SHORT-TERM ACUTE EFFECTS OF SELECTED KINETIC CHAIN EXERCISE ON SURFACE ELECTROMYOGRAPHICAL SIGNAL AMPLITUDES

Tajmed Khan[1], Papan Mondal[1], Sumanta Kumar Mondal[2], Sridip Chatterjee[1], Najmun Nahar[3], Chandra Sankar Hazari[4]

[1]Department of Physical Education, Jadavpur University, Kolkata, India.
[2]Department of Physical Education and Sport Science, Visva-Bharati University, West Bengal, India.
[3]Department of Food Science, Maulana Abul Kalam Azad University of Technology, West Bengal, India.
[4]Department of Physical Education, Bhatter College, Dantan, West Bengal, India

Corresponding Author: Papan Mondal, **Email ID:** papanju2010@gmail.com

Abstract

Electromyography is a neuromuscular assessment technique that involved investigating, monitoring, and evaluating bio-potential produced inside in the muscular tissue during voluntary and non-voluntary action. Electromyographical parameter such as maximum surface electromyographical parameter, Root means square amplitude by science supports training programme. In this regards the aim of the study was to evaluate the short-term acute effects of the kinetic chain exercise protocol on Surface Electromyographical Signal Amplitudes in dominant and non-dominant forearm muscles across different recovery intervals (30 seconds, 2 minutes, and 5 minutes). Twenty- seven untrained young adult males were requited for the study. Performed five forearm-focused KCEs. sEMG data were recorded pre-exercise and at 30 seconds, 2 minutes, and 5 minutes of post-exercise. Maximum and RMS amplitudes were analyzed using one-way ANOVA with Bonferroni method. Maximum EMG amplitude significantly decreased in the dominant forearm at 30 seconds ($p = 0.004$). RMS amplitudes decreased significantly in the non- dominant forearm at 30 seconds ($p = 0.01$) and 2 minutes ($p = 0.04$). Values returned near baseline by 5 minutes.

KCE induced a transient suppression of neuromuscular activity, particularly within the first 2 minutes' post-exercise, with limb-specific variations. The dominant forearm exhibited greater immediate EMG suppression, while the non-dominant forearm showed stronger RMS amplitude reductions. These findings highlight the importance of timing and limb dominance in post-exercise neuromuscular assessments and suggest potential considerations for rehabilitation and performance monitoring.

Keywords: EMG Amplitudes, Recovery, Neuromuscular response, CKC exercise.

1. Introduction

Electromyography (EMG) is a widely recognized non-invasive method for assessing neuromuscular function by recording the electrical activity generated by skeletal muscles during contraction. As a physiological marker, EMG provides valuable insights into muscle strength, endurance, and motor unit recruitment, which are essential indicators of physical fitness and muscular performance (1). Moreover, deviations in EMG patterns have been associated with various clinical conditions, including sarcopenia, neuromuscular disorders, and metabolic diseases, highlighting its utility in both health and disease contexts (2).

Kinetic chain exercises (KCE) involve coordinated, multi-joint movements with a fixed distal segment and are increasingly employed in rehabilitation and functional training settings(3). These exercises have been shown to enhance muscular strength, neuromuscular efficiency, proprioception, and joint stability, particularly in the upper limbs (4) . Because they closely replicate real-world functional activities, KCE are frequently recommended for performance enhancement and injury prevention across a range of populations (5).

Surface electromyography (sEMG), using electrodes placed on the skin over the target muscle, enables dynamic assessment of neuromuscular activation during exercise. It is extensively applied in fields such as exercise physiology, rehabilitation science, and neuro-engineering for monitoring motor unit behavior, fatigue progression, and muscle coordination (6). Notably, the root mean square (RMS) amplitude is a key time-domain feature of the EMG signal that has been validated as a robust measure of muscle activation intensity, correlating with muscle force output and the number of recruited motor units (7).

While the majority of EMG-based KCE studies have focused on lower limb muscles, there remains a deficiency of research examining the upper limb, particularly the forearm flexor muscles. These muscles play a critical role in grip strength, fine motor control, and overall upper limb function, making them essential in both athletic and everyday tasks. Additionally, neuromuscular performance may vary significantly between dominant and non-dominant limbs due to differences in habitual usage patterns, cortical representation, and motor control strategies (8,9). Such limb-specific responses may have important implications for individualized training and rehabilitation planning.

Given this gap, the current study aimed to evaluate the short-term acute effects of selected KCEs on sEMG signal characteristics, specifically RMS and maximum EMG amplitude in the forearm flexor muscles of non-athlete young adult males. By analysing muscle activation at baseline and at 30 seconds, 2 minutes, and 5 minutes' post-exercise, the study sought to identify the temporal and lateralized neuromuscular recovery patterns. These findings are expected to provide practical insights for clinicians, sports scientists, and rehabilitation specialists seeking to optimize exercise programming and post-exercise assessment strategies in general populations.

2. Materials and Methods

2.1 Participants

A total of 27 young adult males participated in the study; the age of the participants was 20 ± 1 years. Prior to data collection, all participants received a standardized orientation outlining the experimental procedures. Inclusion criteria encompassed individuals who had not participated in any fitness training program, ensuring that prior training age would not influence the short-term acute effects of kinetic chain (KCE) exercises on electromyographical (EMG) amplitudes. Exclusion criteria involved individuals with a history of any injury or surgical procedure occurring within the six months preceding this study (10).

2.2 Instrumentations

Iworx Surface EMG analyzing software (Iworx System, Inc.) was used, with a band-pass filter set at 20–450 Hz. Data collection occurred at a sampling rate of 2000 Hz (11). a human muscle EMG device (iwire-B3G), and foam solid gel disposal electrodes (A-GC-7165, 5×54 mm) were used to collect EMG amplitude data. Cotton wool and scrubbing gel were applied to clean the skin, and a razor was used to remove hair. Stadiometer were utilized to measure the height of the participants.

2.3 Experimental Design

Data were taken in the exercise physiology laboratory, Department of Physical Education in Kolkata at Jadavpur University, West Bengal, India, on a designated day during the study periods. Before exercising, the researchers measured the anthropometric variables. Each participant engaged in selected kinetic chain (KCE) exercises (Cheon et al., 2020). The experimental design was presented in the following figure 1.

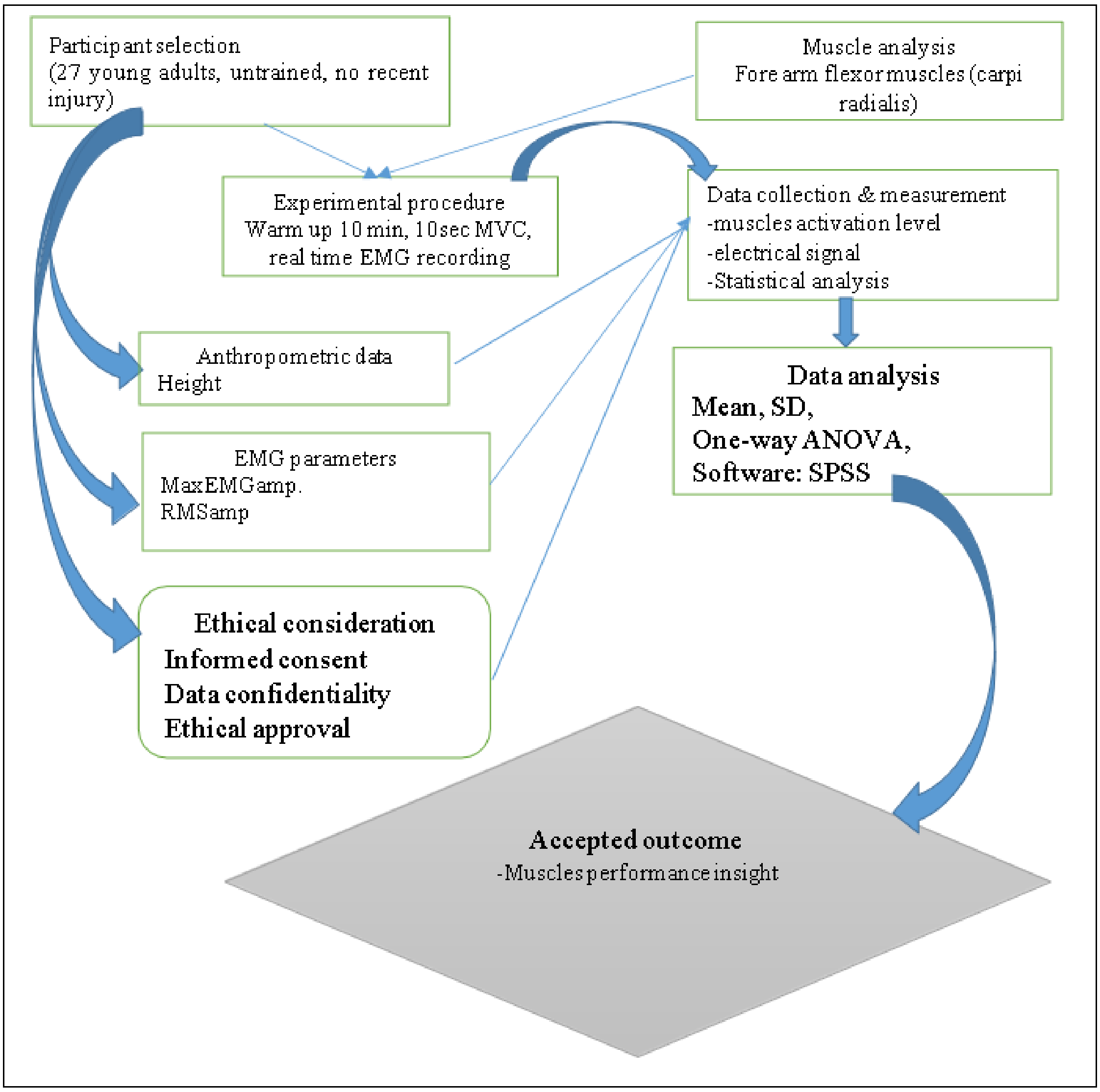

Figure 1: Illustration of the "Experimental Design"

2.4 Exercise protocol

Participants underwent an initial orientation session that outlined the research objectives, the equipment utilized, data collection procedures, and specific details of the experimental tasks. To prepare for the exercises, subjects engaged in a standardized three-minute warm-up protocol, incorporating dynamic stretches targeting the involved joints (13). The study employed selected Kinetic Chain exercises (KCE), selecting five movements recognized for their effectiveness in enhancing flexor muscle strength (14).

(A) Palms-up wrist curl: The palms-up wrist curl is an isolation exercise activating the flexor carpi radialis and flexor carpi ulnaris (15). Seated with their forearms resting on the thighs, participants executed wrist flexion with dumbbells using a supinated grip, followed by a controlled eccentric phase (16).

(B) Palms-down wrist curl: The palms-down wrist curl engaged the wrist extensors, requiring subjects to maintain a pronated grip while performing controlled wrist extension movements with dumbbells (17). The grip crush exercise involved squeezing a hand gripper with maximum effort, ensuring isolated contraction of the hand flexor muscles, followed by a gradual release (18).

(C) Forearm squeeze: The forearm squeeze, required subjects to compress a grip trainer, 10– 30 seconds per repetition, maintaining a neutral wrist posture throughout (19).

(D) Fingertip push-ups: fingertip push-ups demanded significant forearm stabilization as participants performed push-ups while supporting their body weight on the pads of their fingers rather than the palms, emphasizing controlled eccentric and concentric phases (20). Each exercise was executed at maximum intensity for a duration of two minutes to ensure optimal muscular engagement and performance adaptation. A one-minute rest was given between exercises to allow for better physiological recovery and subsequent performance (21)

2.5 Data processing

Participants were trained on each exercise before data collection to ensure correct performance. For surface electromyography (sEMG) electrode placement**,** the electrodes were placed on flexor carpi radialis muscles approximately 4–5 centimeters distal to the medial epicondyle**,** aligned along the muscle belly and the line connecting the medial epicondyle to the radial styloid process. This location ensures that the electrodes are positioned over the bulk of the FCR muscle (fig 2), capturing optimal electrical activity during wrist flexion and radial deviation movements. Proper skin preparation and a 2 cm inter-electrode distance are essential for reliable signal acquisition (22).

After electrode placement, Clear instructions were given to them to perform maximum voluntary contractions (MVC) by gripping the dynamometer (Fig. 3). They were asked to gradually exert up to their maximal force in 3 to 5 s, hold it for 3 s, and gradually decrease the force in 3 s (23).

2.6 Peak EMG Normalization

Peak EMG normalization methods were applied to normalize the raw EMG values. Each participant performed three trials targeting muscles, and the average of the three trials was recorded as the actual value (24)

$$\text{Normalized EMG} = \frac{\textbf{Peak Trial1+Peak Trial2+Peak Trial3}}{\textbf{Total number of trail}}$$

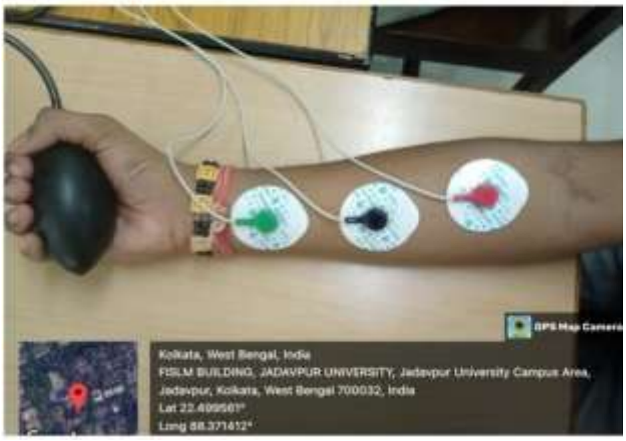

Figure 2: Electrode placement

Figure 3: Data collection

2.7 Statistical Analysis

One-way analysis of variance (ANOVA) was used to assess the effects of the CKC exercise on forearm flexor muscle EMG. Post-hoc pairwise comparisons were performed using the Bonferroni test to determine the source(s) of the significant effect. A significance level (α) of 5% was used. Descriptive statistics were applied to analyze the general characteristics of the subjects, and the mean and standard deviation were calculated for the measured variables. The Shapiro-Wilk test was used to assess the normality of the measured variables.

2.8 Ethical Clearance

The Jadavpur University Institutional Research Ethics Committee approved the study, reference number IEC/41/C/25.

3. Results

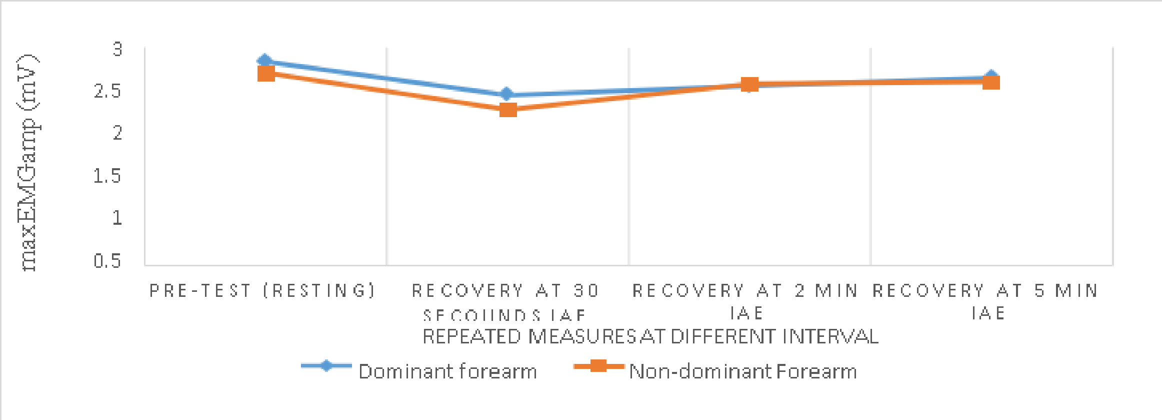

Figure 4: Descriptive statistics for the max sEMG amplitude in the dominant and non-dominant forearms.

Figure 4 illustrates the mean and standard deviation (SD) of maximum EMG signal amplitudes at all selected observations for both the “dominant and non-dominant forearms”. For the dominant forearm, the calculated mean ± SD values were 2.81 ± 0.75 mV for the pre-test, 2.35 ± 0.55 mV for recovery at 30 seconds, 2.58 ± 0.55 mV for recovery at 2 minutes and 2.59 ± 0.82 mV for recovery at 5 minutes. For the non-dominant forearm, 2.64 ± 1.05 mV for the pre- test, 2.14 ± 0.15 mV for recovery at 30 seconds, 2.49 ± 0.85 mV for recovery at 2 minutes, and 2.52 ± 0.83 mV for recovery at 5 minutes.

Table 1: Pairwise comparisons of maximum EMG amplitudes at successive recovery time-points for dominant and non-dominant forearms.

Dominant forearms EMG signal amp. (mV)				Non-dominant forearms EMG signal amp. (mV)			
observation	Recovery time point	Mean difference	P-value	observation	observation	Mean difference	P-value
Pre-test	R30SIAE	0.46	0.004*	Pre-test	R30SIAE	0.50	0.08
	R2MIAE	0.33	0.192		R2MIAE	0.15	1.00
	R5MIAE	0.22	1.00		R5MIAE	0.12	1.00
R30SIAE	Pre-test	-0.46	0.004*	R30SIAE	Pre-test	-0.50	0.08
	R2MIAE	-0.13	1.00		R2MIAE	-0.35	0.90
	R5MIAE	-0.24	1.00		R5MIAE	-0.38	0.61
R2MIAE	Pre-test	-0.33	0.19	R2MIAE	Pre-test	-0.15	1.00
	R30SIAE	0.13	1.00		R30SIAE	0.35	0.90
	R5MIAE	-0.11	1.00		R5MIAE	-0.03	1.00
R5MIAE	Pre-test	-0.22	1.00	R5MIAE	Pre-test	-0.12	1.00
	R30SIAE	0.24	1.00		R30SIAE	0.38	0.61
	R2MIAE	0.11	1.00		R2MIAE	0.03	1.00

*R30sIAE; Recovery at 30 seconds immediately after exercise. *R2mIAE; Recovery at 2 min immediately after exercise. *R5mIAE; Recovery at 5 min immediately after exercise.

The muscle activation levels in both dominant and non-dominant forearms were examined before and after the interventions. Mean differences and statistical significance were analyzed to assess changes across different conditions.

Dominant Forearm maximum surface EMG amplitude (max SEMG amp). The R30sIAE condition showed a notable increase in max EMG amplitude post-intervention (mean difference = 0.46 mV, $p = 0.004$), indicating enhanced neuromuscular activation. In contrast, the R2mIAE and R5mIAE observations exhibited minimal changes, with differences of 0.33 mV ($p = 0.192$) and 0.22 mV ($p = 1.00$), respectively (Table 2).

Non-Dominant Forearm maximum surface EMG amplitude (max SEMG amp). Although the R30sIAE observations showed a 0.50mV increase, statistical significance was not achieved ($p = 0.08$). The R2mIAE and R5mIAE conditions presented negligible changes (mean differences < 0.38 mV, $p \geq 0.61$), indicating a limited impact of the interventions on the non-dominant limb.

For the inter-group comparison, among all conditions, R30sIAE had the most pronounced effect on EMG amplitude in the dominant forearm. However, the non-dominant forearm showed no significant differences. Both R2sIAE and R5sIAE yielded minimal changes, suggesting that higher-intensity interventions may be more effective in promoting neuromuscular adaptation.

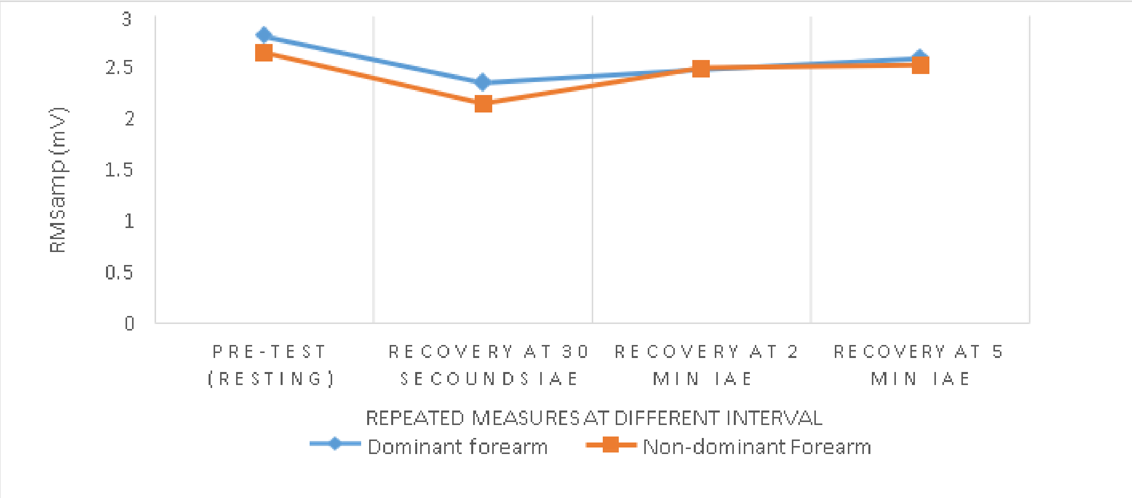

Figure 5: Descriptive statistics for the maximum Root Mean Square (RMS) amplitude of the EMG signal

Figure 5 presents the descriptive statistics of RMS amplitudes of the EMG signal for the dominant and non-dominant forearms of the selected subjects. Dominant forearm, the calculated mean and SD values of pre-test, recovery at 30 seconds, recovery at 2 min, and recovery at 5 min were 0.60 ± 0.13 mV, 0.51 ± 0.16 mV, 0.53 ± 0.12 mV, and 0.59 ± 0.12 mV, respectively. The calculated mean and SD values of pre-test, recovery at 30 seconds, recovery at 2 min, and recovery at 5 min were 0.59 ± 0.17 mV, 0.49 ± 0.13 mV, 0.50 ± 0.10 mV, and 0.53 ± 0.13 mV, respectively, for the non-dominant forearm.

Table 2: Pairwise comparisons of maximum root-mean-square (RMS) EMG amplitudes at successive recovery time-points for dominant and non-dominant forearms.

Dominant forearms RMS amplitudes				Non-dominant forearms RMS amplitudes			
Observatio n	Recovery time point	Mean differen ce	P-valu e	observatio n	observatio n	Mean differen ce	P-valu e
Pre-test	R30SIAE	0.10	0.053	Pre-test	R30SIAE	0.13	0.01*
	R2MIAE	0.07	0.135		R2MIAE	0.08	0.04*
	R5MIAE	0.03	1.000		R5MIAE	0.05	0.94
R30SIAE	Pre-test	-0.10	0.053	R30SIAE	Pre-test	-0.13	0.01*
	R2MIAE	-0.03	1.000		R2MIAE	-0.04	1.00
	R5MIAE	-0.06	0.329		R5MIAE	-0.08	0.32
R2MIAE	Pre-test	-0.07	0.135	R2MIAE	Pre-test	-0.08	0.04*
	R30SIAE	0.03	1.000		R30SIAE	0.04	1.00
	R5MIAE	-0.04	1.000		R5MIAE	-0.03	0.59
R5MIAE	Pre-test	-0.03	1.000	R5MIAE	Pre-test	-0.05	0.94
	R30SIAE	0.06	0.329		R30SIAE	0.08	0.32
	R2MIAE	0.034	1.000		R2MIAE	0.03	0.59

*R30SIAE; Recovery at 30 seconds immediately after exercise. *R2MIAE; Recovery at 2 min immediately after exercise. *R5MIAE; Recovery at 5 min immediately after exercise.

The results indicate that the Electromyographical (EMG) root mean square (RMS) amplitudes varied across pre-test and post-test conditions in both dominant and non-dominant forearms. In the dominant forearm, the R30sIAE condition showed an increase in maximum EMG RMS amplitude post-test compared to pre-test (mean difference = 0.10 mV, p = 0.053), approaching significance but not reaching the threshold. The R2sIAE group displayed a minor increase (mean difference = 0.07 mV, p = 0.135), while R5mIAE exhibited negligible changes (mean difference = 0.03 mV, p = 1.000), indicating minimal neuromuscular response. In contrast, the non-dominant forearm showed a statistically significant increase in EMG amplitude in the R30sIAE condition (mean difference = 0.13 mV, p = 0.01), suggesting enhanced muscle activation (Table 3). Similarly, the R2mIAE condition demonstrated a significant increase (mean difference = 0.08 mV, p = 0.04), while R5mIAE exhibited little to no change (mean difference = 0.05 mV, p = 0.94), reinforcing its limited effect on neuromuscular activity. Comparisons between intervention groups suggest that R30sIAE led to the most pronounced increase in max sEMG RMS activation, especially in the non-dominant forearm, while lower- intensity. Interventions, such as R5mIAE, had minimal impact. These findings highlight the importance of higher-intensity exercise protocols in inducing neuromuscular adaptations, particularly in the non-dominant forearm.

4. Discussion

This study investigated the short-term acute effects of selected kinetic chain exercises (KCE) on surface electromyographical (sEMG) activity of the forearm flexor muscles in non-athlete young adult males. Both maximum EMG amplitude and root mean square (RMS) amplitude significantly declined immediately post-exercise, particularly within the first 30 seconds, followed by recovery nearing baseline within five minutes. These findings indicate transient neuromuscular suppression due to fatigue-related physiological changes.

The dominant forearm showed a statistically significant decline in maximum EMG amplitude at 30 seconds post-exercise (p = 0.004), suggesting acute central and peripheral fatigue that impairs motor unit recruitment and firing rate (6) . Similarly, RMS amplitude, a robust indicator of global muscle activation (25) exhibited significant reductions in the non-dominant forearm at 30 seconds (p = 0.01) and 2 minutes (p = 0.04). These results are consistent with existing evidence that EMG signal amplitudes are sensitive to fatigue following high-intensity muscle contractions (26).

The asymmetric responses observed between limbs align with earlier studies on neuromuscular laterality. Dominant limbs typically display more efficient motor control and resistance to fatigue due to habitual use (8). However, they may also experience sharper initial declines in performance under maximal loads. In contrast, non-dominant limbs, often less conditioned, show slower recovery, evidenced by prolonged RMS amplitude suppression (27). These findings reinforce the need to consider limb dominance in neuromuscular assessment and training.

Fatigue-related mechanisms likely underlie the EMG reductions observed, including impaired sarcoplasmic calcium handling, reduced neuromuscular transmission, and lower motor unit firing rates (28). Although post-activation potentiation (PAP) can temporarily enhance muscular performance following intense contractions (29), its effects are typically diminished during the early recovery phase when fatigue dominates (Fry et al., 2017). Thus, the interaction between fatigue and PAP likely shaped the post-exercise EMG profile in this study.

From an applied perspective, these findings emphasize the importance of timing in post- exercise neuromuscular evaluations. The most pronounced suppression occurred within 30 seconds post-exercise, a period during which EMG readings may underestimate true muscle capacity. Delaying assessments by at least 2–5 minutes is advisable for more accurate evaluation of neuromuscular readiness. Moreover, the asymmetrical recovery patterns observed suggest that training and rehabilitation protocols should be limb-specific, addressing differences in strength, fatigue resistance, and recovery(30).

This study further confirms the value of sEMG as a non-invasive and sensitive diagnostic tool to monitor acute neuromuscular changes, even in untrained individuals (19). The KCE protocol—comprising functional, multi-joint forearm movements—effectively triggered measurable EMG responses and can serve as a model for designing strength and rehabilitation programs aimed at improving grip and forearm function.

Our findings agree with previous literature showing that EMG amplitude rapidly declines in the early post-exercise phase due to altered motor unit behavior (31) (also reported that EMG declines may be followed by a compensatory increase in amplitude during recovery as the nervous system attempts to restore muscle function. This compensation may explain the gradual normalization of EMG values by the fifth minute post-exercise.

Further supporting limb-specific adaptations, Hunter et al. (2016) highlighted that dominant limbs recover faster due to higher neuromuscular efficiency, while non-dominant limbs lag behind. Our data echo this pattern, with dominant forearms showing significant early suppression in max amplitude, while the non-dominant forearm demonstrated more persistent reductions in RMS amplitude—indicative of sustained lower-level motor unit fatigue.

As reported by Arabadzhiev et al. (2008) and Gerdle et al. (1997), RMS fluctuations can reflect effort level and neuromuscular fatigue. In this study, the marked drop in RMS post-exercise confirms reduced muscle activation and motor unit engagement. The delayed recovery in the non-dominant limb's RMS may be attributed to less efficient neuromuscular control and motor unit synchronization (32).

Practical applications of these findings are significant. In rehabilitation and athletic training contexts, understanding EMG suppression and recovery timelines can help practitioners avoid misinterpreting muscle performance or readiness. Since the first 30 seconds post-exercise represent peak fatigue, assessments during this window may not reflect actual muscular capability. Accordingly, performance tests or neuromuscular diagnostics should ideally be delayed to minimize fatigue interference.

Moreover, limb dominance influences recovery and activation, suggesting that bilateral assessments are critical when planning interventions. For instance, the non-dominant limb may benefit from targeted recovery strategies or additional conditioning to achieve symmetry in muscular performance (12).

These findings highlight the need for future research to explore fatigue-recovery dynamics across different populations, including trained individuals, females, and older adults. Investigations involving multiple muscle groups and varied kinetic chain patterns could offer deeper insights into functional neuromuscular adaptations. Additionally, incorporating central fatigue measures such as transcranial magnetic stimulation (TMS) or near-infrared spectroscopy (NIRS) may enhance understanding of the neuro-mechanical recovery process. Finally, tracking the temporal profiles of both RMS and maximum EMG across muscle groups could help establish fatigue-resistant training regimens and objective recovery markers, particularly in occupational or high-performance settings. Limitations and Future Directions Despite its strengths, this study is limited by its sample untrained young males and focus on a single muscle group (flexor carpi radialis). Future studies should include diverse demographics and evaluate a broader range of upper limb muscles to generalize findings. Incorporating long- term intervention studies could also determine whether repeated KCE sessions induce lasting neuromuscular adaptations. Additionally, multimodal approaches integrating EMG with central fatigue indicators would offer a more comprehensive view of post-exercise recovery dynamics.

5. Conclusion

The present study demonstrates that short-term acute bouts of closed kinetic chain exercises (KCE) result in a temporary suppression of surface electromyographical (sEMG) activity in the forearm flexor muscles of young, untrained adults. Specifically, both maximum EMG and RMS amplitudes declined significantly within 30 seconds post-exercise, with partial to full recovery observed by 5 minutes. The dominant forearm exhibited a significant reduction in maximum EMG amplitude, while the non-dominant forearm showed more pronounced and statistically significant reductions in RMS amplitude. These limb-specific neuromuscular responses underscore the importance of considering laterality in both performance evaluation and rehabilitation planning.

Importantly, the study confirms that sEMG is a sensitive tool for capturing acute neuromuscular changes following functional exercise, even in non-athletic populations. The findings support the practical utility of KCE protocols for general fitness enhancement and early-phase strength training, particularly in populations new to structured exercise. Practitioners should be mindful of the timing of assessments post-exercise, as measurements taken within the immediate recovery window may not accurately reflect true muscular capacity due to transient fatigue effects.

Future investigations should explore long-term adaptations to KCE in both trained and untrained populations and examine additional muscle groups and functional outcomes. Such research will deepen the understanding of neuromuscular recovery dynamics and support the development of targeted, evidence-based intervention programs.

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Conflicts of interest: The authors stated that they have no conflicts of interest.

Author's Contribution

Tajmed Khan: Investigation, experimentation, methodology, manuscript writing.

Dr. Papan Mondal: Supervision

Dr. Sumanta Kumar Mondal: experimentation, methodology

Dr. Sridip Chatterjee: Supervision

Dr. Najmun Nahar: manuscript editing

Dr. Chandra Sankar Hazari: manuscript editing

Disclosure statement: "The authors reported no potential conflicts of interest".

Data Availability

The electromyography recordings and anthropometric data used in this study are available from the corresponding author on reasonable request. All relevant results have been presented within the manuscript.

Reference

1. Al-Ayyad M, Owida HA, De Fazio R, Al-Naami B, Visconti P. Electromyography Monitoring Systems in Rehabilitation: A Review of Clinical Applications, Wearable Devices and Signal Acquisition Methodologies. Electron. 2023;12(7).
2. Al-Qaisi S, Saba A, Alameddine I. Electromyography analysis: Comparison of maximum voluntary contraction exercises for the latissimus dorsi. Work. 2022;71(3):803–8.
3. Allen DG, Lamb GD, Westerblad H. Skeletal muscle fatigue: Cellular mechanisms. Physiol Rev. 2008;88(1):287–332.
4. Arulkumar A, Babu P. Selective activation of Forearm muscles for improving Wrist Joint Stability. IOP Conf Ser Mater Sci Eng. 2021 Mar 1;1084(1):012025.
5. Banks NF, Rogers EM, Jenkins ND. Neither Traditional Nor Flywheel Resistance Training Increase Carotid-femoral Pulse Wave Velocity In Healthy Young Adults. Med Sci Sport Exerc. 2023 Sep;55(9S):406–406.
6. Behm D, Colado JC. The effectiveness of resistance training using unstable surfaces and devices for rehabilitation. Int j sports Phys ;7(2):226.
7. Bigland Ritchie B, Jones DA, Hosking GP, Edwards RHT. central and peripheral fatigue in sustained maximum voluntary contractions of human quadriceps muscle. Clin Sci Mol Med. 1978 Jun 1;54(6):609–14.
8. Blasimann A, Koenig I, Baert I, Baur H, Vissers D. Which assessments are used to analyze neuromuscular control by electromyography after an anterior cruciate ligament injury to

determine readiness to return to sports? A systematic review. BMC Sports Sci Med Rehabil . 2021;13(1):1–33.

9. Boonstra TW. Cortical adaptations during muscle fatigue: the role of sensorimotor oscillations. Acta Physiol. 2017 Jul 1;220(3):307–9.
10. Chanavirut R, Udompanich N, Udom P, Yonglitthipagon P, Donpunha W, Nakmareong S, et al. The effects of strengthening exercises for wrist flexors and extensors on muscle strength and counter-stroke performance in amateur table tennis players. J Bodyw Mov Ther . 2017 Oct 1 2025 ;21(4):1033–6.
11. Cheon S, Lee JH, Jun HP, An YW, Chang E. Acute effects of open kinetic chain exercise versus those of closed kinetic chain exercise on quadriceps muscle thickness in healthy adults. Int J Environ Res Public Heal 2020, Vol 17, Page 4669. 2020 Jun 29 ;17(13):4669.
12. Del Vecchio A, Negro F, Felici F, Farina D. Associations between motor unit action potential parameters and surface EMG features. J Appl Physiol. 2017;123(4):835–43.
13. Feldner HA, Howell D, Kelly VE, McCoy SW, Steele KM. "Look, Your Muscles Are Firing!": A Qualitative Study of Clinician Perspectives on the Use of Surface Electromyography in Neurorehabilitation. Arch Phys Med Rehabil. 2019 Apr 1;100(4):663–75.
14. González-Badillo JJ, Izquierdo M, Gorostiaga EM. Moderate volume of high relative training intensity produces greater strength gains compared with low and high volumes in competitive weightlifters. J Strength Cond Res. 2006 Feb;20(1):73–81.
15. Greene KA, Withers SS, Lenchik L, Tooze JA, Weaver AA. Trunk Skeletal Muscle Changes on CT with Long-Duration Spaceflight. Ann Biomed Eng. 2021 Apr 1 Mar;49(4):1257.
16. Guruhan S, Kafa N, Ecemis ZB, Guzel NA. muscle activation differences during eccentric hamstring exercises. sports health . 2021 Mar 1;13(2):181–6.
17. Behm D, Colado JC. The effectiveness of resistance training using unstable surfaces and devices for rehabilitation. Int j sports Phys ;7(2):226.
18. Hermens HJ, Freriks B, Disselhorst-Klug C, Rau G. Development of recommendations for SEMG sensors and sensor placement procedures. J Electromyogr Kinesiol. 2000 Oct 1;10(5):361–74.
19. Herchenhan A, Kalson NS, Holmes DF, Hill P, Kadler KE, Margetts L. Tenocyte contraction induces crimp formation in tendon-like tissue. Biomech Model Mechanobiol . 2012
20. Herchenhan A, Kalson NS, Holmes DF, Hill P, Kadler KE, Margetts L. Tenocyte contraction induces crimp formation in tendon-like tissue. Biomech Model Mechanobiol . 2012
21. Khan T, Mondal P, Chatterjee S, Nahar N, Hazari C. Effects of Close Kinetic Chain Exercise on Hand Grip Strength in Young Adult Males. Int J Sport Sci Phys Educ. 2025 Jul 28;10(3):101–8.
22. Kibler W Ben, Press J, Sciascia A. The role of core stability in athletic function. Sports Med. 2006 Nov 27 ;36(3):189–98.
23. Konrad P. The ABC of EMG - A Practical Introduction to Kinesiological Electromyography. Noraxon USA Inc; 2005. 29–34 p.
24. Krogh-Lund C, Jørgensen K. Changes in conduction velocity, median frequency, and root mean square-amplitude of the electromyogram during 25% maximal voluntary contraction of the triceps brachii muscle, to limit of endurance. Eur J Appl Physiol Occup Physiol . 1991 Jan ;63(1):60–9.
25. Lee DR, Kim LJ. Reliability and validity of the closed kinetic chain upper extremity stability test. J Phys . 2015 ;27(4):1071.

26. Lustig jr, strauss bjg. Nutritional assessment | Anthropometry and Clinical Examination. Encycl Food Sci Nutr. 2003 Jan 1;4181–4.
27. Proske U, Gandevia SC. The proprioceptive senses: Their roles in signaling body shape, body position and movement, and muscle force. Physiol Rev. 2012 ;92(4):1651–97.
28. Ramsook AH, Molgat-Seon Y, Schaeffer MR, Wilkie SS, Camp PG, Reid WD, et al. Effects of inspiratory muscle training on respiratory muscle electromyography and dyspnea during exercise in healthy men. J Appl Physiol. 2017;122(5):1267–75.
29. Ravanbod R, Eslami N, Ashtiani MN. Immediate effects of footwear with vibration applied to the swing phase of the gait cycle on dynamic balance in patients with diabetic peripheral neuropathy. J Biomech . 2021;128:110710.
30. Guruhan S, Kafa N, Ecemis ZB, Guzel NA. muscle activation differences during eccentric hamstring exercises. sports health . 2021 Mar 1;13(2):181–6. 31. Boonstra TW. Cortical adaptations during muscle fatigue: the role of sensorimotor oscillations. Acta Physiol. 2017 Jul 1;220(3):307–9.
31. Tramontano M, Li S, Merletti R. Editorial: Surface EMG and other measurement techniques in rehabilitation research and practice: are new educational programs needed? Front Rehabil Sci. 2025 Feb 14 ;6:1565879.
32. Woods K, Bishop P, Jones E. Warm-up and stretching in the prevention of muscular injury. Sport Med. 2007;37(12):1089–99.