repetitions, the power output was recorded using a data reader and transmitter (Kmeter, Exxentric, ABTM, Bromma, Sweden) attached to the FD. Data were then transmitted and recorded via Bluetooth on an iOS device (iPad mini, Apple Inc., Cupertino, CA, USA).

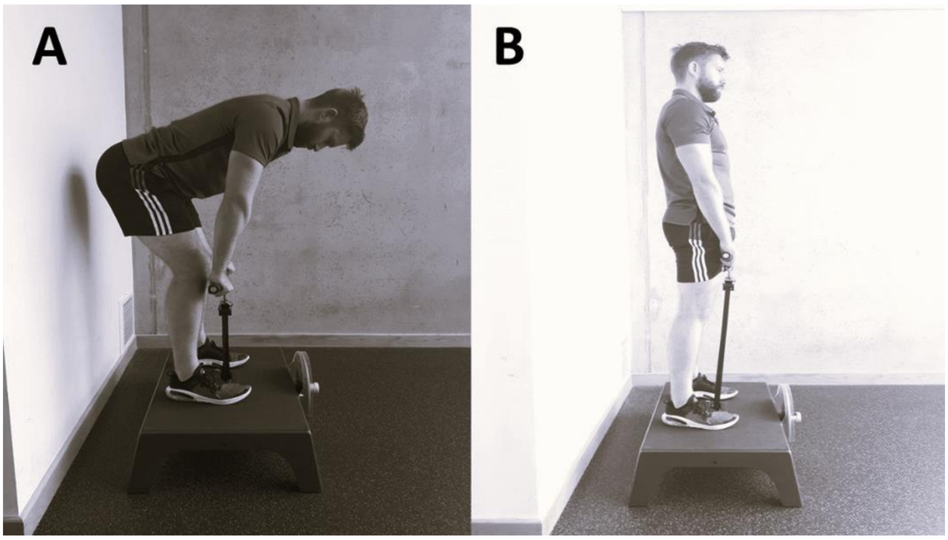

Figure 1. (**A**) start position, (**B**) point of change from CON to ECC phase.

2.2.1. Power Measurements

The variables used for data analysis were peak CON power, peak ECC power, and the ratio between ECC peak power and CON peak power, reported as the % ECC overload and calculated as (ECC peak power − CON peak power/CON peak power) × 100 [10]. Peak CON, peak ECC, and % ECC overload for each inertial load on both testing days were recorded for reliability analysis, whereas the peak value from each variable over both days was recorded for correlation analysis, regardless of which inertial load achieved it.

2.2.2. Measurements

The maximal dynamic strength was assessed using the 1RM Romanian deadlift. All participants received a thorough technical session before the test to acquaint them with the Romanian deadlift and ensure their ability to perform it safely. Once the appropriate technique was demonstrated, the participants were cleared to participate in the testing session. The Romanian deadlift-specific warm-up consisted of five repetitions at 40–60% of their perceived 1RM; after three minutes of full recovery, they performed three repetitions at 60–80% of their perceived maximum. The load was continuously increased until the athletes could not perform another trial using the required technique. The maximum weight they could lift for one repetition was recorded for data analysis. During testing, lifting straps were used to ensure that the weight was maximal and was not limited by the grip strength of the subjects.

2.3. Statistical Analysis

All statistical analyses were performed using JASP software version 0.9.1 (Amsterdam, Netherlands) for Windows. Data are presented as mean ± standard deviation (SD). Normality was assessed for all variables using the Shapiro–Wilk statistical test. The absolute reliability and relative reliability of power variables were assessed using the coefficient of variation (CV) and intraclass correlation coefficient (ICC), respectively. ICC and 95% CI values less than 0.5, between 0.5 and 0.75, between 0.75 and 0.9, and greater than 0.90 revealed poor, moderate, good, and excellent reliability, respectively [20]. The coefficient of variation (CV) was considered acceptable, with values <5% and between 5% and 10%, respectively [21]. The relationships between the strength variables and inertial load were determined using the Pearson product–moment correlation. Correlations were evaluated as small (0.1–0.3), moderate (0.3–0.5), large (0.5–0.7), very large (0.7–0.9), nearly perfect (0.9–1.0), and perfect (1.0) [22]. Statistical significance was set at $p < 0.05$.

3. Results

Participants' descriptive data (mean ± SD) are shown in Table 1. The inter-day reliability of the outcome measures with each inertial load between sessions 1–2 is reported in Table 2. All variables were normally distributed. Both concentric power and eccentric power showed excellent reliability, while the reliability for % eccentric overload ranged from poor to excellent depending on the inertial load. Only participants who performed all the testing sessions were included in the reliability analysis ($n = 10$). The descriptive statistics (mean ± SD) for all inertial variables are presented in Table 3. Pearson correlation coefficients between inertial variables and body weight, absolute strength, and relative strength are shown in Table 4. No significant effect ($p < 0.05$) was found between any of the variables in the correlation analysis. There were large positive correlations between the 1RM and peak CON power, relative strength, and peak CON and ECC peak powers. Both body weight and relative strength showed moderate negative correlations with % ECC overload, while moderate positive correlations were observed between 1RM and peak ECC power. All the other relationships showed a small correlation.

Table 2. Reliability of the variables considered in the study between sessions 1–2.

Variable	1–2 ICC (95% CL)	ICC Interpretation	CV %
Pcon 0.05 kg·m^2	0.99 (0.99–1.00)	Excellent	0.06
Pecc 0.05 kg·m^2	0.98 (0.92–1.00)	Excellent	2.98
% OL	0.52 (0.16–0.86)	Moderate	45.79

Table 2. *Cont.*

Variable	1–2 ICC (95% CL)	ICC Interpretation	CV %
Pcon 0.075 kg·m^2	0.94 (0.77–0.99)	Excellent	1.54
Pecc 0.075 kg·m^2	0.93 (0.74–0.98)	Excellent	4.11
% OL	0.82 (0.40–0.95)	Good	11.69
Pcon 1.00 kg·m^2	0.94 (0.77–0.99)	Excellent	0.72
Pecc 1.00 kg·m^2	0.98 (0.92–1.00)	Excellent	0.98
% OL	0.92 (0.71–0.98)	Excellent	13.23

Pcon = Peak CON power output; Pecc = Peak ECC power output; % OL = percentage ECC overload; ICC = Reliability; CL = Confidence limits, CV = Coefficient of Variation.

Table 3. Descriptive statistics (mean ± SD) for all inertial variables.

	Pcon (W)	Pecc (W)	%OL (W)
Participants	865.8 ± 328.8	931.6 ± 345.4	19.7 ± 18.1

Pcon = Peak CON power output; Pecc = Peak ECC power output; % OL = percentage ECC overload; W = Watts.

Table 4. Correlation matrix between inertial variables and mass, absolute and relative strength.

	Pcon	Pecc	%OL
Bodyweight	0.19 (0.82 to −0.69)	0.28 (0.85 to −0.60)	−0.31 (0.86 to −0.57)
1RM	0.51 (0.91 to −0.38)	0.48 (0.90 to −0.42)	−0.08 (0.71 to −0.78)
Relative	0.65 (0.94 to 0.20)	0.50 (0.91 to −0.40)	−0.44 (0.46 to −0.90)

The results are presented as r (95% CI). Pcon = Peak CON power output; Pecc = Peak ECC power output; % OL = percentage ECC overload.

4. Discussion

This study aimed to analyze the relationship between individual characteristics, body weight maximum and relative strength, and power variables during flywheel training, specifically the flywheel Romanian deadlift. The study also assessed the inter-day reliability of a protocol to determine the inertial load that produced the maximum power output. The main findings of this study were that there were large positive correlations between 1RM and peak CON power and relative strength and peak CON and ECC peak power, although no significant relationship ($p < 0.05$) was found between variables. All other variables showed low to moderate correlations. A protocol to determine which inertial load produced the maximum power output showed excellent reliability for both CON and ECC powers over all inertial loads. However, the % ECC overload exhibited moderate to excellent reliability over different inertial loads.

The current study showed excellent reliability values for both CON and ECC peak powers, but % ECC OL demonstrated moderate to excellent values. An inconsistency was observed across all inertial loads in % ECC OL. The smallest inertial load (0.05 kg·m^2) showed the lowest reliability 0.52 (0.16–0.86), whereas the highest inertial load (1.00 kg·m^2) showed the highest reliability 0.92 (0.71–0.98). This inconsistency in this variable has been reported in previous research [10,11]. Considering the inconsistency of inertial loads, this variable should be used cautiously. The current study showed higher reliability for % ECC OL than previous studies [10,11], but it should be noted that different flywheel exercises were used; therefore, the results may not be fully comparable to those of previous studies. Participant familiarization may have affected the results. A previous study [23] reported that participants with experience in flywheel training achieved higher ECC peak power than CON peak power, resulting in ECC overload, whereas participants with no previous experience did not. Participants in the current study had more flywheel training experience compared to participants in previous research [10,11], which may account for the higher reliability values shown in this study for % ECC OL and suggests that this variable may be sensitive to flywheel training background. This study had comparable reliability results for both CON and ECC peak powers with previous research [8,10,11]. Another more recent study [18] investigated the reliability of a flywheel squat test to measure both CON and ECC power outputs and showed excellent reliability with ICC and CV% ranging from 0.92 to 0.97 and from 2.0% to 5.9%, respectively. These findings are again in line with the current study, which highlights the fact that the CON and ECC power variables are reliable and stable across inertial loads and can be used during flywheel training.

This study highlights the reliability of a protocol to determine which inertial load produces maximum power output; however, previous familiarization with flywheel training is warranted. Previous research suggests that to achieve reliable measures in a flywheel squat exercise [10], two to three familiarization sessions are required, but four sessions are warranted in a flywheel leg curl exercise [11]. These authors proposed that a certain amount of coordination is needed to execute the movement correctly, and that a learning period is required to become comfortable with ECC overload devices, which implies that even in highly trained athletes who have never performed ECC overload training, the time of movement learning is three to four sessions. It may also be possible that less complex exercises such as a flywheel leg curl or leg extension may require shorter familiarization periods than more complex exercises such as flywheel squats or Romanian deadlifts, but further research is needed.

The current study found no significant relationship ($p < 0.05$) between variables but large positive correlations between 1RM and peak CON power, relative strength, and both peak CON and ECC peak power, with all other variables showing low to moderate correlations. These findings suggest that maximum and relative strength may be more associated with CON and ECC peak power than body weight, but neither shows excellent relationships, suggesting that flywheel training requires an individualized approach. It may be feasible to consider that both maximum and relative strengths would have a strong relationship with power variables when considering the flywheel principle itself. It is plausible to suggest that stronger individuals would produce a large CON muscle contraction during the unwinding of the flywheel's strap, resulting in a large CON peak power output, while also demonstrating a large ECC strength to aggressively decelerate the flywheel, resulting in large peak ECC power and ECC overload outputs. However, the current study suggests that this is not the case.

A constraint that may alter the training stimulus is the technique used. According to previous research, the most effective method for achieving peak power values is to gently resist the inertial force during the first third of the ECC action and then exert maximum effort to decelerate the spinning flywheel and bring it to a halt at the end range of motion [24]. However, it has previously been noted that individuals may not always adopt this optimal technique [17]. Increases in inertial load increased the ECC peak and mean force in both moderately active men and women [25]; however, there was no additional increase in the ECC stimulus beyond a 0.0375 $\text{kg}\cdot\text{m}^2$ inertial load during a flywheel squat. These findings could be explained in part by the deceleration strategies of individuals for larger inertial loads. According to a previous study [25] ECC duration increased from a small to a large extent in males and to a moderate extent in women as the inertial load increased. It is plausible that the participants attempted to slow down the squat descent in anticipation of a more complex stimulus at the end of the movement, which would diminish the ECC force generated. This suggests that an individual's technique may change the training stimulus and negate the effects of maximal and relative strengths.

Another constraint may be the participant's strength. As discussed earlier, owing to their ability to handle larger loads, stronger athletes require a more significant overload stimulus than weaker athletes. This study found a low to moderate relationship between maximum strength and ECC overload. In addition, stronger athletes may not experience the same ECC overload stimulation as weaker athletes owing to the stronger athlete's ability to adapt a more compliant technique to slow down the ECC load and control the movement to a greater extent [26]. Participants may have had adequate resistance training experience, but their relative strength (1.53 ± 0.2 kg/bw) would not be classed as elite level. This may have affected their ability to produce and tolerate higher power outputs, which was a limitation of this study. Another limitation of this study was the COVID-19 global pandemic. The various lockdowns and restrictions significantly impacted the research and data collection process. This challenging period presented a myriad of obstacles, from limited access to participants, facilities, to the need to adapt research methods in response to evolving health guidelines. Thus, due to the low sample size of this study (n = 10), findings must be carefully interpreted.

5. Conclusions

These results highlight the need for an individualized approach to flywheel training. For this reason, a protocol to determine which inertial load produces the maximum power in a flywheel Romanian deadlift is essential. The current study shows that a previously used protocol has excellent reliability for both ECC and CON power and may be used in future flywheel training if the maximum power output is warranted. In the present study, body weight and maximum and relative strength were not significantly related to power variables, and future research is warranted to investigate elite-level strength athletes in flywheel training and its variables.

6. Practical Applications

- Both CON and ECC power variables are reliable and stable across inertial loads and can be used during flywheel training, but due to inconsistency over inertial loads, ECC overload should be used cautiously.
- This study demonstrates the reliability of a protocol for determining which inertial load generated the highest power output. However, prior experience with flywheel training is advised.
- Maximum and relative strength may be more associated with CON and ECC peak power than bodyweight, but neither show strong relationships, suggesting that flywheel training requires an individualized approach.
- One constraint that may alter the training stimulus is technique; if athletes do not adopt an optimal technique, this may alter the training stimulus and negate the effect of maximal and relative strength.

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