Six weeks of unilateral flywheel hip extension and leg curl training improves flywheel eccentric peak power but does not enhance hamstring isokinetic or isometric strength.

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Abstract

Purpose: This pre-registered trial investigated how 6-weeks of unilateral flywheel leg curl and hip extension training impact isokinetic, isometric, and flywheel strength and power outcomes. **Methods:** The study involved 11 male university athletes (age 22 ± 2 years; body mass 77.2 ± 11.3 kg; height 1.74 ± 0.09 m) with one leg randomly allocated to flywheel training and one leg to control. Unilateral eccentric and isometric knee flexion torque and flywheel unilateral leg curl and hip extension peak power were tested. Training intensity and volume (3-4 sets of 6+2 repetitions) was progressively increased. **Results:** The intervention enhanced hip extension concentric ($p < 0.01$, $d = 1.76$, *large*) and eccentric ($p < 0.01$, $d = 1.33$, *large*) peak power more so than the control (significant interaction effect). Similarly, eccentric ($p = 0.023$, $d = 1.05$, *moderate*) peak power was enhanced for the leg curl. No statistically significant differences between conditions were found for isokinetic eccentric ($p = 0.086$, $d = 0.77$, *moderate*) and isometric ($p = 0.431$, $d = 0.36$, *small*) knee flexor strength or leg curl concentric peak power ($p = 0.339$, $d = 0.52$, *small*). Statistical parametric mapping analysis of torque-angle curves also revealed no significant ($p > 0.05$) time-limb interaction effect at any joint angle. **Conclusion:** Unilateral flywheel hamstring training improved knee flexor eccentric peak power during unilateral flywheel exercise but not flywheel concentric, isokinetic eccentric or isometric (long-lever) knee flexor strength.

Keywords: strength; isoinertial; overload; sports; knee flexors

Introduction

Hamstring strain injuries, such as those occurring during high-speed running, have affected team sports for decades [1]. Likelihood of hamstring re-injury also increases after initial injury, with issues sometimes persisting for years [2]. A concerted effort through testing and training interventions has been made to curb their negative financial, performance, and health-related effects [3]. Several injury risk factors are older age, shorter biceps femoris long head fascicles, and poor eccentric hamstring strength amongst soccer players [2,4]. Although a gold-standard method to prevent hamstring strain injuries remains unknown and would likely be multifactorial [3,4], eccentric strength is amongst the most easily and frequently tested and trained capacities. Additionally, the use of isometric testing has gained traction and may play a role in better understanding hamstring capacity [5]. Although isokinetic dynamometers are considered the gold standard assessment for eccentric hamstring strength [6], they could be adopted alongside more practical testing methods by practitioners (*e.g.,* isometric, bodyweight strength-endurance or flywheel testing) to monitor hamstring strength and capacity [7–9].

Several resistance training methods have been proposed to improve hamstring strength and reduce likelihood of hamstring injury [4]. Specifically, the incorporation of knee-dominant (such as the Nordic hamstring exercise [NHE]) or hip-dominant (hip extension) exercises have improved hamstring eccentric strength [10,11]. Hip extension exercises performed on the 'glute-ham raise' machine enhanced isokinetic eccentric knee flexor strength of healthy males and 3-RM hip extension strength of recreationally active men [9,11]. Greater improvements in eccentric strength following eccentric training interventions (such as the NHE) in comparison to traditional resistance training or concentric-only isotonic exercises may be due to greater cortical activity, preferential recruitment of high threshold motor units, upregulation of satellite cell activity and transcriptional pathways in fast-twitch muscle fibers [12,13]. Nonetheless, the application of such interventions are not reducing hamstring strain injury incidence [1]. The efficacy of current interventions, such as the NHE, may be limited by poor adherence and/or their actual capability to reduce injury likelihood [14]. Knee- and hip-dominant strength training interventions based on alternative equipment (*e.g.,* flywheel devices) have therefore become of interest for improving strength and may help reduce hamstring injury likelihood [9–11,15,16].

Flywheel devices use inertial disc(s) which rotate and store kinetic energy during the concentric phase according to the achieved rotational speed, moment of inertia, and machine characteristics [17]. To complete an exercise, the inertial disc(s) must then be decelerated during the eccentric phase. If device, moment of inertia, and technique are appropriate, an 'eccentric overload' (*i.e.*, eccentric output > concentric output) is attainable [17]. Indeed, the unique nature of flywheel training exposes the neuromuscular system to a stretch and tension stimulus during overloaded eccentric contractions and repeated maximal concentric contractions [18]. For this reason, flywheel training has received a great amount of attention for its implications for strength and performance outcomes within healthy and athletic populations [19–21]. Specifically for the hamstrings, bilateral flywheel hamstring curls or deadlifts have improved strength of professional and youth team sport athletes [10,15,16]. For example, a 10-week intervention involving 16 sessions of bilateral flywheel leg curl training significantly enhanced concentric (Hedges g = 0.79, moderate) and eccentric (Hedges g = 1.14, *moderate*) knee flexor peak torque of professional Swedish soccer players [10]. Currently, the only application of unilateral flywheel leg curl training in the literature did not improve hamstring strength in healthy males [22]. Such findings slightly contrast the limited unilateral hip extension and knee flexion training literature available [9,11]. Further investigation into the efficacy of a combined flywheel-based hip and knee dominant unilateral hamstring training program should be performed to support integration of such training.

The aim of the present investigation was therefore to determine whether unilateral flywheel hamstring training (a combination of hip extension and knee flexion exercises) enhances isokinetic knee flexor strength more than a control condition. A secondary aim was to determine the effect on concentric and eccentric peak power during the flywheel exercises. It was hypothesised that 6 weeks of unilateral hip extension and knee flexion flywheel hamstring training would improve peak eccentric and isometric knee flexion torques as well as concentric and eccentric peak power during the unilateral flywheel hip extension and leg curl exercises.

Methods

Experimental design

A randomised controlled trial design was used to determine the effects of a 6-week unilateral flywheel hamstring training protocol on isokinetic and isometric hamstring strength and flywheel peak power in amateur male university athletes. This trial was pre-registered on the Open Science Framework registry prior to data collection (DOI to be inserted after peer review).

The protocol consisted of one familiarisation session, two testing sessions, and twelve training sessions (performed twice per week). Initially, participants' body mass and height were recorded using a stadiometer (Seca 286dp; Seca, Hamburg, Germany) and participants were familiarised with the lower limb tests (isokinetic, isometric and unilateral flywheel assessments) and flywheel training. Familiarisation with flywheel training involved 4-5 sets x 6+2 repetitions of maximal flywheel hamstring exercises. In the subsequent session, participants performed isokinetic eccentric and isometric knee flexor testing, as well as the unilateral flywheel assessments (hip extension and knee flexion). All sessions were performed on weekdays and separated by 2 days from other intense activities (training or competition). All isokinetic, isometric and flywheel testing protocols were performed at baseline (week 1 / session 2) and post-training (week 8 / session 15) in the laboratory (19-21 °C) at a similar time of day to reduce the impact of circadian rhythms on performance. Participants were required to maintain their habitual nutritional intake during the experimental period. Depressants (*i.e.,* alcohol) and stimulants (*i.e.,* caffeine) were not permitted within 12 hours prior to the experimental sessions. All sessions were evaluated qualitatively by a qualified strength and conditioning coach (NSCA) to ensure appropriate technique.

Participants

An *a priori* power analysis determined the appropriate sample size using G*Power (version 3.1.9.3, Düsseldorf, Germany). Considering the study design (one limb per participant was randomly assigned to either experimental or the control condition), a two-way analysis of variance (ANOVA) analysing time (pre-post) and within-participant (between limbs) effects, a moderate effect size of $f = 0.35$, an α-error of 0.05, and a required power (1-β) of 0.80, a total sample size of 10 participants was required (actual power = 0.84). Eleven male participants (age 22 ± 2 years; body mass 77.2 ± 11.3 kg; height 1.74 ± 0.09 m) were enrolled and completed all training, with one limb randomly allocated (http://www.randomizer.org/) to either experimental or control condition (n = 22).

Inclusion criteria were the absence of any injury or illness confirmed by completion of a physical activity readiness-questionnaire (PAR-Q); participation in a minimum of 2 resistance training sessions per week; and at least 6 months of resistance training experience. All participants completed a written informed consent form after a verbal and written rationale of the experimental procedure was given. The Ethics Committee of the University of Suffolk

(UK) approved this study (RETH(S)21/015). All procedures were conducted in line with the Declaration of Helsinki for studies involving human participants.

Standardised warm-up

Prior to each session, a standardised warm-up was performed including 10 min of cycling at a constant power (1 $W \cdot kg^{-1}$ body mass) on a Watt bike (Trainer, Nottingham, United Kingdom) and dynamic mobilization (8 repetitions of each of squats, Romanian deadlifts, and reverse lunges).

Isokinetic testing

An isokinetic dynamometer (Bide Medical Systems, Shirley, NY, USA) was used to measure eccentric knee flexion torque at $60° \cdot s^{-1}$. Participants were seated on the dynamometer chair, with an internal hip angle of 95° and the crank axis aligned with the tested knee joint centre of rotation. The trunk, hip, and thigh were firmly strapped to the isokinetic dynamometer. Participants performed three maximal eccentric knee flexion repetitions at $60° \cdot s^{-1}$. Isokinetic measures were sampled at 100 Hz, with the device calibrated (gravity correction) according to manufacturer's guidelines. The data were then processed via open-source (http://www.ikd1d.org/) MATLAB (v 2022b, MathWorks, Natick, MA) script. Torque and crank angular velocity data were filtered using a recursive second-order digital low-pass Butterworth filter with a cut-off frequency of 5 Hz and a torque threshold of 0.1 $Nm \cdot kg^{-1}$ applied. Data points were only considered for further analysis if crank angular velocity was within 5% of the target angular velocity. Crank angle was consistently considered as joint angle (although this likely changes somewhat at smaller knee flexion values). For continuous analysis of one-dimensional torque-angle data, all trials were normalized via linear length normalization to one value per degree of range of motion within the range common to all participants [23]. The three trials per participant-condition combination were ensemble averaged to produce a single representative normalized torque-angle curve per participant and condition. For discrete analyses, peak torque of the singular best trial was taken. The reliability of the isokinetic discrete analysis was performed prior to testing and was considered *good* (ICC = 0.85 [0.71;0.92]).

Isometric testing

The isokinetic dynamometer was also used to measure maximal voluntary isometric contraction (MVIC) at 30° of knee flexion (crank angle). Participants performed two 3-second practice trials at 50% of perceived maximal effort before performing two 3-second MVICs separated by 30 s rest. Peak torque of the singular best trial was considered for further analysis. The reliability of the isometric testing was performed prior to testing and was considered *excellent* (ICC = 0.90 [0.81;0.95]).

Flywheel testing

Flywheel testing and training was performed on a flywheel ergometer (V11 Full, Desmotec, Biella, Italy). Participants performed 2 sets of 2+6 repetitions (2 submaximal repetitions to attain rhythm followed by 6 maximal repetitions) with a moment of inertia of 0.061 $kg·m^2$ and 120 s of inter-set rest for both knee flexion and hip extension. Hip extension was initiated at 80-90° of hip flexion and ended at 0-5° hip flexion . Knee flexion range of motion was established prior to each set as beginning at approximately 20° of knee flexion and ending at approximately 150° knee flexion, as described previously [7]. A built-in rotational encoder recorded concentric and eccentric peak power. The reliability for such exercises have recently been investigated [7].

Flywheel training

The training protocol consisted of a unilateral knee flexion and unilateral hip extension exercise, with a training frequency of two sessions per week over a 6-week period (120 seconds of rest between sets). The volume and moments of inertia (intensity) prescribed were progressively incremented during the training period (presented alongside results in Figures 1 and 2). Participants were encouraged to perform every concentric action maximally and to delay each eccentric action as late as possible, as described previously [7]. The mean of all concentric and eccentric peak power outputs was recorded separately for each session. Strong standardised verbal encouragements were provided to maximise performance throughout all testing and training.

*****Please insert Figures 1 & 2 here*****

Statistical analyses

The Shapiro-Wilk test was used to determine normality of distributions for all discrete values. Data were presented as mean ± standard deviation (SD). Reliability of isokinetic testing was assessed via intraclass coefficient correlation (ICC) (two-way mixed model) 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 [24]. A two-way repeated measures ANOVA reporting *f* values was used to detect possible between and within condition (control *vs* intervention) effects and time-limb effects for knee flexion eccentric and isometric peak torque, and hamstring concentric and eccentric peak power. The between-effect of the training intervention was assessed by analysis of covariance (ANCOVA) with baseline values used as covariate. Delta difference with 95% confidence intervals (CI) were reported where appropriate, with significance set at $p < 0.05$ throughout. If a significant difference was reported, post hoc tests (using the Bonferroni correction) were performed. The effect size based on Cohen's *d* principle was calculated and interpreted as: *trivial* < 0.2; 0.2 ≤ *small* < 0.6; 0.6 ≤ *moderate* < 1.2; 1.2 ≤ *large* < 2.0; *very large* ≥ 2.0 [25]. All discrete value statistical analyses were performed using JASP (version 0.9.4; JASP, Amsterdam, the Netherlands). Normalised one-dimensional isokinetic torque-angle waveforms were compared between limbs (control and intervention) and time-points (pre- and post-intervention) via a statistical parametric mapping two-way repeated measures ANOVA (main and interaction effects as above for the discrete ANOVA) using open-source (https://www.spm1d.org) MATLAB script. The critical test statistic and supra-threshold cluster were to be reported if the test statistic field exceeded the critical threshold.

Results

After 6 weeks of training, the two-way repeated measures ANOVA reported no statistically significant within group differences in eccentric isokinetic ($F = 4.578$, $p = 0.058$) or isometric ($F = 3.256$, $p = 0.105$) knee flexor strength (Figure 3). The same pattern of results occurred across the range of motion, with the statistical parametric mapping ANOVA reporting no significant interaction effect between time and limb at any joint angle (Figure 4). The greatest (non-significant) interaction effect size ($F = 2.51$, $p > 0.05$) occurred at 87° of knee flexion. An ANCOVA (with baseline values as covariates) reported no significant differences between intervention and control for isokinetic eccentric ($F = 3.27$; $p = 0.086$; $d = 0.77$ [-0.16; 1.70], *moderate*) or isometric ($F = 0.65$; $p = 0.431$; $d = 0.36$ [-0.59; 1.32], *small*) knee flexor strength.

*****Figures 3-4 here please*****

Statistically significant within group differences was reported for flywheel hip extension concentric ($F = 18.343$, $p = 0.002$) and eccentric ($F = 13.032$, $p = 0.005$) peak power (Figure 5) and leg curl eccentric ($F = 12.593$, $p = 0.005$) but not concentric ($F = 2.469$, $p = 0.147$) peak power (Figure 6). Post hoc tests for flywheel hip extension and leg curl testing are reported in Table 1, with significant *moderate* changes in peak power occurring only in the intervention limb and not in the control limb.

*****Figures 5-6 and Table 1 here please*****

The ANCOVA also reports that training enhanced hip extension concentric (F = 107.21; p < 0.001; d = 1.76 [0.69; 2.83], *large*) and eccentric (F = 95.98; p < 0.001; d = 1.33 [0.33; 2.33], *large*) peak power more than the control did. Leg curl eccentric peak power significantly improved after training (F = 6.08; p = 0.023; d = 1.05 [0.09; 2.01], *moderate*) but not concentric (F = 9.75; p = 0.339; d = 0.52 [-0.39; 1.43], *small*) peak power.

Discussion

This is the first investigation to study the effects of unilateral flywheel knee flexion and hip extension training on hamstring strength and power. Six weeks of unilateral flywheel hamstring training, performed twice per week, significantly improved eccentric peak power assessed with a flywheel device (Table 1). Such training does not significantly enhance isokinetic eccentric or isometric (long-lever) hamstring strength within 6 weeks (Figure 3-4). Additionally, the present study confirms previous evidence that unilateral flywheel leg curl training obtains a large eccentric overload of peak power while such overload is not as pronounced for unilateral flywheel hip extension exercises (Figure 1-2).

Several factors including training duration, intensity, and exercise modality are likely to play a key role in the effectiveness of a hamstring strength training program. Only one previous investigation used unilateral flywheel hamstring training, performing 6 weeks (392 repetitions) of either conventional unilateral flywheel leg curls (with 0.05 kg·m^2) or eccentrically biased (2 legs during concentric, 1 leg during eccentric) flywheel leg curls (with 0.10 kg·m^2) [22]. Similar to the lack of significant eccentric knee flexor torque enhancement in the present study (Figure 3, p = 0.086; d = 0.77; Figure 4), no enhancements in eccentric strength were seen after either conventional (p = 0.171; d = 0.52) or eccentrically biased (p = 0.329; d = 0.33) unilateral flywheel leg curl training [22]. In agreement with the present unilateral hamstring flywheel literature, a variety of resistance training interventions involving the Nordic hamstring exercise (NHE) [26], Romanian deadlifts (75% 1-repetition maximum [1RM]) [13], or unilateral isometric weighted hip extensions did not enhance eccentric hamstring strength [9]. In contrast to unilateral flywheel hamstring interventions, bilateral flywheel leg curl training over a longer duration (10 weeks, 512 repetitions) significantly enhanced eccentric hamstring peak torque (Hedges g = 1.14, *moderate*) of professional Swedish soccer players [10]. Similarly, other resistance training interventions based on the NHE [13,27,28], isotonic (60-80% 1RM) and eccentric (only) weighted hip extensions [9,11] have also enhanced eccentric hamstring strength. Specifically, NHE protocols prescribed over 10 weeks (340 - 726 repetitions) elicited significant (11-15%) increases in isokinetic eccentric strength [27,28] and NHE eccentric strength ($p < 0.05$; $d = 2.07$) [11]. Additionally, a six week unilateral eccentric hip extension intervention (involving only 120 weighted repetitions [5 seconds per repetition]) also enhanced isokinetic eccentric knee flexor strength of healthy males (p = 0.003; $d = 0.66$) [9], contrasting the present findings.

The present investigation included isometric testing due to its perceived clinical value and increasing interest within performance and rehabilitation [22]. The findings suggest that isometric knee flexor strength at 30° knee flexion also does not increase after 6 weeks of flywheel unilateral hamstring training (Figure 3). Similar to these findings, neither unilateral flywheel knee flexion ($p = 0.77$) nor eccentric Roman chair hip extension training previously enhanced isometric hamstring strength [9,22]. In contrast to the present findings, 6 weeks of isometric hip extension training enhanced isometric knee flexion torque ($p < 0.01$; $d = 0.54$) and hip extension force ($p = 0.04$; $d = 0.41$) [9]. Similarly, NHE training protocols enhanced isometric knee flexion torque at 30° (7%; 8Nm) [27]. The effects of unilateral flywheel hamstring training, alongside other strength training interventions, remain unclear on isometric strength and should be further analysed alongside other strength parameters in future investigations.

The present literature highlights some inconsistency between resistance training interventions but highlights that both knee and hip dominant exercises can effectively enhance eccentric and isometric knee flexor strength. Several factors may explain why the present flywheel training intervention, involving unilateral hip extension (320 repetitions) and unilateral flywheel knee flexion (320 repetitions) training over 6 weeks, did not enhance eccentric or isometric hamstring strength. Firstly, a greater training duration (*e.g.*, 10 weeks; 16 sessions) rather than a shorter intervention (6 weeks; 12 sessions) [22] may be necessary to enhance eccentric hamstring strength [10]. Secondly, it is well acknowledged that appropriate intensity and progressive overload are key to increasing peak forces during training and eliciting strength adaptations with flywheel training [4,17]. Indeed, it is possible that the low initial moment of inertia previously (0.05 $kg{\cdot}m^2$) and presently (0.041-0.061 $kg{\cdot}m^2$) used during unilateral leg curl training did not allow for maximal strength enhancement [22]. Although the present investigation progressively increased the moments of inertia from 0.041 to 0.089 kg·m^2 in line with current guidelines [18,22], the present (< 0.069 kg·m^2 for 4 weeks) and previous (0.05 kg·m^2 for 6 weeks) study may have progressed intensity insufficiently to enhance maximal strength. Thirdly, volume per flywheel training session may have influenced strength adaptations. The only previous investigation which enhanced isokinetic eccentric hamstring strength after flywheel training performed 24 repetitions per session (after warm up) [10]. This differs to the prescription of 48-64 repetitions per session in the present study and >30 repetitions per session (4 of 6 weeks) in the previous study, where eccentric hamstring strength was not enhanced [22]. It is possible that the higher volume prescribed per session may have influenced inter-set fatigue, peak force, and therefore impacted maximal strength adaptations in flywheel hamstring interventions [4,17]. In support of this, greater variability in peak power during unilateral leg curls occurred when 64 repetitions per session were prescribed (Figure 1 & 2). Such variability in parameters when greater volume was prescribed supports the notion that excessive volume may have negatively impacted strength outcomes. In agreement, intensity was of greater importance than volume when prescribing NHE training for enhancing eccentric strength [29]. Such findings highlight the importance of better understanding the effects of flywheel training prescription (volume and intensity) and periodization [7].

Although the high-volume approach presently utilised may not have stimulated greater maximal strength (Figure 3), it may have developed other neuromuscular capacities. Flywheel eccentric peak power was increased for both leg curl (115 W; d = 1.01) and hip extension (194 W; d = 0.98) exercises (Figure 5 and 6). It is possible that the higher volume per session allowed for greater adaptation in the flywheel specific tests. Such testing involved 32 repetitions whereas isokinetic eccentric testing only involved 3 repetitions. Tests involving more repetitions may highlight the hamstrings' ability to maintain maximal power and resist fatigue – potentially warranting its inclusion within a hamstring testing battery. Some previous studies have reported similar findings of improvement in one hamstring specific test, but not another [9,30]. For example, Carmichael and colleagues [9] performed a low volume (120 repetitions) 6 week unilateral hip-extension protocol that enhanced isokinetic eccentric strength but not bodyweight hamstring strength endurance capacity or isometric strength [9]. It is also possible that enhancement of knee flexor capacity (measured as strength or power) is more likely to be significant if testing is performed on the training apparatus utilised. In agreement with this, 16 sessions of NHE or isokinetic eccentric knee flexor training performed over 6 weeks (220 repetitions) significantly enhanced knee flexor strength only if testing was performed on the training apparatus [30]. Specifically, NHE training only significantly enhanced NHE eccentric strength (28-32%) but not isokinetic eccentric strength (3-8%), while isokinetic training did not enhance NHE eccentric strength (3-8%) but did enhance isokinetic eccentric strength (22-28%) [30]. Similarly, *moderate* to *large* improvements in flywheel leg curl (78 W) and hip extension (101 W) eccentric specific outcomes occurred (Figure 5-6), while isokinetic isometric (9 Nm; *small*) or eccentric (12 Nm; *moderate*) knee flexor strength changes were not significant and modest (Figure 3-4). It is therefore likely that mode (flywheel *vs* isokinetic) and position specific differences between training (prone) and testing (seated) in the present study may have also contributed to the findings [30].

This study is not without limitations. Importantly, the within-subjects design may have predisposed participants to a cross-education effect and therefore reduced or masked the effect of training on the intervention limb. Although this study found that flywheel training is effective for improving hamstring eccentric power, it remains unclear whether this parameter is relevant to strength, injury or sport performance. Additionally, the *moderate* effect on eccentric strength (with large confidence intervals) potentially highlights a practical increase in eccentric hamstring strength, although further studies must confirm this. Although a progressive increase in moment of inertia was used, the limited information available for unilateral hamstring exercises likely impacted training periodisation. Indeed, future studies may benefit from autoregulated training and evidence based guidelines to further optimise training prescription [19]. For instance, a greater intensity (> 0.069 kg·m^2), lower volume per session (< 24 repetitions), and a prolonged training duration (>10 weeks) may be necessary to enhance isokinetic eccentric knee flexor strength with unilateral hamstring flywheel training.

Conclusions

This study supports the use of 6-weeks of unilateral hamstring flywheel training for enhancing flywheel eccentric peak power although no improvements in isokinetic eccentric or isometric (long-lever) hamstring strength were seen. A large variation in eccentric overload seen between exercises (larger eccentric overload during leg curl in comparison to hip extension) and sessions supports the need for monitoring of mechanical outputs (and eccentric overload) during flywheel training. Finally, this investigation is the first to report eccentric isokinetic strength utilising a statistical parametric mapping (SPM) approach after flywheel training, which provides additional information regarding the entirety of the range of motion and potential changes in strength.

Practical Application

Practitioners must consider that altering execution of flywheel training exercises (*i.e.,* unilateral variations) may influence strength and performance outcomes. Additionally, the inclusion of flywheel specific tests should be further investigated alongside eccentric and isometric specific testing. It is recommended that practitioners monitor and utilise mechanical outputs to guide training and periodisation as significant differences between flywheel hamstring exercises are evident.

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