Comparison of Neuromuscular Fatigue in Powerlifting Paralympics in Different Training Methods

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ABSTRACT

Mean propulsive velocity (MPV) has been associated with neuromuscular fatigue; however, its suitability for strength training in Paralympic powerlifting (PP) remains uncertain. The objective of this work was to evaluate the MPV in two training methods (traditional-TRAD and eccentric-ECC). Eleven PP athletes were evaluated pre, during the intervention and post intervention at a load of 80 % of the 1RM for TRAD and 110 %–80 % of 1 RM for ECC. The results demonstrated that there was no significant neuromuscular fatigue for the TRAD (~5 % performance loss), as well as no significant decline in MPV during the intervention. For the ECC, there is a significant reduction in MPV before and after training (~12 % loss of performance). A difference between TRAD and ECC after the intervention was also identified (0.87 m/s ± 0.22, 95 % CI 0.72–1.02 vs. 0.72 ± 0.20, 95 % CI 0.59–0.86 $p = 0.042$, $F(3.30) = 10.190$, $\eta 2p = 0.505$ - very high effect). During the intervention for ECC, no significant decline in MPV was observed. The results of this study suggest that the mechanical indices of MPV do not seem to be effective indicators of neuromuscular fatigue in the sample studied or in the context of this specific training regime, being more indicated as a control of training volume.

Introduction

Athletic performance in certain disciplines necessitates ongoing enhancement of muscle strength and power, and various training methods can be employed for this purpose [1]. While extensive research has focused on strength training in sports involving individuals "without physical disabilities" [2], limited attention has been given to parasports, particularly Paralympic Powerlifting (PP). PP is a sport heavily reliant on maximal strength for achieving athletic success [3].

It is well established that fatigue serves as a limiting factor in the progressive improvement of performance. Place et al. [4], have reported that prolonged dynamic exercises induce muscle fatigue, resulting in a decline in the capacity for maximum voluntary contraction. Enoka and Duchateau [5], have also highlighted that muscle fatigue can arise from various mechanisms and is initiated when the capacity for maximum strength or power diminishes, which may not necessarily be the limiting factor in an individual's task performance ability.

From a mechanical perspective, Jones [6], suggests that muscle fatigue can be identified by an increase in the slope of the force-velocity curve, as identifying the specific metabolic causes for these alterations can be challenging. In 2011, Sánchez-Medina and González-Badillo [7] proposed that the reduction in mean propulsive velocity (MPV) can serve as an indicator of neuromuscular fatigue because it is associated with increased levels of metabolites in the bloodstream, such as lactate and ammonia. They also argued that velocity-based training (VBT) would be more adequate to control training, however, in the study [7], no changes were observed in the velocity profile after performing a low number of repetitions, (3 × 4 [8]) repetitions at 80 % 1RM; (3 × 4 [6]), (3 × 3 [6]) repetitions at 85 % 1RM and (3 × 2 [4]) repetitions at 90 % 1RM. This low number of repetitions is characteristic of PP training [8] and it is possible that, for training methodologies where small numbers of repetitions are used, the VBT may not be reliable for the analysis of neuromuscular fatigue as well as for training control. Thus, there are uncertainties regarding the ideal method [9], particularly in the context of PP, where most studies examining PP have used methods based on zones of one repetition maximum (1RM) (PBT) to control training [8]. Therefore, the objective of this study was to evaluate the neuromuscular fatigue indicators in Paralympic weightlifting athletes using two different training methods: the inertial method (traditional denominated - TRAD) and the eccentric/concentric training method (ECC) incorporating loads supramaximal in the eccentric phase of the adapted bench press. The following hypotheses were formulated for this study: I) Within a TRAD training session consisting of five sets of five repetitions at 80 % of 1RM, there will be no significant loss in velocity; II) ECC training will result in a greater reduction in velocity between sessions compared to TRAD training; III) Neuromuscular fatigue indicators will be adversely affected 24 hours after both training methods, and only the ECC method will continue to exhibit negative alterations in neuromuscular fatigue indicators after 48 hours.

Materials and methods

Research design

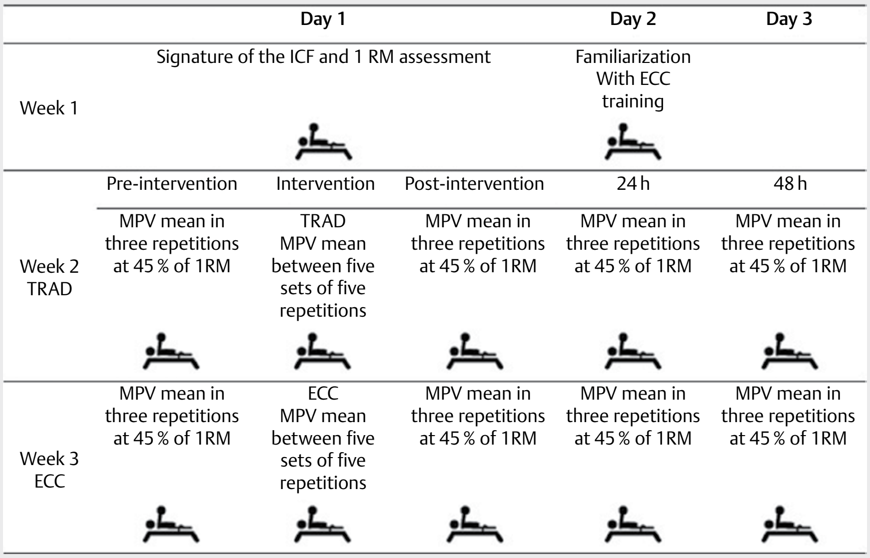
This study is characterized as a non-randomized crossover study carried out over a period of three weeks (▶ **Fig. 1**). During the first week, participants provided informed consent (ICF) and underwent a one-repetition maximum (1RM) test. Twenty-four hours later, they received a verbal explanation of the ECC training method, specifically regarding the controlled bar repetitions. No additional familiarization was provided as the athletes were already accustomed to both TRAD and ECC training. The sample comprised highly skilled Paralympic powerlifting (PP) competitors, including three Brazilian champions in their respective categories for the year 2022, with one athlete having participated in the Tokyo Paralympics (2020/2021) and achieving an eighth place.

To assess neuromuscular fatigue, the methodology proposed by Sánchez-Medina and González-Badillo [7] was employed at five-time points: pre-intervention, intervention, post-intervention, 24 hours after the training session, and 48 hours after the training session. Both training methods utilized five sets of five repetitions during the intervention phase. TRAD training was conducted in the second week, followed by ECC training in the third week. This sequencing was based on previous research suggesting that ECC training may impact recovery time [10].

Sample

The sample consisted of eleven male Paralympic Powerlifting athletes (▶ **Table 1**). The types of physical disability are as follows: four athletes have congenital arthrogryposis multiplex; three have polio sequelae; two athletes are affected by spinal cord injuries and two athletes suffered lower limb amputation. We emphasize that despite different disabilities, athletes are evaluated based on their functional capacity to guarantee a fair competition [11]. For inclusion criteria in the study, athletes would have to be ranked among the top 10 in their respective weight categories at the national level. Having a minimum experience of 3 years of practice in the modality, athletes would be excluded from the research if they had pain or any physical problem that made it impossible to carry out the intervention and voluntarily withdraw. All athletes included in this research met the eligibility criteria established by the Brazilian Paralympic Committee and had the necessary qualifications to participate in the sport [11]. They voluntarily enrolled in the study and provided informed consent by signing the required documents. The research protocol received approval from the Research Ethics Committee, with technical advice number 2.637.882.

The sampling power was calculated a priori using the open-source software GPower (Version 3.0; Berlin, Germany), choosing a "F family statistics (ANOVA)" considering a standard $\alpha < 0.05$, $\beta = 0.80$ and the effect size of 1.33 found for the force indicator in Paralympic powerlifting athletes [12]. Thus, it was possible to estimate a sample power of 0.80 (F (2.0): 4.73) for a minimum sample of eight subjects per group, suggesting that the sample size of the present study has statistical strength to respond to the research approach.



	Day 1			Day 2	Day 3
Week 1	Signature of the ICF and 1 RM assessment			Familiarization With ECC training	
Week 2 TRAD	Pre-intervention	Intervention	Post-intervention	24 h	48 h
	MPV mean in three repetitions at 45 % of 1RM	TRAD MPV mean between five sets of five repetitions	MPV mean in three repetitions at 45 % of 1RM	MPV mean in three repetitions at 45 % of 1RM	MPV mean in three repetitions at 45 % of 1RM
Week 3 ECC	MPV mean in three repetitions at 45 % of 1RM	ECC MPV mean between five sets of five repetitions	MPV mean in three repetitions at 45 % of 1RM	MPV mean in three repetitions at 45 % of 1RM	MPV mean in three repetitions at 45 % of 1RM

▶ **Fig. 1** Experimental design. TRAD: Traditional Training; ECC: Eccentric training; MPV: Mean propulsive velocity.

▶ **Table 1** Sample Characterization.

Variables	(Mean ± SD)
Age (years)	31.54 ± 9.72
body mass (kg)	73.63 ± 17.55
1RM Bench Press Test (kg)	121.63 ± 40.94
1RM/Body mass	1.63 ± 0.38
Time Experience (years)	4 ± 1.18

MPV - Mean propulsive velocity, TRAD - Traditional training, ECC - Eccentric training, ICF - Informed consent form, 1RM - Maximum load, SD - Standard deviation.

Instruments

A linear position encoder (encoder) manufactured by Vitruve (Madrid, Spain) was utilized to evaluate neuromuscular fatigue [13]. The mean propulsive velocity (MPV) obtained from the encoder was used to determine the changes in velocity loss before, after, 24 hours, and 48 hours following the training session, as well as the velocity loss decline during the five sets of five repetitions.

Procedures

Traditional training (TRAD): This training protocol involved using inertial loads set at 80 % of 1RM for both concentric and eccentric movements. Athletes were instructed to perform at their usual training speed. Additionally, participants were advised to maintain a consistent grip width for both training methods, as this variable has the potential to influence movement kinetics [14].

ECC training: In this training method, the load used during the eccentric phase exceeded that of the concentric phase. Specifically, a load of 110 % was applied during the eccentric phase, while the concentric phase utilized 80 % of 1RM [15]. To introduce the supramaximal load, two devices called Berenice were affixed to the bar. As the bar touched the athlete's sternum during the bench press movement, the equipment made contact with the ground and disconnected from the bar, releasing 30 % of the total load. This allowed the athlete to perform the concentric phase with 80 % of their 1RM.

For both training methods, a mechanical pause of approximately 1.5 seconds [7], was implemented between the eccentric and concentric actions to minimize the rebound effect of the movement. Additionally, in the ECC method, a pause of approximately 1 second was observed at the end of each concentric action to facilitate the re-coupling of the Berenice devices.

Maximum Load Determination

The bench press 1RM test followed the protocol proposed by Brown & Weir [16]. Prior to the test, a five-minute period of light activities involving the tested muscle group (using an arm cycle ergometer) was performed, followed by specific stretching targeting the chest, triceps, and shoulder muscles. Subsequently, the specific warm-up for the test commenced, which included eight repetitions at 50 % of the estimated 1RM, followed by an additional set of three repetitions at 70 % of the estimated 1RM.

During the bench press 1RM test, weight increments were uniformly added based on the weight lifted during the sets at 70 % of the estimated 1RM. Each successful attempt resulted in a 5 % increase in weight. This approach aimed to ensure that at least two attempts at 1RM could be performed. In the event of concentric failure, the load was reduced by 2.5 %. The test protocol included a maximum of five attempts, with a five-minute rest interval provided between each attempt.

Neuromuscular Fatigue Evaluation

As per the methodology proposed by Sánchez-Medina & González-Badillo [7], the mean propulsive velocity (MPV) was utilized to determine the percentage change in the loss of velocity at a load of 45 % of 1RM for three repetitions at four different time points: pre-training, immediately post-training, 24 hours post-training, and 48 hours post-training. The calculation employed the following equation provided by the authors: 100 x (average MPV post − average MPV pre)/average MPV pre. This calculation was used to assess neuromuscular fatigue at the 24-hour and 48-hour time points following training.

To analyze the percentage loss of mean propulsive velocity in each set, the velocity decline across the repetitions within the five consecutive sets of the exercise was evaluated. This calculation involved considering the fastest and slowest repetition (typically the first and last repetition) within each set, and the average of these values was computed across the five sets.

However, in order to account for the observed discrepancy in the velocity of the first repetition within our sample, both at the load of 45 % of 1RM and during the training sessions, we identified a consistent movement pattern where the first repetition consistently exhibited lower speed compared to the subsequent repetitions. Therefore, in our analysis of velocity during training as well as in the pre-training, post-training, 24-hour, and 48-hour assessments, we excluded the data associated with the first repetition. Instead, we calculated the average velocity of the subsequent repetitions for each evaluation (▶ **Fig. 2**).

Statistical Analysis

Descriptive statistics were conducted using measures of central tendency, specifically mean (X), along with Standard Deviation (SD). The Shapiro-Wilk test was employed to assess the normality of the variables, taking into account the sample size. To examine the performance differences across the various moments, a Two-Way repeated measures ANOVA (Condition x Moment) was conducted, followed by Bonferroni's Post Hoc test. Effect size in the ANOVA was evaluated using partial square eta (η2p), with values categorized as low effect (≤ 0.05), medium effect (0.05 to 0.25), high effect (0.25 to 0.50), and very high effect (> 0.50) [17]. The variation coefficient (CV %) was calculated by the formula: CV % = (standard deviation (SD)/mean) × 100, Where a variation between 10 to 15 % is acceptable [18, 19].

Statistical analysis was performed using the Statistical Package for the Social Sciences (SPSS), version 22.0, (IBM, New York, USA). The significance level was set at $p < 0.05$.

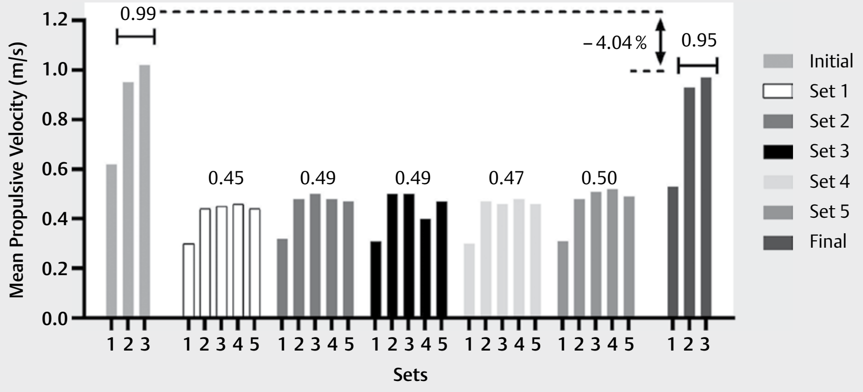
Results

No significant differences were observed for TRAD training in any of the evaluations, as illustrated in ▶ **Fig. 2**. However, a significant reduction in the loss of mean propulsive velocity was noted in the pre x after ECC training (0.95 m/s ± 0.24), 95 %CI 0.84–1.06, CV = 6 % vs. (0.83 m/s ± 0.24), 95 %CI 0.72–0.94, CV = 8.05 % respectively, p = 0.001, F(3.63) = 8.866, η2p = 0.297 - high effect) and pre x 24 h (0.95 m/s ± 0.24), 95 %CI 0.84–1.06, CV = 6 % vs. (0.85 m/s ± 0.21), 95 %CI 0.75–0.94, CV = 5.32 %, p = 0.004, F(1.21) = 8.866, η2p = 0.297 - high effect (▶ **Fig. 3,4**). A significant difference was also observed between the post-intervention moments between TRAD x ECC (0.95 m/s ± 0.22), 95 %CI 0.85–1.05, CV = 4.67 % vs. (0.83 m/s ± 0.24), 95 %CI 0.72–0.94, CV = 8.05 %, p = 0.003, F(1.21) = 12.158, η2p = 0.367 - high effect (▶ **Fig. 4**).

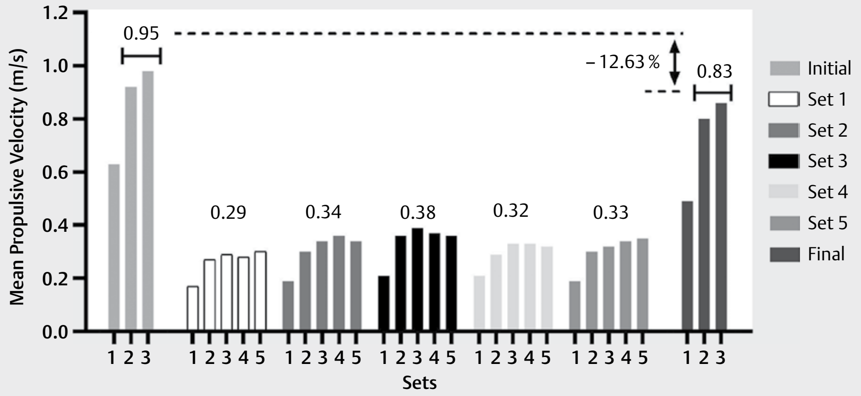
There was a significant difference (CV = set 1 Trad [6.52 %] x set 1 Ecc [12.38 %]; set 2 Trad [6.50 %] x set 2 Ecc [10.08 %]; set 3 Trad [7.54 %] x set 3 Ecc [11.66 %]; set 4 Trad [10.61 %] x set 4 Ecc [12.08 %]; set 5 Trad [8.69 %] x set 5 Ecc [11.10 %], p < 0.001) between the percentage of mean propulsive velocity between all series when comparing TRAD x ECC. Both comparisons produced a value of F(4.172), 12.222, η2p = 0.221, indicating a medium effect size (▶ **Fig. 5**).

Discussion

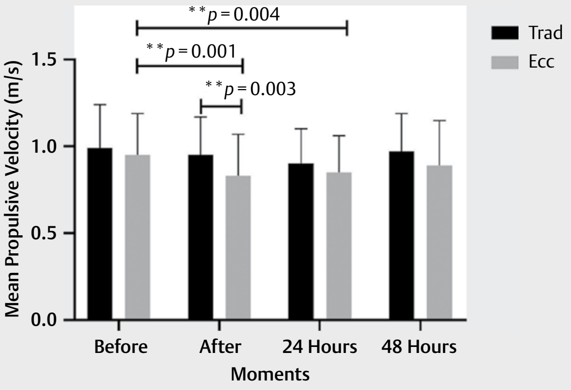
The main objective of this study was to evaluate indicators of neuromuscular fatigue and compare them between traditional (TRAD) and eccentric (ECC) training methods. The main finding of this study reveals that there was no significant percentage loss in average propulsive velocity (MPV) during the series, and there were no significant differences in the variation in the percentage loss of MPV



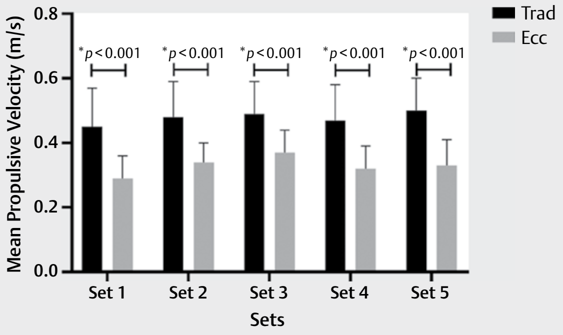
▶ **Fig. 2** Quantification of neuromuscular fatigue during traditional training at the respective times: Pre (45 % 1RM), intervention (80 % 1RM) and post (45 % 1RM).



▶ **Fig. 3** Quantification of neuromuscular fatigue during eccentric training at the respective times: Pre (45 % 1RM), intervention (110/80 % 1RM) and post (45 % 1RM).



▶ **Fig. 4** Analysis of neuromuscular fatigue at a load of 45 % of 1 RM between pre, post, 24 and 48 h post-intervention. TRAD: Traditional Training, ECC: Eccentric Training.



▶ **Fig. 5** Analysis of neuromuscular fatigue during five sets of five repetitions between traditional and eccentric training. TRAD: Traditional Training, ECC: Eccentric Training.

in the pre, post, 24 h and 48 h moments for TRAD Training, as illustrated in ▶ **Fig. 2,4**. On the other hand, for ECC training, there was a reduction in MPV variation between pre x post-intervention and pre x 24 h as shown in ▶ **Fig. 3,4**, but no significant percentage loss was observed during the sets of training.

The use of MPV as a reliable indicator for strength analysis has been well-documented in the literature since 2010 [20], including its application for assessing neuromuscular fatigue. However, most of these analyses have focused on specific interventions targeting muscular endurance and 1RM prediction [21, 22]. Our findings do not align with the results reported by Sánchez-Medina & González-Badillo [7], as the traditional training did not lead to a loss of mean propulsive velocity within each set or in the pre, post, 24 h, and 48 h assessments, using a load of 45 % 1RM (▶ **Fig. 2**).

It is important to consider certain specificities when interpreting these data, such as the type of training employed in this particular sample. This study is the first to analyze MPV as an indicator of mechanical fatigue in strength training for Paralympic Powerlifting athletes. Strength training for these athletes typically involves submaximal to maximal loads ranging from 60 % to 100 % of 1RM, with sets ranging from 5 to 8 and repetitions from 1 to 12 [23].

In 2006, Izquierdo et al. [18], identified that the mean velocity of the bench press starts to decline when reaching approximately one-third of the total repetitions performed until failure, within the range of 60 to 75 % of 1RM. However, it is possible that this relationship does not hold for higher loads, as the time under tension is directly linked to oxidative stress levels, which can directly impact muscle fatigue [24]. A recent study by Aidar et al. [25], revealed that a training session consisting of five sets of five repetitions at intensities between 80 % and 90 % of 1RM in Paralympic Powerlifting athletes did not result in significant oxidative stress. Furthermore, João et al. [24], demonstrated that performing 15 repetitions at 60 % of 1RM or 10 repetitions at 75 % of 1RM led to greater caloric expenditure compared to performing 5 repetitions at 90 % of 1RM, and there were no significant differences in lactate concentrations among these conditions. When exercises are performed to exhaustion, high levels of oxidative stress are observed, which subsequently impairs the ability to sustain physical activity [26].

Velocity-based training (VBT) has gained significant attention in recent years; however, there is still ongoing debate regarding its practicality. Suchomel et al. [9], reported that using VBT for training monitoring can be advantageous for novice athletes, but its ability to accurately track absolute load variations may diminish over extended periods. Conversely, monitoring based on percentage zones of the one-repetition maximum (1RM) tends to yield greater variability in strength and power adaptations. However, this method fails to capture daily performance changes in athletes. According to Jaric [27], there exists a negative correlation between force and velocity, meaning that as force increases, velocity decreases. Based on this assertion, it is hypothesized that VBT may be more effective when combined with controlling training volume based on predefined 1RM loads [28].

Dorrell et al. [29], conducted a study comparing VBT methods with training based on 1RM zones and found no significant difference in muscle strength gains between the two methods. However, they observed a 6 % reduction in the total volume of bench press repetitions performed in the VBT method compared to the 1RM zone-based training. Furthermore, in the study by Sánchez-Medina & González-Badillo [7], it was demonstrated that with a lower number of repetitions per set (e. g., 4 reps of 8 possible at 80 % 1RM, 4 reps of 6 possible at 85 % 1RM, 3 reps of 6 possible at 85 % 1RM, and 2 reps of 4 possible at 90 % 1RM), there was no significant loss of speed. In our present study, using 5 repetitions, we did not observe differences in speed loss during the training sets, and there was no significant speed loss with a load of 45 % 1RM between the pre, post, 24-hour, and 48-hour time points (as shown in ▶ **Fig. 2,4**).

Another noteworthy aspect of our study is that irrespective of the load (45 % or 80 % 1RM) during the concentric phase of the movement, the Mean Propulsive Velocity (MPV) was consistently lower in the first repetition. This finding contradicts the lifting profile reported in the study by Sánchez-Medina & González-Badillo [7], where the authors state that the first repetition is typically the fastest within a set of repetitions. We hypothesize that the characteristics of our sample may have influenced this profile. The participants in the study by Sánchez-Medina & González-Badillo were "able-bodied" individuals, without physical disabilities and with their feet in contact with the ground [7]. In contrast, our sample comprised Paralympic Powerlifting athletes who do not utilize their lower limbs for support on the ground. It has been previously documented that these athletes exhibit lower bar speeds compared to non-injured competitors [30]. The support provided by the legs on the ground can induce changes in the kinematics of the movement, thereby influencing the vertical displacement of the bar [31]. Therefore, it is plausible that the first repetition, regardless of the load used, is associated with postural stabilization and adjustment of the body to the adapted flat bench press, resulting in percentage loss of MPV between for these Paralympic powerlifting athletes.

When comparing the percentage loss of Mean Propulsive Velocity (MPV) between the TRAD and ECC training methods, it became apparent that the ECC method induced a more pronounced MPV reduction, as anticipated. This disparity was evident when evaluating the impact at a 45 % 1RM load for both methods (refer to ▶ **Fig. 4,5**). Surprisingly, after a 48-hour period, when we conducted a mechanistic assessment of neuromuscular fatigue via MPV at 45 % 1RM, these initial discrepancies ceased to hold statistical significance. Initially, our hypothesis centered around the notion that ECC training would lead to a heightened level of neuromuscular fatigue compared to TRAD training, especially after the 48-hour mark. However, it turns out that this hypothesis did not align with the actual outcomes.

Bartolomei et al. [32], conducted a study where participants performed 6 sets of 5 repetitions in the bench press at loads ranging from 120 % to 80 % of their 1RM in the ECC training. They found that even after 48 hours, individuals still exhibited impaired performance for power at a load of 30 % of their 1RM. In our sample, however, no loss of velocity was observed at 48 hours post-intervention. Although the evaluation methods differed, our study focused on MPV while Bartolomei et al. [32] assessed power. The velocity values measured between repetitions during the sets in both studies were consistently lower compared to the 80 % 1RM load (TRAD). Hence, acute recovery was significantly more negatively affected by the ECC protocol, as depicted in ▶ **Fig. 4**.

In another study, both mean velocity and power were evaluated. The 120/80 % load of 1RM did not increase speed or power significantly. However, when analyzing a load range from 120 % to 65 % of 1RM, there was an increase in speed and power. This suggests that the eccentric load exceeding the maximum capacity is sensitive to the load used during the concentric phase of the movement [33].

However, despite yielding relevant results, our study has certain limitations. The small number of athletes included in the study prevents us from making broad generalizations. It is also crucial to consider the potential impact of the athletes' impairments in order to explain why the first repetition consistently exhibited inferior performance compared to subsequent repetitions.

Moreover, it is essential to examine the variables' behavior within specific movement conditions, particularly during the stick point region of the bench press, to gain a more comprehensive understanding of the utilization of the leg/bench interface in Paralympic weightlifting. Therefore, future studies should incorporate additional morphological, biodynamic, and functional variables that could potentially influence the performance of Paralympic weightlifting athletes.

In summary, the outcomes of this study indicate that the mechanical indicators of neuromuscular fatigue, specifically the "Mean Propulsive Velocity," do not demonstrate effectiveness within the scope of this particular sample or training modality. While there existed a notable disparity in MPV for eccentric training across the pre-training, post-training, and 24-hour intervals, no substantial decline in MPV was noted for either traditional (TRAD) or eccentric (ECC) training during the sets, even extending to the 48-hour post-training phase. These findings corroborate our initial hypothesis while simultaneously refuting the validity of our second and third hypotheses.

Practical Applications

- Paralympic weightlifting coaches and competitors should exercise caution when relying solely on mean propulsive velocity as an indicator of neuromuscular fatigue, as there was no significant reduction in mean propulsive velocity during and between sets of traditional training.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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