Concentric phase assistance enhances eccentric peak power during flywheel squats: intersession reliability and the linear relationship between concentric and eccentric phases.

Running Head: Concentric phase assistance enhances flywheel squat eccentric phase peak power

Cion Wren [1,2], Marco Beato [1,2], Stuart A. McErlain-Naylor [1,2,3], Antonio Dello Iacono[4], Kevin L. de Keijzer[1,2*]

[1] *School of Health and Sports Sciences, University of Suffolk, Ipswich, United Kingdom*
[2] *Institute of Health and Wellbeing, University of Suffolk, Ipswich, United Kingdom*
[3] *School of Sport, Exercise and Health Sciences, Loughborough University, Loughborough, United Kingdom*
[4] Institute for Clinical Exercise and Health Science, School of Health and Life Sciences, University of the West of Scotland, Hamilton, United Kingdom

Corresponding author:
Kevin L. de Keijzer
School of Health and Sports Sciences, University of Suffolk, Ipswich, United Kingdom.
email: k.dekeijzer@uos.ac.uk

Concentric phase assistance enhances eccentric peak power during flywheel squats: intersession reliability and the linear relationship between concentric and eccentric phases.

Running Head: Concentric phase assistance enhances flywheel squat eccentric phase peak power

Abstract

Background: It remains unknown if flywheel assisted squats can be reliably utilised to increase power outputs and if such outputs are related. **Objectives:** Compare assisted and unassisted flywheel squat peak power outputs, determine their reliability and analyse the relationship of the delta difference between peak power outputs during the squats. **Methods:** Twenty male athletes attended the laboratory six times – performing three sets of eight repetitions of assisted and unassisted squats during 2 familiarisation sessions and then three sets of eight repetitions during experimental sessions 3-6 (2 sessions for unassisted and assisted squat in randomised order, respectively). **Results:** Concentric and eccentric peak power were significantly greater during assisted squats (both $p < 0.001$, d = 1.59, d = 1.57, respectively). Rate of perceived exertion (RPE) ($p = 0.23$) and eccentric:concentric (E:C) ratio ($p = 0.094$) did not differ between squat conditions. Peak power measures obtained *excellent* reliability, while RPE and E:C ratio estimates were rated as *acceptable* to *good*, with greater uncertainty. A *large* to *very large* correlation ($r = 0.77$) was found between concentric and eccentric peak power delta difference of assisted and unassisted squats. **Conclusions:** Greater concentric outputs during assisted squats induce greater eccentric outputs and obtain greater mechanical load. Peak power is a reliable metric for monitoring flywheel training, whereas the E:C ratio should be used with caution. Eccentric and concentric peak power are strongly related during flywheel squats, evidencing the need to maximise the concentric output to enhance the eccentric output.

Introduction

The development of strength and power capabilities through resistance training is central to many strength and conditioning programmes [1,2]. To enhance strength and power outcomes, coaches often manipulate or monitor training intensity by utilising a variety of mechanical outputs (*i.e.,* force, velocity, power) or rate of perceived exertion (RPE) during resistance training [3–6]. Specifically, the manipulation of mechanical outputs during resistance training has received a lot of attention: weight releasers with traditional resistance training [7] and different moments of inertia with flywheel training [5]. Over the years, the quantification of such mechanical outputs has become much more accessible through technology [5], which has specifically enabled flywheel training prescription to be conceptualised [5,8]. Although flywheel training has been successfully applied with a variety of athletic populations [9], alternative methods to prescribe and manage flywheel training intensity (*i.e.,* by altering limb involvement or assistance) remain under investigated [10].

Flywheel training relies on the concentric phase being initiated by an unwinding of the strap that attaches the participant to the ergometer (with a harness/attachment) and thereby generates angular momentum that must be decelerated during the eccentric phase [11]. A key advantage to flywheel training is the ability to achieve an eccentric overload [12,13], which is an eccentric output relatively greater to the precedent concentric output [5]. A great focus has been placed on obtaining eccentric overload during flywheel training by practitioners [14] and researchers alike [5]. Peak power is commonly used due to its association with key performance indicators in sport [15]. The main method to increase eccentric overload is to manipulate moment of inertia [16]. Several studies report the distinct effects moment of inertia has on kinetic and kinematic variables during the squat at the group or individual level [17–19]. The most recent guidelines suggest that moment of inertia should be individualised to improve training prescription [16]. Although individualised 'optimal' moments of inertia should be used over a 'one-size fits all' approach [20], this is not commonly performed [21].

Traditionally, 'braking in the last third of the eccentric phase' was recommended to increase peak eccentric demands within flywheel training [22]. Although this technique can obtain eccentric overload, heterogeneity in the eccentric overload outputs has been reported in the flywheel squat literature [5]. Alternative methods have been applied to increase the eccentric demand by manipulating the concentric phase. For example, Presland and colleagues [10] applied 6 weeks of unassisted and eccentrically biased (2 legs during the concentric and 1 leg during the eccentric phase) flywheel leg curl training. In a similar fashion, practitioners have begun to incorporate assisted squats into training and therefore increase force and velocity (either simultaneously or specifically) during the flywheel squat. Assisted squats involve assistance from the arms during the concentric phase but not the eccentric phase. This approach could be used to accentuate peak power during the eccentric phase and obtain a greater eccentric overload, but this has never been investigated using flywheel devices in the literature. Although concentric and eccentric outputs during flywheel training are logically associated [11], the assumption that as concentric power increases, a corresponding linear increase in eccentric power will occur has not been demonstrated.

The reliability of flywheel training measures can also affect the ability to monitor and prescribe training, and so must be investigated. The effects of altering moment of inertia on reliability of open [23,24] and closed [17,25] kinetic chain exercises have recently been investigated. For the flywheel squat, the reliability of concentric and eccentric peak power has previously been rated *acceptable* to *excellent* [15,26], while the eccentric:concentric (E:C) ratio has been rated *poor* to *questionable* [17]. The eccentric:concentic ratio reliability ranged lower (ICC = 0.54-0.66) relative to concentric and eccentric peak power outputs (ICC = 0.70-0.89) using moments of inertia that are typically prescribed in practice (0.025 – 0.075 kg·m^2) [17]. A similar trend was reported with unilateral hamstring exercises [24]. It remains unknown how incorporating the upper limbs during the flywheel squat would impact reliability of mechanical outputs, and if the eccentric:concentic ratio can be reliably utilised, particularly given the increased movement complexity during the assisted squat.

Therefore, the aims of this study was twofold: (i) To investigate the comparative effects of assisted and unassisted flywheel squats on peak power outputs; (ii) To determine the reliability of assisted and unassisted squat peak power measures; and (iii), To analyse the relationship of the delta difference between concentric and eccentric peak power of assisted and unassisted squats. It was hypothesised that concentric and eccentric peak power would be greater in the assisted compared to unassisted flywheel squat, that assisted squats would have lesser reliability than the unassisted flywheel squat, and that eccentric peak power correlates positively with concentric peak power.

Methods

Experimental design

Participants attended the laboratory on six separate occasions (Figure 1). Sessions 1 - 2 served as familiarisation sessions, and all analyses (including test-retest reliability) were performed during sessions 3 - 6. In sessions 3 - 6, a randomised cross-sectional design was used to compare concentric peak power, eccentric peak power, the ratio of eccentric to concentric peak power, and rate of perceived exertion (RPE) between assisted and unassisted flywheel squats.

*** Please add Figure 1 here ***

Participants

An a priori power analysis in G*Power (version 3.1.9.3, Düsseldorf, Germany) indicated that a sample of 20 participants was required to detect a *moderate* effect (t = 0.7) with an α of 0.05 and a power (1-β) of 0.80 in a paired samples t-test (actual power = 0.82). Twenty amateur male university athletes (age 24 ± 3 years; body mass 79.3 ± 10.3 kg; height 1.77 ± 0.08 m) were therefore recruited for this study. Inclusion criteria were the absence of any injury or illness, confirmed by completion of a Physical Activity Readiness-Questionnaire; participation in a minimum of 2 training sessions per week; and at least 6 months of resistance training experience. All participants completed a written informed consent form. The Ethics Committee at the University of Suffolk (UK) approved this study. All procedures were conducted in line with the Declaration of Helsinki for studies involving human participants.

Data collection

All sessions were performed at least 48 h apart, and at least 48 h after the last training session or competition performed by the athlete, to avoid the effects of accumulated fatigue. Most participants performed a session at the beginning of the week and at the end of the week. Each participant performed all testing sessions at the same time of day to reduce the impact of circadian rhythms. Participants were required to maintain their habitual nutritional intake during the experimental period. Depressants (*e.g.,* alcohol) and stimulants (*e.g.,* caffeine) were not permitted for 24 hours prior to the experimental sessions, and participants were encouraged to hydrate as necessary during all sessions.

Prior to each session, a standardised warm-up (as reported in Figure 1) was performed including 8 min of cycling at a constant power (1 W·kg^{-1} body mass) on a Watt bike (Trainer, Nottingham, United Kingdom) and dynamic bodyweight mobilization (8 squats, 8 lunges, 8 deadlifts). Participants were requested to avoid static stretching. During the first familiarisation visit (Session 1), participants' body mass and height were recorded through a stadiometer (Seca 286dp; Seca, Hamburg, Germany). The participants were familiarised with the procedure of the experimental protocol [15]. Self-selected recovery was allowed between familiarisation of assisted and unassisted flywheel squats (see Figure 1 for protocol details). This familiarisation was repeated in session 2. For experimental visits (Sessions 3 - 6), participants performed the four protocol sessions in a randomised order.

Flywheel squat and assisted flywheel squat were performed using the same flywheel ergometer (D11 Full, Desmotec, Biella, Italy). One pro disc (moment of inertia 0.06 kg·m^2) was utilised for both protocols, based on a previous study [15]. The moment of inertia of the ergometer is estimated as 0.0011 kg·m^2 (totalling 0.061 kg·m^2), a moment of inertia utilised in a previous study [15]. Both conditions consisted of 3 sets of 6 maximal repetitions (+2 initial submaximal repetitions per set to attain rhythm), interspersed by 2 min of passive recovery [15]. Participants were asked to perform the concentric phase with maximal velocity and to achieve approximately 90° of knee flexion during the eccentric phase. It was encouraged that the participants brake maximally in the final third of the eccentric phase, as recommended previously [22]. All sessions were evaluated qualitatively by an investigator to ensure appropriate technique, offering kinematic feedback to participants during the familiarisation period. During the concentric phase of the assisted squat protocol, participants used their arms (from a slightly flexed elbow position; Figure 2) to push maximally on a bar positioned 20-30 cm anterior to the edge of the flywheel device at a height as close as possible to the participant's anterior superior iliac spine when standing on the flywheel ergometer. Participants were required to remove their hands from the bar during the eccentric phase. Peak power during the concentric and eccentric phases were collected via a built-in rotatory position transducer. RPE (CR100 scale) was utilised to help understand if sessions were perceived of greater or less exertion [6]. All parameters were deemed to be normally distributed.

*** Please add Figure 2 here ***

Statistical Analyses

All statistical analyses were performed using JASP (version 0.9.2., JASP, Amsterdam, the Netherlands). The Shapiro-Wilk test was used to assess normality of the residuals distributions. Data were presented as mean ± standard deviation (SD). For each exercise type, the two experimental sessions were compared to calculate inter-session reliability, with the values from both sessions averaged to obtain average estimates prior to comparing the two exercises. Inter-session reliability of peak power measures and respective confidence intervals was assessed using a two-way mixed model intraclass coefficient correlation (ICC) and interpreted as: *excellent* ≥ 0.9; 0.9 > *good* ≥ 0.8; 0.8 > *acceptable* ≥ 0.7; 0.7 > *questionable* ≥ 0.6; 0.6 > *poor* ≥ 0.5; *unacceptable* < 0.5 [27]. Technical error of estimate (TEE) was calculated using the following formula: TEE = SD√(1-ICC). Coefficient of variation (CV), which represents absolute reliability, was calculated and interpreted in an identical manner to o a previous investigation [15]. Specifically, values were considered *good* if CV <5% and *acceptable* if CV = 5-10%. A paired samples t-test compared parameters between the exercises, with significance set at $p < 0.05$. Delta differences (assisted − unassisted) with 95% confidence intervals (CI) were reported. Cohen's *d* effect size (and 95% CI) was interpreted as: *trivial* < 0.2; 0.2 ≤ *small* < 0.6; 0.6 ≤ *moderate* < 1.2; 1.2 ≤ *large* < 2.0; *very large* ≥ 2.0 [28]. Pearson's correlation coefficient (r) was computed to assess the relationship between concentric delta difference (assisted − unassisted) and eccentric delta difference (assisted − unassisted) of peak power. The strength of the relationship was assessed as *trivial* < 0.1; 0.1 ≤ *small* < 0.3; 0.3 ≤ *moderate* < 0.5; 0.5 ≤ *large* < 0.7; 0.7 ≤ *very large* < 0.9; 0.9 ≤ *almost perfect* <1.0 [27].

Results

The reliability of the assisted squat concentric (TEE = 66; CV = 4.1%; ICC = 0.98 [0.96; 0.99]) and eccentric (TEE = 102; CV = 5.8%; ICC = 0.96 [0.91; 0.99]) outputs were similar to the unassisted squat concentric (TEE = 40; CV = 2.8%; ICC = 0.99 [0.97; 0.99]) and eccentric outputs (TEE = 79; CV = 5.3%; ICC = 0.97 [0.93; 0.99]). The inter-session reliability (ICC) of all concentric and eccentric peak power values was *excellent* while the absolute reliability (CV%) of concentric peak power outputs were all rated as *good* and eccentric peak power outputs were rated as *acceptable.*

The reliability of the eccentric:concentic ratio (ICC values) were rated as *unacceptable* to *good* (0.70 [0.23, 0.88]) for assisted squats (TEE = 0.05; CV = 4.4%) and *poor* to *excellent* (0.81 [0.51, 0.92]) for unassisted squats (TEE = 0.04; CV = 3.8%). The ICC values for RPE were *poor* to *excellent* (0.84 [0.59, 0.94]) for assisted squats (TEE = 6.4; CV = 9.4%, acceptable) and *unacceptable* to *excellent* (0.76 [0.40, 0.91]) for unassisted squats (TEE = 7.3; CV = 11.2%). Although ICC values varied largely with regards to uncertainty for both RPE and E:C ratio in comparison to peak power outputs, the absolute reliability of the eccentric:concentric ratio was rated as *good* while the RPE was poorer (CV = 9.4 - 11.2%).

Significant differences (p < 0.01; Figure 3) were observed between assisted and unassisted flywheel squats for concentric (*moderate* to *very large*) and eccentric (*moderate* to *very large*) peak power measures. No differences were found for eccentric:concentic ratio (p = 0.094, *trivial* to *moderate*) or RPE (p = 0.230, *trivial* to *moderate*).

*** Please insert Figure 3 and Table 1 here ***

A *large* to *very large* correlation between the concentric and eccentric peak power delta differences (assisted − unassisted) was reported (r = 0.77 [0.62, 0.88]; Figure 4).

*** Please insert Figure 4 here ***

Discussion

The first aim of this study was to investigate whether assisting the concentric phase of the squat can be a practical method to increase eccentric phase loads (greater eccentric overload measured as peak power values) in comparison to the traditional unassisted flywheel squat. The *moderate* to *very large* significant difference in concentric and eccentric peak power measures between assisted and unassisted squats supports the hypothesis that assisted flywheel squats can enhance concentric and eccentric peak power. Secondly, we aimed to determine test-retest reliability of peak power during assisted and unassisted flywheel squats. In disagreement with the hypothesis that reliability would differ between squats, our findings suggest that peak power measures are *excellent* for both squat conditions, while the E:C ratio reliability estimates ranging from *acceptable* to *good*. Our third objective was to understand the relationship between the delta difference of concentric and eccentric peak power outputs between assisted and unassisted squats. The present findings suggest concentric peak power and eccentric peak power are positively correlated, highlighting the importance of maximising the concentric phase output to enhance the eccentric phase output.

The present investigation highlights for the first time that assisted squats can be used to increase training intensity (eccentric peak power output) without changing moments of inertia during flywheel squats [20]. Specifically, a *moderate* to *very large* difference in eccentric peak power was obtained between assisted and unassisted squats (Figure 3). The eccentric peak power produced during the assisted squats was also much larger than the concentric peak power obtained during unassisted squats with the same participants in the present study (Table 1). The high intensity eccentric mechanical load achieved with assisted squats may be of particular interest to stimulate greater neuromuscular adaptations [12,13] and may warrant inclusion into periodisation guidelines to optimise flywheel training outcomes [2,9,16]. The assisted squat provides alternatives to progressively increase mechanical load to those that are typically limited by the few combinations of moments of inertia used in practice (0.025 to 0.0100 kg·m^2) [16]. Specifically, the assisted squat can be programmed to increase training mechanical load for a specific athlete or manage different athletes within the same session more effectively [16]. The use of assisted flywheel squats must be further investigated for this purpose.

The findings of the present investigation align with the literature reporting that flywheel squats have *excellent* reliability for peak power measures [15,26], as well as being the first to report the reliability of such measures during assisted flywheel squats. Like the unassisted flywheel squat, the assisted flywheel squat obtained *excellent* reliability for both concentric and eccentric peak power outputs. The reliability of concentric and eccentric peak power outputs highlights they can be used for real-time feedback and may enhance flywheel training prescription [5]. The reliability of mechanical outputs and their (real-time) application in practice may considerably enhance the long term periodisation of training within team sport environments [15,16].

Although this study reports *acceptable* to *good* reliability estimates for assisted and unassisted eccentric:concentic ratios (albeit with relatively greater uncertainty), the use of ratios remains a debated topic [29]. Previous studies report that the E:C ratio are not as reliable as its peak power components [17,24]. Specifically, in the present investigation, the use of the E:C ratio remains questionable due to its lower reliability in comparison to peak power values and its inability to discern higher and lower peak power outputs [24]. A bias towards smaller values may deceive practitioners when using the E:C ratio. For example, if two participants obtained 1100:1000 W and 2200:2000 W, each would have a E:C ratio of 1.1. A conclusion that both athletes are doing an equivalent eccentric overload would be fair despite the second participant achieving greater absolute eccentric peak power outputs (1100 vs. 2200 W, respectively) and eccentric overload (100 vs 200 W, respectively). The E:C ratio disregards some valuable information that could inform the monitoring and prescription of training. The authors therefore recommend utilising absolute concentric and eccentric values rather than the eccentric:concentric ratio.

Our findings highlight that the level of eccentric output in peak power is largely related to the prior magnitude of concentric output. Intuitively, increases in concentric outputs would therefore be expected to lead to a direct and proportional increase in eccentric outputs [11]. Indeed, our findings support the notion that greater eccentric phase outputs cannot be obtained without greater concentric phase outputs [2]. Although our findings suggest outputs are related, it is possible that some athletes do not increase both concentric and eccentric outputs linearly (Figure 4). Such differences could be due to differences in technique utilised (premature or delayed braking), muscular strength, or familiarisation with the exercise [2]. Practitioners should therefore still monitor both concentric and eccentric phases since neuromuscular and morphological adaptations associated with flywheel training are derived from the combination of both phases (rather than only the concentric or eccentric phase) [2]. Further research is necessary to better understand the relationship between concentric and eccentric outputs (such as mean or peak force, power, or velocity) and how these may differ between exercises and populations. The present findings highlight that if the concentric phase of an assisted flywheel squat is performed maximally after sufficient familiarisation with a cylindrical shaft, concentric and eccentric peak power increases are closely correlated.

The perception of exertion is an important and useful aspect when aiming to prescribe resistance training [3,6]. Indeed, the pairing of external and perceptual responses in training by practitioners may help better manage the training process and enhance outcomes [3,30]. Interestingly, although RPE has been applied with traditional resistance training methods [3,30], it has not been utilised in many flywheel training investigations [4,9]. The present investigation shows that although there were significant differences in concentric and eccentric peak power between the assisted and unassisted squat, no significant differences were reported in RPE. The relative contributions of the upper and lower body limbs to the concentric phase of the assisted squat cannot be determined within the present study and so it is possible that the greater contribution of the upper limbs afforded a lesser contribution from the legs and so a similar overall RPE. The present findings underline the importance of utilising mechanical outputs for determining exercise intensity with flywheel training [5] but also support the need for further research to better understand whether RPE can be used to determine flywheel training intensity [4].

A few limitations of the present investigation are worthy of acknowledgement. It is unknown whether the present findings are consistent with other moments of inertia. Additionally, it is likely that participants with greater upper body strength may experience a greater benefit from the assisted squat – although this was not accounted for. Secondly, the present protocol only included the squat and was performed by male university athletes. Investigation into the effects of concentric phase assistance with different populations (*i.e.,* athletes and females) and exercises (*i.e.,* leg curl) are warranted. It remains unclear if movement mechanics and exercise outcomes are altered by concentric phase assistance during the flywheel squat. Finally, it would be of interest to investigate the long-term effects of concentric phase assistance during flywheel training.

Conclusions

Significantly greater concentric and eccentric peak power can be achieved during assisted squats in comparison to unassisted squats without increasing the exercise perceived fatigue. Peak power is a reliable metric that can be used during assisted and unassisted squats, whereas the eccentric:concentric ratio should be used with caution. Variation in concentric peak power is strongly related to variation in eccentric peak power, evidencing the need to maximise power output in the concentric phase to enhance the subsequent eccentric phase.

Practical Application

The prescription of assisted and unassisted squats allows for two distinctly different training intensities without needing to change moments of inertia. The assisted variation of the flywheel squat may therefore allow for a greater eccentric overload in a practical manner. The use of reliable metrics (peak power) provided in real-time feedback may be relevant for confirming whether eccentric overload was obtained with individual athletes and may also help guide exercise selection. Unreliable metrics such as the eccentric:concentric ratio should be used with caution.

References

1. Suchomel TJ, Nimphius S, Stone MH. The importance of muscular strength in athletic performance. *Sport Med*. 2016;46(10):1419-1449. doi:10.1007/s40279-016-0486-0
2. Beato M, Dello Iacono A. Implementing flywheel (isoinertial) exercise in strength training: current evidence, practical recommendations, and future directions. *Front Physiol*. 2020;11. doi:10.3389/fphys.2020.00569

3. Zourdos MC, Klemp A, Dolan C, et al. Novel Resistance Training–Specific Rating of Perceived Exertion Scale Measuring Repetitions in Reserve. *J Strength Cond Res*. 2016;30(1):267-275. doi:10.1519/JSC.0000000000001049

4. Martín-Rivera F, Beato M, Alepuz-Moner V, Maroto-Izquierdo S. Use of concentric linear velocity to monitor flywheel exercise load. *Front Physiol*. Published online 2022. doi:10.3389/fphys.2022.961572

5. Muñoz-López A, de Souza Fonseca F, Ramírez-Campillo R, Gantois P, Javier Nuñez F, Y. Nakamura F. The use of real-time monitoring during flywheel resistance training programmes: how can we measure eccentric overload? A systematic review and meta-analysis. *Biol Sport*. Published online 2021. doi:10.5114/biolsport.2021.101602

6. McLaren SJ, Smith A, Spears IR, Weston M. A detailed quantification of differential ratings of perceived exertion during team-sport training. *J Sci Med Sport*. 2017;20(3):290-295. doi:10.1016/j.jsams.2016.06.011

7. Wagle JP, Taber CB, Cunanan AJ, et al. Accentuated Eccentric Loading for Training and Performance: A Review. *Sport Med*. Published online 2017. doi:10.1007/s40279-017-0755-6

8. Maroto-Izquierdo S, Raya-González J, Hernández-Davó JL, Beato M. Load Quantification and Testing Using Flywheel Devices in Sports. *Front Physiol*. 2021;12. doi:10.3389/fphys.2021.739399

9. de Keijzer KL, Gonzalez JR, Beato M. The effect of flywheel training on strength and physical capacities in sporting and healthy populations: An umbrella review. Cortis C, ed. *PLoS One*. 2022;17(2):e0264375. doi:10.1371/journal.pone.0264375

10. Presland JD, Opar DA, Williams MD, et al. Hamstring strength and architectural adaptations following inertial flywheel resistance training. *J Sci Med Sport*. 2020;23(11):1093-1099. doi:10.1016/j.jsams.2020.04.007

11. Berg HE, Tesch A. A gravity-independent ergometer to be used for resistance training in space. *Aviat Space Environ Med*. 1994;65(8):752-756. https://europepmc.org/article/med/7980338

12. Norrbrand L, Pozzo M, Tesch PA. Flywheel resistance training calls for greater eccentric muscle activation than weight training. *Eur J Appl Physiol*. 2010;110(5):997-1005. doi:10.1007/s00421-010-1575-7

13. Norrbrand L, Fluckey JD, Pozzo M, Tesch PA. Resistance training using eccentric overload induces early adaptations in skeletal muscle size. *Eur J Appl Physiol*. 2007;102(3):271-281. doi:10.1007/s00421-007-0583-8

14. de Keijzer K, McErlain-Naylor SA, E. Brownlee T, Raya-González J, Beato M. Perception and application of flywheel training by professional soccer practitioners. *Biol Sport*. Published online 2022. doi:10.5114/biolsport.2022.109457
15. Beato M, Fleming A, Coates A, Dello Iacono A. Validity and reliability of a flywheel squat test in sport. *J Sports Sci*. Published online October 6, 2020:1-7. doi:10.1080/02640414.2020.1827530
16. Beato M, Maroto-Izquierdo S, Hernández-Davó JL, Raya-González J. Flywheel Training Periodization in Team Sports. *Front Physiol*. 2021;12. doi:10.3389/fphys.2021.732802
17. Sabido R, Hernández-Davó JL, Pereyra-Gerber GT. Influence of Different Inertial Loads on Basic Training Variables During the Flywheel Squat Exercise. *Int J Sports Physiol Perform*. 2018;13(4):482-489. doi:10.1123/ijspp.2017-0282
18. Carroll KM, Wagle JP, Sato K, et al. Characterising overload in inertial flywheel devices for use in exercise training. *Sport Biomech*. 2019;18(4):390-401. doi:10.1080/14763141.2018.1433715
19. McErlain-Naylor SA, Beato M. Concentric and eccentric inertia–velocity and inertia–power relationships in the flywheel squat. *J Sports Sci*. Published online December 18, 2020:1-8. doi:10.1080/02640414.2020.1860472
20. Raya-González J, Castillo D, de Keijzer KL, Beato M. The effect of a weekly flywheel resistance training session on elite U-16 soccer players' physical performance during the competitive season. A randomized controlled trial. *Res Sport Med*. Published online January 5, 2021:1-15. doi:10.1080/15438627.2020.1870978
21. Coratella G, Beato M, Cè E, et al. Effects of in-season enhanced negative work-based vs traditional weight training on change of direction and hamstrings-to-quadriceps ratio in soccer players. *Biol Sport*. 2019;36(3):241-248. doi:10.5114/biolsport.2019.87045
22. Tesch PA, Fernandez-Gonzalo R, Lundberg TR. Clinical Applications of Iso-Inertial, Eccentric-Overload (YoYo^{TM}) Resistance Exercise. *Front Physiol*. 2017;8. doi:10.3389/fphys.2017.00241
23. Piqueras-Sanchiz F, Sabido R, Raya-González J, et al. Effects of Different Inertial Load Settings on Power Output Using a Flywheel Leg Curl Exercise and its Inter-Session Reliability. *J Hum Kinet*. 2020;74(1):215-226. doi:10.2478/hukin-2020-0029
24. de Keijzer KL, McErlain-Naylor SA, Beato M. The Effect of Flywheel Inertia on Peak Power and Its Inter-session Reliability During Two Unilateral Hamstring Exercises:

Leg Curl and Hip Extension. *Front Sport Act Living*. 2022;4. doi:10.3389/fspor.2022.898649

25. Brien J, Browne D, Earls D, Lodge C. The effects of varying inertial loadings on power variables in the flywheel romanian deadlift exercise. *Biol Sport*. 2022;39(3):499-503. doi:10.5114/biolsport.2022.106159
26. Beato M, de Keijzer KL, Fleming A, et al. Post flywheel squat vs. flywheel deadlift potentiation of lower limb isokinetic peak torques in male athletes. *Sport Biomech*. Published online October 28, 2020:1-14. doi:10.1080/14763141.2020.1810750
27. Atkinson G, Nevill AM. Statistical methods for assessing measurement error (reliability) in variables relevant to sports medicine. *Sports Med*. 1998;26(4):217-238. doi:10.2165/00007256-199826040-00002
28. Hopkins WG, Marshall SW, Batterham AM, Hanin J. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc*. 2009;41(1):3-13. doi:10.1249/MSS.0b013e31818cb278
29. Curran-Everett D. Explorations in statistics: the analysis of ratios and normalized data. *Adv Physiol Educ*. 2013;37(3):213-219. doi:10.1152/advan.00053.2013
30. Singh F, Foster C, Tod D, McGuigan MR. Monitoring Different Types of Resistance Training Using Session Rating of Perceived Exertion. *Int J Sports Physiol Perform*. 2007;2(1):34-45. doi:10.1123/ijspp.2.1.34