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Post-activation Performance Enhancement of Flywheel Training VS. Accentuated Eccentric Loading Training on Lower Limb Explosive Power Performance

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Abstract. The primary objective of this study was to investigate the intervention effects of flywheel training and accentuated eccentric loading training on the post-activation performance enhancement effects in sprinters. Twenty sprint-trained athletes were assessed across 4 days. Countermovement jump height, squat jump peak power, and 30-meter sprint times were measured at 4, 8, 12, and 16 minutes post-intervention for two training methods, noting transient changes. The results showed that the flywheel training intervention significantly enhanced the three indexes, and the peak value appeared at the 4th minute. The enhancement effect gradually weakened with time and was absent at the 16th minute. Accentuated eccentric loading significantly improved countermovement jump height and squat jump peak power, with effects peaking around 12 minutes post-intervention. However, it did not enhance 30-meter sprint time; sprint times notably increased at 4, 8, and 12 minutes. The results of this study suggest that flywheel training yields a quicker, more pronounced post-activation performance enhancement at equivalent loads compared to accentuated eccentric loading, though this effect diminishes rapidly. Centrifugal hook-induced enhancement endures longer but is initially masked by fatigue, with noticeable effects primarily at 12 or 16 minutes.

Keywords: Eccentric overload training, Post-activation performance enhancement, Flywheel training, Accentuated eccentric loading

1. Introduction

Eccentric overload training applies a greater load at the eccentric phase of resistance training than the concentric phase, because the muscle can produce a higher peak force during the eccentric stage. This method has been proven to deliver better training results than traditional resistance training [1]. There are two mainstream eccentric overload training methods, Flywheel Training (FT) and Accentuated Eccentric Loading (AEL), which have different equipment requirements, movement patterns, load measurements, and other aspects. Many researchers have compared flywheel training and accentuated eccentric loading under the same concentric load to the traditional resistance

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training effect. However, there is still little research about these two methods to enhance post-activation performance under the same training load during concentric and eccentric phases.

Flywheel training is a training method using special resistance training equipment, and its load application method is slightly different from traditional barbell resistance training, which mainly utilizes the rotational inertia of the flywheel to pull the trainer, forcing it to generate forces in the opposite direction, to achieve the purpose of resistance training [2]. Due to its special load application method, flywheel training is widely used to prevent muscle atrophy in astronauts, sports injury rehabilitation, sports training and other fields.

Accentuated eccentric loading is very similar to traditional barbell training, with the only difference being that an eccentric release hook is applied to the left and right sides of the barbell as the trainer performs the eccentric contraction, causing a greater load to be used during the eccentric phase than during the concentric phase as a way to achieve eccentric overload [3].

The post-activation performance enhancement refers to the transient enhancement of strength, explosiveness, speed, and other indicators of athletic performance observed in a short period after a submaximal resistance contraction of a muscle [4, 5]. The post-activation performance enhancement can be induced in a variety of ways, including accentuated eccentric loading [6] and flywheel training [7], in addition to numerous studies confirming that both eccentric overload training methods enhance the post-activation performance enhancement to varying degrees when compared to traditional resistance training [8, 9].

This study aimed to compare the effects of two different forms (flywheel and eccentric hook) of eccentric overload interventions with equal eccentric and concentric loads on the post-activation performance enhancement in sprinters. This study expands acute research on eccentric overload, addresses the lack of comparative analysis between two mainstream eccentric overload training methods, and offers a theoretical foundation for researchers, coaches, and athletes to select suitable equipment for research and training.

2. Methodology

2.1. Objects of study

Twenty male athletes (age 20.8±1.7 years; height 1.82±0.06 meters; weight 80.5±5.9 kilograms) with more than 6 years of sprint training experience and more than 3 years of resistance training experience were recruited for this experiment. Participants were recruited according to the following inclusion criteria: (1) absence of lower limb injuries within the preceding three months; (2) a minimum of three years'experience in high-load resistance training targeting the lower extremities; and (3) a half-squat one-repetition maximum equivalent to 1.5–2.0 times their body mass.

This range was chosen because the strength of the post-activation enhancement effect is highly correlated with the subject's maximal strength [10], and to avoid experimental errors due to a large gap in maximal lower extremity strength. The Declaration of Helsinki was followed in all experimental procedures, subjects were informed of the possible benefits and potential risks before experimentation, and all subjects signed an informed consent form.

2.2. Experimental design and experimental procedure

The experiment was a crossover design in which 20 subjects were randomly divided into two groups of 10 subjects each one(N=10), where one group of subjects was first tested with the flywheel training and the other with the accentuated eccentric loading, with a 72-hour interval between the completion of the tests, followed by the intervention as well as the testing of the different intervention in each of the two groups. All subjects underwent 3 flywheel (DESMOTEC, Italy) familiarization training sessions before the start of the formal experiment to ensure that they could consistently produce eccentric overloads, and mean concentric velocities were recorded for different flywheel load combinations. Next, subjects were also required to perform a half-squat 1RM test, which was used to construct the half-squat load-velocity profile. In addition, subjects performed two accentuated eccentric loading familiarization exercises on a Smith machine while recording eccentric hook length. Baseline values for all participants were obtained outside the 24 hours before the start of the formal intervention. Participants underwent testing at 4, 8, 12, and 16 minutes post-intervention, with measurements of countermovement jump height and squat jump peak power taken at the same intervention. A 30m sprint time test was conducted during a separate intervention, separated by a minimum of 72 hours to mitigate carryover effects. All subjects performed a standardized warm-up routine consisting of 10 minutes of jogging at a speed of 10km/h and 10 minutes of dynamic stretching, focusing primarily on the lower extremity muscles and the peripheral hip, knee, and ankle muscle groups.

2.3. Measurement of load-velocity profile in the half squat

The primary purpose of measuring the load-velocity profile for the half-squat was to utilize mean concentric velocity as a measure of concentric load instead of weight to standardize concentric loads for both the flywheel intervention and the eccentric hook intervention, which was used because the movements employed by the subjects while training for the intervention were all half-squats (knee angle of 90 degrees).

Load-velocity profiles were assessed during a half-squat exercise using a standardized FPV testing protocol [11]. The half-squat 1RM test was performed first: subjects performed 5-10 repetitions of the squat using an unloaded barbell bar, followed by 5-6 repetitions using 50% of the predicted 1RM, then 3-5 repetitions using 70% of the predicted 1RM, and finally 1 repetition using 90% of the predicted 1RM, followed by increments of weight from 2.5-10 kg until the subject was unable to complete 1 repetition with the standard half-squat movement. If the subject failed to complete 1 repetition with the standard movement, 5kg weight decrements were performed. If the subject completed 1 repetition with the standard movement, the weight was recorded as the subject's 1RM. If the subject was still unable to complete it, the weight previous to the weight that was unable to be completed the first time was recorded as the subject's 1RM It is important to note that the standard movement for the half-squat is a knee angle equal to or less than 90 degrees, and that an experienced researcher was responsible for observing whether the subject's movement met the standard at each repetition.

Subsequently, after an interval of 72h, a formal load-velocity profile measurement was performed: subjects performed three repetitions using 20%, 40%, and 60% of the measured 1RM weight, and one repetition using 80%, and 90%, respectively, and the concentric mean velocity of each repetition was recorded using a velocity tester (GYMAWARE, Australia), and for multiple repetitions the weights selected as the fastest one to be recorded. Subsequently, after importing the data into an Excel spreadsheet, they were fitted using a linear regression equation to obtain the half-squat load-velocity profile for the subjects. After 72 hours, a formal load-velocity profile test was conducted: subjects performed three repetitions at 20%, 40%, and 60% of 1RM, and one repetition at 80% and 90%. The concentric mean velocity of each repetition was measured with a GYMAWARE device, recording the fastest velocity for each load. Data were imported into Excel and fitted with linear regression to determine each subject's half-squat load-velocity profile.

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2.4. Flywheel intervention process

Subjects' mean concentric velocities were measured using a Gymaware during the flywheel familiarization test under different weight. Studies have shown that the effect of post-activation performance enhancement derived from different flywheel weights is different [12] because this study needed to unify the training loads of the various interventions. This load was approximately equal to the average concentric velocity of the subject when performing a flywheel workout, which was selected for the intervention [13]. The mean concentric velocity when subjects performed flywheel training was approximately equal to the mean concentric velocity when performing an 85% 1RM half squat for the intervention, and this weight is the optimal load recommended for acute interventions using barbells [13]. In practice, the flywheel load varied depending on the strength level of the subject (0.197m2-0.236m2). In addition, during the third flywheel familiarization training session, the average ground reaction force during eccentric and concentric processes was recorded for each subject, and the ratio was determined to be the intensity of eccentric overload.

During the formal intervention, subjects completed 3 sets of flywheel training (2+6 repetitions) with a 3-minute rest interval. The load was consistent with familiarization training. The initial 2 repetitions were for flywheel speed-up and were excluded from the 8-repetition total.

2.5. Accentuated eccentric loading intervention process

The accentuated eccentric loading intervention was performed using a concentric load of 85% 1RM, the eccentric load was individualized based on the individual subject's varying percentage of the flywheel produced, ranging from approximately 120%-125%, and subjects performed 2 accentuated eccentric loading familiarization training sessions using the target loads. Supervisors immediately rehooked the eccentric hooks to the barbell bar after each dislodgement, and subjects then performed the subsequent repetition.

At the time of the formal intervention, after subjects completed a standard flow warm-up, they performed 3 sets of 6 repetitions each of eccentric hook training, using the load finalized during the familiarization training, with a 3-minute interval between sets of the 3 sets.

2.6. Counter movement jump height and squat jump peak power test procedure

ForceDecks (FDLite V.2, VALD, Brisbane, Australia), a device validated for reliability, was employed to assess countermovement jump height and squat jump peak power [14]. In both tests, no arm swing was allowed, and after weighing, a supervisor gave the command "3, 2, 1, jump," and the participant jumped as hard as they could and remained in the position for about 3s before finishing. CMJ and SJ were tested twice, and the better one was selected for analysis.

2.7. 30-meter sprint time test procedure

30m times were measured using Smartspeed plus (VALD, Brisbane, Australia), and subjects were instructed to use a three-point start with no departure password and only one measurement at each corresponding time point.

2.8. Statistics

Statistical analyses were performed using SPSS 29.0, and data were expressed as means±standard deviations. Data were tested for normal distribution (Shapiro-Wilk Test). Time main effects,

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category main effects, and time-category interaction effects were compared using two-way repeated measures ANOVA. If the effects were significant, the Bonferroni correction removed errors from multiple comparisons, followed by a simple effects analysis. Dependent variables were set as counter movement jump height, squat jump peak power, and 30-meter sprint time.

3. Results

3.1. Counter movement jump height

Simple effects showed that the peak height of the CMJ after intervention using the flywheel appeared at minute 4 (54.31± 4.65cm), which was significantly enhanced compared to the baseline value ($p<0.001$), and the enhancement effect completely disappeared at minute 16 (51.72± 4.68cm), which was not significantly different compared to the baseline value ($p=0.863$), with an overall trend that started at minute 4 began to decline, but significant enhancement was observed at minute 8 (53.565± 4.62cm), and minute 12 (52.28± 4.68cm) ($p<0.001$). The results demonstrated using the accentuated eccentric loading were the opposite of the flywheel, where a decrease in CMJ height was observed at minute 4 (51.61± 4.46cm), which was significantly different compared to the baseline values ($p<0.001$), at minute 8 the height (52.22± 4.33cm) was not significantly different from the baseline value ($p=0.92$), at minute 12 a significant CMJ height increase was observed (52.97± 4.38cm), which was significantly different compared to the baseline value ($p<0.001$) , and at minute 16 there was a decrease in the overall CMJ height (52.61± 4.35cm), but still a significant increase compared to baseline values ($p<0.001$).

Comparison of the two interventions at the same time showed that there was no significant difference between the baseline values of the counter movement jump height of the flywheel group (51.7± 4.55cm) and the accentuated eccentric loading group (52.05± 4.48cm) ($p=0.127$) (Figure 1). The gap was the largest at the 4th minute, with an average difference of 2.7cm, which was significant ($p<0.001$); at the 8th minute, the average difference of 1.35cm, which was significant ($p<0.001$); at the 12th minute, the eccentric hook group surpassed the flywheel group, with a mean difference of 0.69, which was significant ($p=0.012$); and the gap widened further at the 16th minute, with a mean difference of 0.89, which was significant ($p=0.004$).

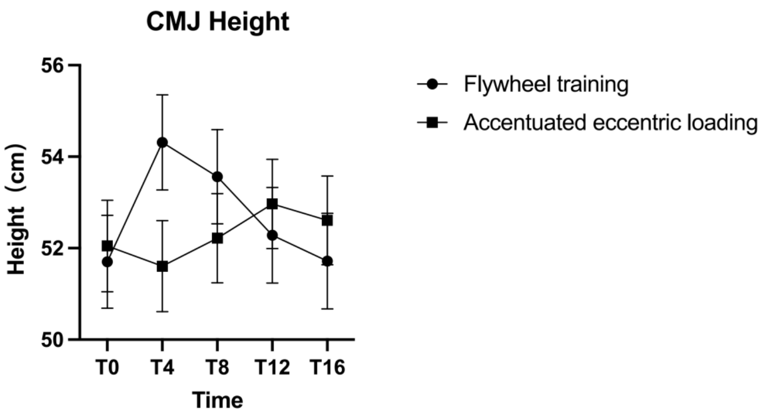

Figure 1. Comparison of counter movement jump height

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3.2. Squat jump peak power

Analyses revealed a significant main effect of time ($F(4,76)=23.42$, $p<0.001$), a significant main effect of category (F($F(1,19)=11.87$, $p=0.003$), and a significant interaction effect of time and intervention ($F(4,76)=21.52$, $p<0.001$).

Simple effects showed that the maximum peak power of the squat jump after the intervention using the flywheel still occurred at minute 4 (5267.30± 528.88W), with a significant enhancement compared to the baseline value ($p<0.001$); the difference between minute 8 (5250.35± 485.80W) and minute 12 (5190.00± 530.96W) remained significant ($p< 0.001$); minute 16 (5135.55± 502.57W) became less different compared to the baseline values, but still significantly different ($p=0.024$). Minute 4 (5052.80±508.19W) after accentuated eccentric loading intervention was not significantly different compared to baseline values ($p=0.591$); minute 8 (5111.70±503.05W) was significantly enhanced ($p<0.001$); minute 12 saw a peak (5177.85±510.72W) that was significant different compared to baseline ($p<0.001$); the peak power at minute 16 decreased (5139.65± 508.37) but still had a significant effect ($p<0.001$).

Comparison of the two interventions at the same time showed that there was no significant difference between the pre-intervention baseline values ($p=0.128$) (Figure 2), and that the enhanced effect of flywheel training was significantly more substantial than the accentuated eccentric loading at the 4th minute post-intervention ($p<0.001$); there was still a significant difference at the 8th minute post-intervention ($p<0.01$); there was no significant difference between them at the 12th minute post-intervention ($p= 0.679$); there was no significant difference at 16 minutes post-intervention ($p=0.900$)

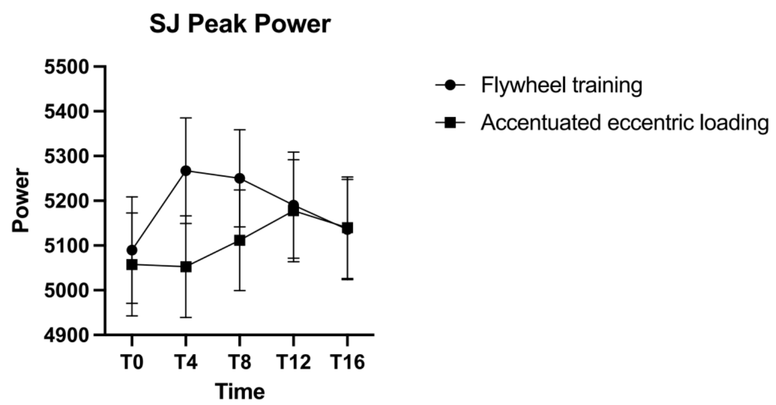

Figure 2. Comparison of squat jump peak power

3.3. 30-meter sprint time

Analyses revealed a nonsignificant main effect of time ($F(4,76)=0.54$, $p= 0.705$), a significant main effect of category ($F(1,19)=37.69$, $p<0.001$), and a significant interaction effect of time and category ($F(4,76)=50.94$, $p<0.001$).

Simple effects showed a significant decrease in 30m sprint time at minute 4 after the flywheel intervention (4.21± 0.10s) compared to the baseline value ($p<0.001$); at minute 8 (4.22± 0.09s) there was still a significant decrease ($p<0.001$); at minute 12 the mean time increased slightly (4.26± 0.85s), but still had a significant difference ($p=0.37$); the mean time taken at minute 16 (4.28±0.82s) was not significantly different from the baseline value ($p=0.989$). The mean time taken for the 30m sprint at minutes 4 (4.34± 0.85s), 8 (4.33± 0.80), and 12 (4.30± 0.88s) after the accentuated

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eccentric loading was significantly higher than the baseline value (p<0.001); no significant difference was found at minute 16 (4.26± 0.87s) (p=0.068).

Comparison of the two interventions at the same time showed that there was no significant difference between the baseline values before the intervention (p=0.632) (Figure 3); the flywheel training had a significant advantage over accentuated eccentric loading at minutes 4 and 8 after the intervention (p<0.001); the advantage disappeared at minute 12 after the intervention (p=0.07); and the mean difference was narrowed to 0.017 by minute 16, no significant effect was found (p=0.263). Simultaneous comparison of the two interventions revealed no significant difference in pre-intervention baseline values (p=0.632). Flywheel training demonstrated a significant advantage over accentuated eccentric loading at 4 and 8 minutes post-intervention (p<0.001). This advantage was attenuated at 12 minutes post-intervention (p=0.07), and the mean difference narrowed to 0.017 by 16 minutes, with no significant effect observed (p=0.263).

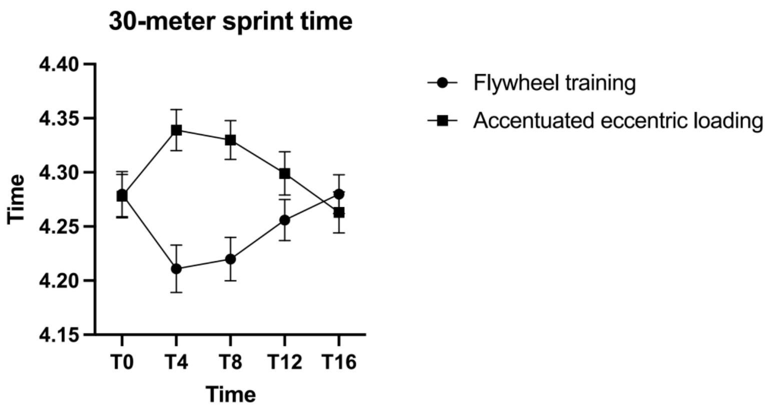

Figure 3. Comparison of 30-meter sprint time

4. Discussion

The present study investigated the difference between two forms of eccentric overload training on post-activation performance enhancement in sprinters. The findings of the flywheel training intervention were consistent with prior research [14, 15], with a one-off enhancement effect on both vertical explosive power (CMJ height, SJ peak power) and horizontal explosive power (30m speed). Both peaked at minute 4 and then continued to decline, with the enhancement effect completely disappearing by minute 16. The outcomes observed under pronounced eccentric loading exhibited minor variations. For vertical explosive force, it did not significantly increased comparing to the baseline value at minutes 4 and 8, and then there was a significant enhancement effect at minute 12, which was still present at minute 16; for 30m speed, the accentuated eccentric loading had the opposite effect, but the overall trend was still a gradual return to the baseline value.

Regarding the enhancement effects and trends embodied in eccentric overload training with both flywheel training and accentuated eccentric loading, perhaps there is a direct connection with the size of the loads, Li Zhe et al. observed that in a resistance training intervention involving experienced male subjects, the application of varying eccentric loads (80% 1RM, 105% 1RM) alongside a consistent concentric load (70% 1RM) revealed a more pronounced and accelerated enhancement effect with the 80% 1RM eccentric load [16]. Kuo-Wei Tseng et al. reported that, in collegiate male volleyball athletes, there was no statistically significant enhancement in CMJ height at 10 minutes post-intervention following the application of an 80% 1RM concentric load and a 105% 1RM eccentric load [6]. Since this experiment used speed monitoring to adjust the load to

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control the variables, the concentric load was uniformly specified to be around 80% 1RM. The eccentric overload was around 20%-25%, so the load of the eccentric phase was around 100%-105% 1RM, and combined with previous studies, the accentuated eccentric loading at this load did not induce the post-activation performance enhancement very well. This may be related to the overload, which increased fatigue and caused the period of post-activation performance enhancement to overlap with the fatigue period, making the enhancement effect at 4 min and 8 min fail to be manifested. At minute 12, the fatigue effect was partly eliminated, and thus the enhancement was demonstrated, while at minute 16, the test performance fell back to baseline values as the enhancement effect subsided. However, a significant post-activation enhancement effect was shown for the same load when the intervention was performed using flywheel training. This may be related to the unique way the load is applied to the flywheel. By comparison, it can be concluded that when flywheel training is used as an acute intervention, heavier loads can be used, the proportion of eccentric overload is also larger, and the post-activation performance enhancement induced is more substantial. In addition, heavier flywheel loads seem to cause more significant enhancement effects and appear earlier, as confirmed in a previous study [17].

5. Conclusion

Through a comparative analysis of two distinct eccentric overload training modalities on post-activation performance enhancement in sprinters, this study determined that the flywheel intervention demonstrated a more rapid onset and superior efficacy in inducing performance gains compared to the eccentric hook intervention. The peak enhancement effect after the flywheel intervention appeared generally at the 4th or 8th minute and disappeared at the 16th minute. The pronounced impact of accentuated eccentric loading emerged after the twelfth minute, demonstrating a facilitative effect exclusively on vertical explosive power, with no observable enhancement in horizontal explosive force. Comparison of the magnitude of change and characteristics of the dependent variables revealed that flywheel training was more effective in avoiding the influence of fatigue on the enhancement effect under the same load. In contrast, the enhancement effect of accentuated eccentric loading was masked by fatigue at minutes 4 and 8. Thus, the enhancement effect appeared later and was weaker than flywheel training.

This study has limitations, including the exclusive selection of male sprinters with strong lower limbs, potentially increasing sensitivity to activation effects. The heavy accentuated eccentric loading may have caused fatigue that masked enhancement effects. Future research should compare the two eccentric overload trainings at varying loads and reduce the accentuated eccentric loading to better assess their acute intervention effects.

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