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Original Article

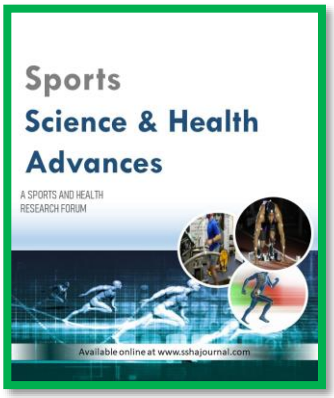
Does Hand Grip Strength Serve as a Reliable Functional Marker for Quantifying Muscle Recovery?

Parveen Kumar[1], Rohit Rathee[2]*, Ari Tri Fitrianto[3]

[1,2]Assistant Professor, Department of Physical Education, Chaudhary Ranbir Singh University, Jind, Haryana, India

[3]Associate Professor, Department of Sports Education, Faculty Education and Teaching, Universitas Islam Kalimantan Muhammad Arsyad Al Banjari, Banjarmasin, Indonesia

***Correspondence**: rohit@crsu.ac.in



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Abstract

Objective: Hand grip strength (HGS) is widely used as an indicator of muscle function, but its potential as a direct marker of functional recovery following exercise-induced muscle damage (EIMD) remains unclear. This study aimed to evaluate the effectiveness of hand grip strength (HGS) as a functional marker for quantifying muscle recovery following exercise-induced muscle damage (EIMD). **Methods:** A repeated-measures design was employed, wherein HGS and VAS were recorded at baseline, immediately post-exercise, and at 24, 48, and 72 hours post-exercise. A one-way repeated measures analysis of variance (ANOVA) was conducted to assess changes over time, followed by Tukey's post hoc analysis. Pearson correlation was used to examine the relationship between HGS and VAS. **Results:** Significant time effects were observed for both HGS ($F(4,48) = 3.950$, $p = 0.008$, $\eta^2 = 0.248$) and VAS ($F(4,48) = 27.134$, $p = 0.000$, $\eta^2 = 0.693$) scores ($p < 0.05$). HGS significantly declined immediately post-exercise, followed by a gradual recovery at 24 and 48 hours, with the smallest difference from baseline at 72 hours. VAS scores remained at zero at baseline, peaked between 24 and 48 hours, and declined at 72 hours. No significant correlation was found between HGS and VAS at any time point, indicating that these measures capture distinct aspects of muscle recovery. **Conclusion:** HGS appears to be a useful objective marker of functional muscle recovery, particularly in settings requiring immediate assessment, such as sports competitions or rehabilitation. However, its use should be complemented with subjective measures like VAS to provide a comprehensive evaluation of muscle recovery post-EIMD.

Keywords: Grip Strength, Recovery, Delayed Onset Muscle Soreness, Muscle Damage, Rehabilitation, Physical Education

Introduction

Monitoring muscle recovery is essential for optimizing athletic performance, preventing injuries, and guiding rehabilitation strategies (Kellmann et al., 2018; Mielgo-Ayuso & Fernández-Lázaro, 2021; Mika et al., 2007). While various biochemical and physiological markers have been used to assess recovery, many require invasive procedures or specialized equipment, limiting their practical application (Bouzid et al., 2014; Brancaccio et al., 2010; Lee et al., 2017; Skorski et al., 2023). Hand grip strength (HGS), a simple and non-invasive measure of neuromuscular function, has been widely used to assess overall muscle strength and fatigue (Nara et al., 2022, 2023). However, its potential role as a direct marker of muscle recovery remains largely unexplored in scientific literature.

Since muscle fatigue and damage can lead to temporary reductions in grip strength, tracking HGS over time could provide valuable insights into the recovery process (Porto et al., 2019; Saraiva et al., 2021). Additionally, subjective assessments like the Visual Analogue Scale (VAS) (Boonstra et al., 2008) for muscle soreness are commonly used in recovery studies, yet their correlation with objective measures such as HGS has not been thoroughly investigated. This study aims to bridge this gap by evaluating the efficacy of hand grip strength as a functional marker of muscle recovery and exploring its relationship with perceived muscle soreness. If validated, HGS could serve as a practical and cost-effective tool for athletes, trainers, and clinicians to monitor recovery status in real-time settings.

Methods

Participants

Twenty-four healthy men with no current or previous upper arm injuries and who had not performed resistance training of the upper limbs for at least six months prior to the present study were recruited. Out of the total, eleven participants did not provide post exercise assessment and thirteen participants completed the intervention. The mean ± standard deviation (SD) of age, body weight, height and BMI were 21.38 ± 3.73 years, 176.61 ± 9.01 cm, 72.53 ± 16.25 kg and 23.14 ± 4.25 kg/m2 (See Table 1) respectively. Before participating in the study, participants were asked to compete an informed written consent form and a medical questionnaire consisted of the checklist of symptoms and known medical conditions. Participants were requested not to change their daily routine and diet, not take any anti-inflammatory drugs or nutritional supplementations and not perform unaccustomed exercise during the experimental period. The study was approved by the Institutional Human Research Ethics Committee and complied with the declaration of Helsinki (Shrestha & Dunn, 2020).

Table 1 Subjects characteristics and descriptive statistics for HGS and VAS measurements at different time points

	MEAN	SD	MIN.	MAX.
Age	21.38	3.73	18.00	28.00
Height	176.61	9.01	167.00	196.00
Weight	72.53	16.65	54.00	114.00
BMI	23.14	4.25	17.59	31.58
HGS Baseline	47.48	9.67	33.50	62.60
HGS Post	43.08	9.88	27.00	60.70
HGS 24	44.58	6.90	34.50	59.00
HGS 48	44.74	8.75	29.00	64.20
HGS 72	46.30	8.19	33.20	62.00
VAS Baseline	0.00	0.00	0.00	0.00
VAS Post	38.46	11.61	20.00	65.00
VAS 24	45.76	19.77	10.00	80.00
VAS 48	43.69	18.02	10.00	65.00
VAS 72	21.92	10.90	10.00	40.00

HGS = Hand Grip Strength, VAS = Visual Analogue Scale, N = 13

Eccentric Exercise Protocol

The eccentric exercise protocol involved a high-volume dumbbell curl regimen designed to induce muscle damage in the biceps. Participants performed 10 sets of six dumbbell curls at 60% of their one-repetition maximum (1RM), emphasizing the eccentric phase by maintaining a 90-degree elbow angle during the lowering motion. Each repetition was executed in a controlled manner to maximize muscle strain, and a 2-minute rest interval was provided between sets to minimize fatigue accumulation while ensuring sufficient mechanical stress on the muscle fibers. This protocol was implemented to elicit muscle damage, facilitating the evaluation of physiological responses to eccentric overload.

Visual Analogue Scale

The level of muscle soreness was measured using a 100 mm visual analogue scale (VAS) (Boonstra et al., 2008). The VAS was ranged from 0 to 100 mm where 0 indicated "no pain" and 100 represented "extreme pain". The participants were asked to mark the level of perceived soreness on the VAS, when the biceps muscle palpated in circular motion by the investigator before, just after, 24 hours, 48 hours, and 72 hours post exercise.

Hand Grip Strength

Hand grip strength was assessed using a CAMRY electronic hand grip dynamometer (Camry Scale - USA, Model: 12365 Barringer St, South El Monte). This digital device has a maximum measurement capacity of 90 kg, ensuring precise and reliable grip strength recordings. Participants were instructed to stand in an upright position, holding the dynamometer in their dominant hand with the palm facing inward toward the body. The grip width of the device was adjusted to fit each participant's hand comfortably to ensure optimal force application. They were then asked to squeeze the dynamometer with maximum effort for a duration of 3 – 5 seconds while maintaining a neutral wrist position. Each participant performed three trials, with a 30 – seconds rest interval between attempts to prevent fatigue. The highest recorded value from the three attempts was considered the final grip strength score. To ensure familiarization and accuracy, a preliminary session was conducted one day before the actual test, during which participants were instructed on the correct use of the device and given practice trials to minimize variability in performance. This familiarization session helped in standardizing the measurement process and reducing potential errors.

Statistical Applications

Kolmogorov-Smirnov test was conducted to check the normality assumptions. Changes in hand grip strength (HGS) and visual analogue scale (VAS) scores over time (pre, post, 24h, 48h, and 72h) were analysed using a one-way repeated measures analysis of variance (ANOVA). When a significant within-subject effect was observed, Tukey's post-hoc test was conducted for pairwise comparisons to determine specific time points with significant differences. The Pearson product-moment correlation coefficient was used to examine the relationship between HGS and VAS measures. Descriptive statistics, including arithmetic mean, standard deviation (SD), minimum, and maximum values, were computed to summarize the data. A statistical significance level of $p \leq 0.05$ was set for all analyses.

Results

Effect of Time on HGS and VAS

In the Table 2 repeated measures ANOVA for hand grip strength (HGS) revealed a significant time effect ($F(4,48) = 3.950$, $p = 0.008$, $\eta^2 = 0.248$), indicating notable changes in HGS across different time points. The partial eta squared ($\eta^2 = 0.248$) suggests a moderate effect size, implying that time had a meaningful impact on grip strength variations. The repeated measures ANOVA for visual analogue scale (VAS) scores showed a significant time effect ($F(4,48) = 27.134$, $p = 0.000$, $\eta^2 = 0.693$), indicating a substantial change in pain perception over time. The partial eta squared ($\eta^2 = 0.693$) suggests a medium effect size, meaning that time had a strong influence on variations in perceived pain levels. The graphical illustration of mean scores presented in Figure 1 respectively.

Table 2 Test of Within Subject Effects (Repeated Measure ANOVA) for HGS and VAS

Source	Type III SS	df	Mean Square	F	Sig	Partial Eta^2
Time $^{(HGS)}$	149.253	4	37.313	3.950	.008	.248
Error (Time) $^{(HGS)}$	453.407	48	9.446			
Time $^{(VAS)}$	19148.708	4	4887.177	27.134	.000	.693
Error (Time) $^{(VAS)}$	8468.492	48	176.427			

Partial Eta^2= η^2

Table 3 Pairwise Comparison (Post hoc Analysis)

Variables	(I) Time	(J) Time	Mean Difference (I – J)	Sig.
HGS	Pre	Post	4.400	.001**
	Pre	24 Hours	2.900	.052
	Pre	48 Hours	2.738	.078
	Pre	72 Hours	1.185	.314
VAS	Pre	Post	38.462	.000**
	Pre	24 Hours	45.769	.000**
	Pre	48 Hours	43.692	.000**
	Pre	72 Hours	21.293	.000**

HGS = Hand Grip Strength; VAS = Visual Analogue Scale; ** = $p < 0.05$

Table 3 depicts outcomes for pairwise comparison. For HGS, a significant reduction was observed immediately after exercise (post-test) compared to baseline (pre-test) ($p = 0.001$), indicating an acute decline in muscle strength due to exercise-induced muscle damage (EIMD). However, no significant differences were observed between pre-test and subsequent time points at 24 hours ($p = 0.052$), 48 hours ($p = 0.078$), and 72 hours ($p = 0.314$). This suggests a gradual recovery of grip strength over time, with the greatest improvement occurring within the first 24 hours, but without a statistically significant return to baseline levels. For VAS, all post-exercise measurements showed a highly significant increase in perceived muscle soreness compared to baseline ($p = 0.000$ for post, 24 hours, 48 hours, and 72 hours). Peak soreness was observed between 24 to 48 hours, as indicated by the highest mean differences from baseline (45.769 and 43.692, respectively). A substantial reduction in VAS scores was observed at 72 hours, though pain levels remained significantly elevated compared to baseline ($p = 0.000$), suggesting ongoing but declining muscle soreness.

Linearity between HGS and VAS

The Pearson correlation analysis examined the relationship between hand grip strength (HGS) and visual analogue scale (VAS) scores at different time points (post, 24h, 48h, and 72h). The results showed no significant correlation between HGS and VAS at any time point ($p > 0.05$ for all comparisons). At the post-exercise time point, the correlation was $r = 0.010$ ($p = 0.993$), indicating a near-zero relationship between grip strength and pain perception. Similarly, at 24 hours, the correlation remained very weak ($r = 0.045$, $p = 0.884$), suggesting that changes in grip strength did not align with variations in pain levels. At 48 hours, a moderate positive correlation was observed ($r = 0.273$, $p = 0.367$), though it was still not statistically significant. By 72 hours, the correlation increased to $r = 0.385$ ($p = 0.194$), indicating a moderate relationship, but the result remained non-significant (See Figure 2).

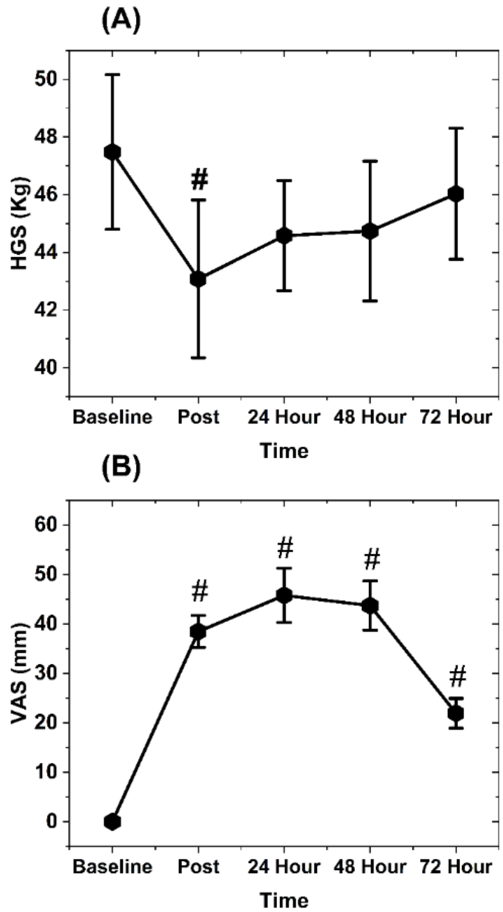

Figure 1 Line graph representing mean score with error bars (standard error) of hand grip strength (A) and visual analogue scale (B) at different time points. (# = mean difference is significant to their baseline value)

Discussion

To the best of our knowledge, this study is the first to investigate hand grip strength (HGS) as a direct marker of functional recovery following exercise-induced muscle damage (EIMD). The findings from repeated-measures ANOVA demonstrated significant time effects in both HGS and Visual Analogue Scale (VAS) scores when compared to their baseline values. Following the eccentric exercise protocol, HGS showed a significant decline immediately after exercise (post-test measurement) and gradually increased over the subsequent 24 to 48 hours. The smallest mean difference was observed at 72 hours post-exercise, suggesting a progressive recovery trend. These results highlight the acute impact of eccentric exercise on muscle function and support the use of HGS as a functional biomarker to monitor short-term muscle recovery. This is particularly relevant for real-time applications such as tracking athletes' recovery during competitions or assessing rehabilitation progress in clinical settings.

Similarly, the VAS results indicated significant differences at all post-exercise time points compared to baseline, where participants initially reported no pain. The peak in muscle soreness occurred between 24-and 48-hours post-exercise, followed by a significant reduction at 72 hours. This pattern aligns with the typical timeline of delayed onset muscle soreness (DOMS) (Gibson et al., 2006; Lewis et al., 2012; MacIntyre et al., 1995), where subjective pain increases after 24 hours and reaches its peak at 48 hours before gradually subsiding (Mizumura & Taguchi, 2016; Palygin et al., 2022). Notably, while grip strength declined immediately post-exercise, participants did not report significant muscle soreness at that time, reinforcing the distinction between functional impairment and subjective pain perception. These findings suggest that HGS provides an objective measure of immediate muscle function loss, whereas VAS captures the delayed pain response, emphasizing the need to integrate both measures for a comprehensive evaluation of muscle recovery.

The key distinction between HGS and VAS lies in the timing of muscle function assessment following eccentric exercise. Delayed onset muscle soreness (DOMS) began to manifest 24 hours post-exercise, peaked at 48 hours, and significantly declined by 72 hours. VAS scores exhibited high variability across time points due to the subjective nature of pain perception (Åström et al., 2023; Sung & Wu, 2018). Notably, participants did not report significant soreness immediately after exercise, whereas HGS showed a marked reduction at the post-test measurement. This suggests that in scenarios requiring real-time recovery monitoring, such as competitive sports or training, HGS serves as a more reliable indicator of immediate muscle function than VAS.

Various pain assessment scales, including the Visual Analogue Scale (VAS) (Boonstra et al., 2008), Verbal Rating Scale (Alghadir et al., 2018), Numerical Rating Scale (Tsze et al., 2018), and Descriptor Differential Scale (Gracely & Kwilosz, 1988), have been utilized in previous studies to measure muscle soreness. Among these, VAS is the most commonly employed for assessing delayed onset muscle soreness (DOMS) (Impellizzeri & Maffiuletti, 2007; Jay et al., 2014; Lau et al., 2013a). However, several factors influence the accuracy of DOMS quantification. Since soreness is not typically perceived when the affected muscle is at rest, a mechanical stimulus – such as palpation, contraction, or stretching—is required to elicit pain (Black et al., 2016; Kahl & Cleland, 2005; Slater et al., 2010; Sluka et al., 2018). While VAS is a reliable and valid tool for evaluating severe pain, it presents challenges in accurately capturing mild pain levels. Therefore, pain intensity plays a crucial role in the effectiveness of pain measurement using VAS (Micalos, 2014).

The analysis of linearity between HGS and VAS measurements revealed no statistically significant relationship between the two methods. Since participants reported zero pain at baseline on the VAS, correlation calculations for pre-test measurements were not possible. At post-test and 24-hour time points, the relationship between HGS and VAS scores was negligible. A slight correlation emerged at 48 and 72 hours; however, it did not reach statistical significance at the 0.05 level. Similar outcomes were reported by a study where a relationship between visual analogue scale and pain pressure threshold was evaluated (Lau et al., 2013b). These findings suggest that HGS and VAS measure distinct aspects of muscle recovery, reflecting different physiological responses following exercise-induced muscle damage.

Comparison with Other Functional Recovery Markers

Compared to traditional pain scales (VAS, numerical rating scale, descriptor differential scale), HGS provides an immediate and quantifiable assessment of muscle function. While VAS is widely used in DOMS studies, it is subjective and highly variable, influenced by individual pain tolerance, perception, and psychological factors. In contrast, HGS offers a more reliable and reproducible measure of muscle strength loss and recovery.

These findings have practical applications in athletic performance monitoring, rehabilitation, and clinical settings. In competitive sports, real-time recovery tracking is crucial for preventing overtraining and optimizing performance, and HGS could serve as an accessible metric for this purpose. Similarly, in clinical rehabilitation, HGS assessments could assist in evaluating muscle function recovery following injury, neuromuscular disorders, or surgical interventions.

HGS and Neuromuscular Fatigue vs. Structural Muscle Damage

The early post-exercise drop in HGS is likely due to neuromuscular fatigue, characterized by reduced motor unit activation and contractile function. Over the next 24

– 48 hours, structural muscle damage indicated by inflammatory responses and increased muscle stiffness becomes more pronounced, which is reflected in peak VAS scores. The subsequent recovery of HGS suggests that neuromuscular function is gradually restored, paralleling the timeline of muscle protein synthesis and tissue repair.

Applications in Sports Science and Rehabilitation

These findings highlight the potential of HGS monitoring for athletes, clinicians, and sports scientists. In competitive sports, where monitoring recovery is crucial for injury prevention and optimal performance, HGS could serve as a real-time indicator of muscle readiness. Additionally, in clinical rehabilitation, HGS assessments could help track muscle function recovery in individuals recovering from injuries, neuromuscular disorders, or overtraining.

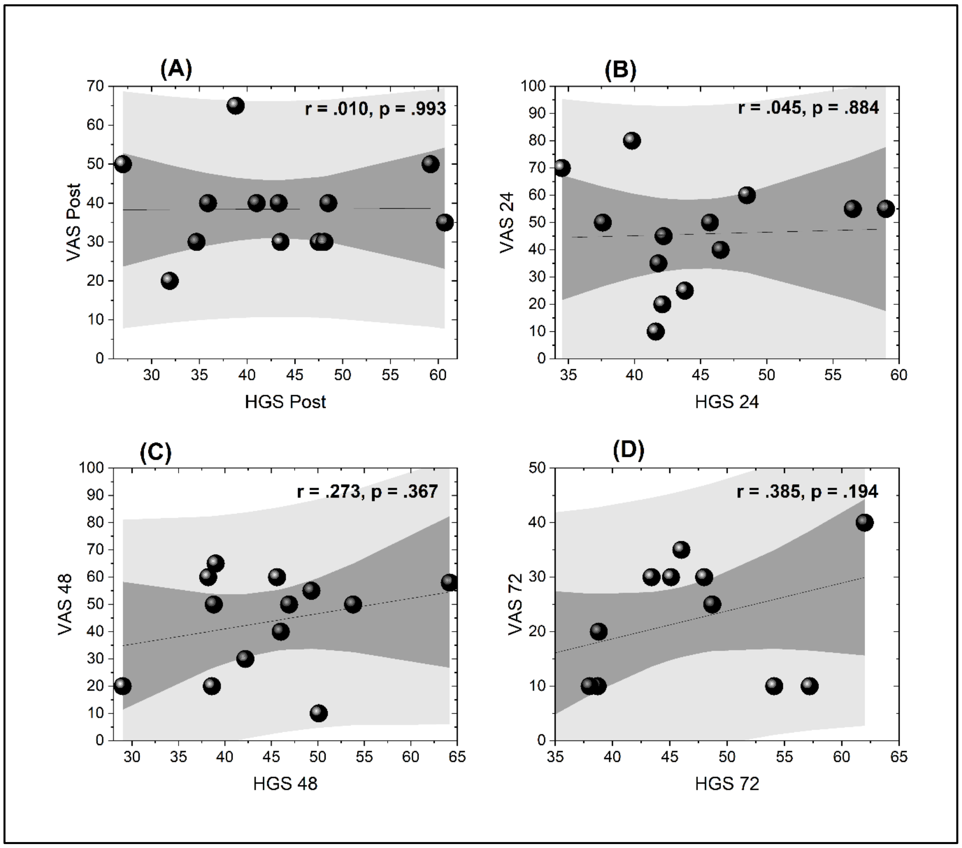

Figure 2 Correlation coefficient with 95 % confidence band prediction interval between hand grip strength (HGS) and visual analogue scale (VAS) measures at different time points.

Limitations of the Study

While the study presents novel insights, several limitations should be considered. First, HGS primarily assesses local muscle function in the forearm and hand, and may not fully represent whole-body muscle recovery. Future studies should examine whether HGS correlates with strength recovery in larger muscle groups (e.g., quadriceps, hamstrings, or core muscles) to determine its applicability as a general recovery marker.

Second, the study measured recovery over only 72 hours post-exercise, whereas muscle damage and inflammation can persist for up to a week. Future research should extend the monitoring period to 5–7 days to capture the full timeline of recovery. Additionally, interindividual variability in muscle recovery due to factors such as training status, sex, age, and muscle fiber composition was not accounted for, which may have influenced the results. A larger and more diverse sample size would improve the generalizability of the findings.

Another limitation is that grip strength is a voluntary effort, meaning psychological and motivational factors may have influenced the results. Since some participants may not have exerted maximal effort, this could have introduced variability. Future studies should incorporate electromyography (EMG) or neuromuscular activation markers to verify muscle activation during HGS assessments.

Additionally, the study did not include biochemical markers of muscle damage, such as creatine kinase (CK), lactate dehydrogenase (LDH), or inflammatory cytokines, which are commonly used to track muscle recovery at a cellular level. Integrating these markers with HGS assessments in future research would help validate grip strength as a robust biomarker of functional recovery.

Conclusion

Our findings suggest that HGS is a reliable and objective functional marker for tracking neuromuscular recovery following eccentric exercise. The significant post-exercise drop in HGS, followed by gradual recovery, underscores its potential as a real-time measure of muscle function impairment and restoration. Compared to subjective pain scales like VAS, HGS provides a quantifiable and reproducible metric for muscle fatigue and recovery, making it a valuable tool in sports science and rehabilitation. However, further research is needed to validate its long-term applicability, interactions with biochemical markers, and role in predicting injury risk and optimizing recovery strategies.

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Conflict of Interest

The authors declare no conflict of interest.

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