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EFFECTS OF FUNCTIONAL ELECTRICAL STIMULATIONS WITH AND WITHOUT MOTOR PRIMING EXERCISES ON TENODESIS GRIP IN PATIENTS WITH SPINAL CORD INJURY

Original Research

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ABSTRACT

Background: Spinal cord injury (SCI) disrupts motor and sensory functions, often impairing hand strength and precision grip, particularly in cervical-level injuries. Tenodesis grip plays a critical role in enabling functional independence in such patients. Rehabilitation strategies like functional electrical stimulations (FES) and motor priming exercises (MPE) aim to enhance grip strength and dexterity. This study evaluates the comparative effects of FES with and without MPE and conventional exercise training (CET) on grip strength and functional recovery in SCI patients.

Objective: To determine the effect of functional electrical stimulations with and without motor priming exercises on improving grip strength, prehension performance, and quality of life in patients with spinal cord injury.

Methods: This randomized controlled trial included 27 participants aged 18 to 60 years with C6-C7 neurological level of injury. Participants were divided into three groups of 9 each: Group 1 received FES combined with MPE, Group 2 received FES alone, and Group 3 underwent CET. Baseline data were collected using manual muscle testing, the modified Ashworth scale, and tenodesis function. Interventions were conducted for six weeks, with daily sessions of 1.5 hours for Group 1 and 30–45 minutes for Groups 2 and 3. Post-intervention assessments included grip strength, lateral pinch grip, prehension performance, and quality of life, measured using validated tools like GRASSP and SCIM.

Results: A statistically significant improvement ($p < 0.05$) was observed in grip strength, lateral pinch grip, and quality of life among the three groups. Post-intervention right-hand grip strength increased to 11.50 ± 2.32 in Group 1, compared to 6.29 ± 1.41 in Group 2 and 4.00 ± 1.41 in Group 3. Left-hand grip strength improved to 10.50 ± 2.13 in Group 1, outperforming Group 2 (5.57 ± 1.38) and Group 3 (3.58 ± 1.31). Prehension scores in Group 1 reached 20.71 ± 3.45, compared to 5.71 ± 1.88 and 4.28 ± 1.88 in Groups 2 and 3, respectively.

Conclusion: The combination of MPE and FES significantly enhanced hand function, including grip strength, lateral pinch grip, and prehension performance, compared to FES alone or CET. These findings support integrating MPE with FES for optimizing functional recovery in individuals with cervical spinal cord injuries.

Keywords: Electric Stimulation Therapy, Functional Task Training, Hand Strength, Motor Recovery, Muscle Contraction, Spinal Cord Injuries, Tetraplegia.

INTRODUCTION

Traumatic spinal cord injury (SCI) represents a critical medical challenge, profoundly impacting both individual health and global economies. SCI involves damage to the intricate network of nerves and cells responsible for transmitting signals between the brain and body. It can result from direct or indirect harm to the spinal cord, vertebrae, or surrounding tissues, with incomplete quadriplegia and paraplegia accounting for the majority of cases. According to the National Spinal Cord Injury Statistical Center (NSCISC), incomplete SCIs constitute approximately 65% of all reported injuries. These neurological injuries, whether traumatic or non-traumatic, impair not only motor, sensory, and respiratory functions but also essential autonomic functions such as bladder, bowel, and sexual activities (2-4).

The severity of SCI varies depending on the location and extent of the injury. Complete SCI results in the total severance of the spinal cord and the irreversible loss of function below the site of injury. Conversely, incomplete SCI preserves some neural communication, allowing limited signal transmission below the damaged region (2, 5). Injuries to the upper spinal levels often result in tetraplegia, characterized by paralysis of all four limbs, whereas lower cervical spine injuries typically cause paraplegia, affecting the legs and lower body (6). The loss of arm function in tetraplegia severely restricts independence and quality of life by hindering essential functional tasks, making improvements in hand function a primary rehabilitation goal (6, 7).

Patients with tetraplegia frequently face challenges in performing basic tasks due to inadequate grip strength. The tenodesis grip, an adaptive mechanism, provides some relief by utilizing passive tension in flexor muscles to facilitate grasp patterns during wrist extension. This biomechanical function enables limited object manipulation despite diminished voluntary hand control. However, the thumb's inward positioning toward the radial side creates a lateral pinch, which, while helpful, requires further enhancement through physiotherapy to restore muscle power and improve functional independence (8, 9).

Functional electrical stimulation (FES) has emerged as a promising therapeutic intervention to address such deficits. FES induces controlled muscle contractions to perform specific tasks, targeting motor and sensory impairments caused by neurological damage. By leveraging cerebral cortex plasticity, FES promotes neural reorganization and restores motor control. For individuals with tetraplegia, FES facilitates activities such as grasping, holding, and releasing objects, thereby enhancing autonomy in daily life (10). However, the benefits of FES alone are often transient, necessitating complementary approaches to achieve long-lasting functional improvements.

Motor priming has gained attention as an innovative strategy to augment rehabilitation outcomes in neurological conditions. This approach relies on implicit learning mechanisms, where prior stimuli induce lasting behavioral changes. By modulating neural activity through techniques such as motor imagery, action observation, sensory input modulation, or movement-based exercises, priming enhances neuroplasticity and motor control, akin to long-term potentiation or depression (11-13). Priming methods aim to create an optimal neural environment, fostering recovery and maximizing rehabilitation potential.

Although FES and motor priming independently offer therapeutic benefits, their combined application remains underexplored in the context of tetraplegia. While motor priming has shown potential as a restorative technique, its synergistic effects with FES on tenodesis grip strength and quality of life have not been comprehensively evaluated. This study addresses this gap by investigating the combined impact of FES and motor priming exercises (MPE) on improving tenodesis functionality in patients with SCI. The findings aim to provide evidence-based recommendations for integrating these approaches into rehabilitation protocols to enhance independence, restore hand function, and improve overall quality of life.

METHODS

The study was a randomized, controlled clinical trial registered under the clinical trial registration number NCT05411692. It was conducted at the outpatient physiotherapy department of a tertiary care hospital and spanned ten months following the approval of the synopsis. The sample size was calculated using Epitool software, yielding 27 participants after accounting for a 10% attrition rate. This calculation was based on a significant difference between two means with a margin of error of 5% and a power of 80%, as shown in Table 1. The distribution of participants included three groups, each comprising nine individuals, ensuring equal representation across interventions.

Participants were recruited using a non-probability convenient sampling technique. The inclusion criteria required participants to be aged between 18 and 60 years, of either gender, and with C6-C7 neurological-level injuries. Eligible participants included those with complete or incomplete injuries graded A to D on the American Spinal Injury Association (ASIA) Impairment Scale (16, 18). Participants were in the chronic stage, defined as more than six months to two years post-injury, and exhibited tenodesis grasp function with wrist extensor strength of at least Grade 3, alongside trace contractions (≥1/5) of the thenar muscles. Exclusion criteria ruled out patients with neurological injuries above T1, spasticity or contractures, brachial plexus injuries, polyneuropathy, bed sores, arrhythmias, implants, brain trauma, central nervous system diseases, or significant cardiac complaints.

Randomization was performed using a simple random sampling method. The assessor responsible for post-intervention data collection was blinded to the group allocations, ensuring unbiased outcomes. Participants who met the inclusion criteria and provided written informed consent were enrolled in the study. Baseline data, including manual muscle testing, modified Ashworth scale scores, and tenodesis function, were collected on Day 0 using validated tools such as the Jamar dynamometer, pinch meter, and the Graded Redefined Assessment of Strength, Sensation, and Prehension (GRASSP) tool (21, 22).

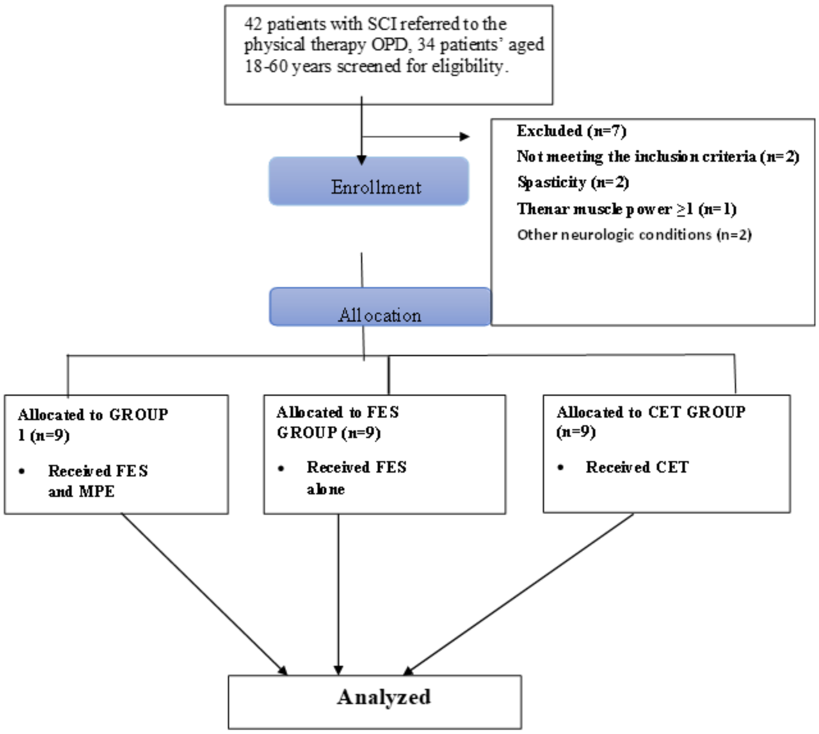
The participants were divided into three groups, each receiving distinct therapeutic interventions. Group 1 underwent functional electrical stimulation (FES) combined with motor priming exercises (MPE). The stimulation parameters for FES included biphasic, balanced electrical pulses regulated by current, with a pulse duration of 300 µs, pulse amplitude of 20–40 mA (mean readings: 17–26 mA), pulse width of 150 ms, and pulse frequency of 35 Hz. Transcutaneous electrodes were placed bilaterally on the volar wrist to target the median nerve for thumb flexion. Additional electrodes were applied to stimulate the flexor digitorum profundus, flexor digitorum superficialis, and flexor pollicis longus, along with extensor carpi radialis and extensor digitorum for coordinated finger extension. MPE included task-oriented activities such as grasping and releasing objects, holding utensils, and manipulating small items like coins, performed in conjunction with the stimulator for 30–45 minutes per session, five days a week for four weeks. Each session lasted 1.5 hours and emphasized tasks relevant to daily functional needs, such as holding books, writing, and lifting objects (23-25).

Group 2 received FES with a simpler set of movements, such as wrist flexion and extension, palm rotations, and finger curling and uncurling, performed alongside FES for 30–45 minutes. Group 3 received conventional exercise therapy (CET), comprising stretching, strengthening, and endurance exercises. This included 2–3 sets of gentle stretching for the wrist and fingers, strength training at 60–70% of one-rep max, and endurance exercises with increased repetitions and reduced load. The CET sessions were conducted three days per week, focusing on maintaining muscle strength, mobility, and functional improvements.

Post-intervention assessments were conducted after 30 sessions over six weeks. Outcomes were measured using a handheld dynamometer, pinch meter, and the GRASSP tool. Primary outcomes included variations in grip and lateral pinch strength, while secondary outcomes evaluated hand function and quality of life using the GRASSP tool and the Spinal Cord Independence Measure (SCIM) questionnaire. The SCIM assessed self-care, mobility, and sphincter control, providing a comprehensive evaluation of functional independence.

Figure 1 Surface electrodes on flexors and extensors

Data analysis was performed using SPSS version 23, with a significance threshold of p=0.05. The Shapiro-Wilk test was used to verify the normality of data distribution. Baseline comparability among groups was assessed using one-way ANOVA. Within-group differences were evaluated using paired sample t-tests, while multiple group comparisons were analyzed using post hoc tests to identify specific sources of significant differences.



CONSORT DIAGRAM

FES: Functional electrical stimulation, MPE: Motor priming exercises, CET: Conventional exercise training, SCIM: Spinal Cord Independence Measure.

RESULTS

The results revealed that the mean age of participants was comparable across all three groups, with Group 1 showing a mean age of 36.71 ± 4.536 years, Group 2 showing 36.00 ± 5.888 years, and Group 3 showing 35.86 ± 6.669 years. The body mass index (BMI) was also similar, with Group 1 averaging 27.13 ± 3.233, Group 2 averaging 27.31 ± 2.945, and Group 3 averaging 26.26 ± 2.235. Gender distribution indicated that the majority of participants were male, with Group 1, Group 2, and Group 3 consisting of 57.1%, 71.4%, and 57.1% males, respectively. Marital status showed similar trends, with married participants representing 57.1% in Groups 1 and 3, and 71.4% in Group 2. Participants with neurological levels of injury (NLOI) at C6 and C7 and ASIA classifications (A, B, C, D) were evenly distributed across the groups.

The intervention analysis demonstrated significant improvements in right and left-hand grip strength in Group 1 compared to Groups 2 and 3. Post-intervention right-hand grip strength increased to 11.500 ± 2.327 in Group 1, compared to 6.285 ± 1.410 in Group 2 and 4.000 ± 1.414 in Group 3 ($p < 0.05$). Left-hand grip strength improvements followed a similar trend, with Group 1 achieving 10.500 ± 2.126 compared to 5.571 ± 1.389 and 3.585 ± 1.315 in Groups 2 and 3, respectively. Lateral pinch grip strength showed significant improvement only in Group 1, with a post-intervention value of 2.064 ± 0.645 on the right and 1.750 ± 0.612 on the left, while Groups 2 and 3 showed minimal changes ($p < 0.05$).

Sensory and motor function improvements assessed by the GRASSP tool and SCIM revealed substantial progress in Group 1 compared to Groups 2 and 3. Right-hand prehension performance increased significantly to 20.71 ± 3.45 in Group 1, compared to 5.71 ± 1.88 in Group 2 and 4.28 ± 1.88 in Group 3. SCIM self-care and mobility scores showed similar improvements, with Group 1 achieving significant gains (20.71 ± 3.45 for self-care and 17.85 ± 3.93 for mobility), while Groups 2 and 3 showed limited advancements ($p < 0.05$). The findings indicate that combining FES and MPE provided superior outcomes in grip strength, lateral pinch strength, and functional independence.

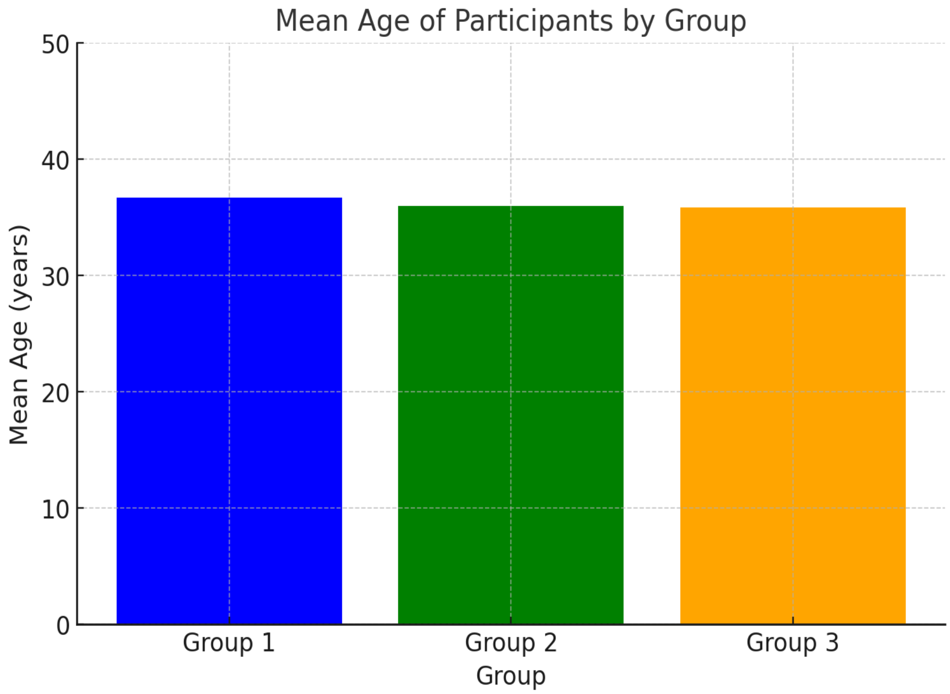


Figure 2 Mean Age of Participants by Group

The mean age of participants was comparable across all groups, indicating a balanced distribution. Group 1 had a mean age of 36.71 ± 4.536 years, while Group 2 averaged 36.00 ± 5.888 years, and Group 3 reported a mean age of 35.86 ± 6.669 years. This similarity ensures demographic consistency across the groups, minimizing age-related bias in the study outcomes.

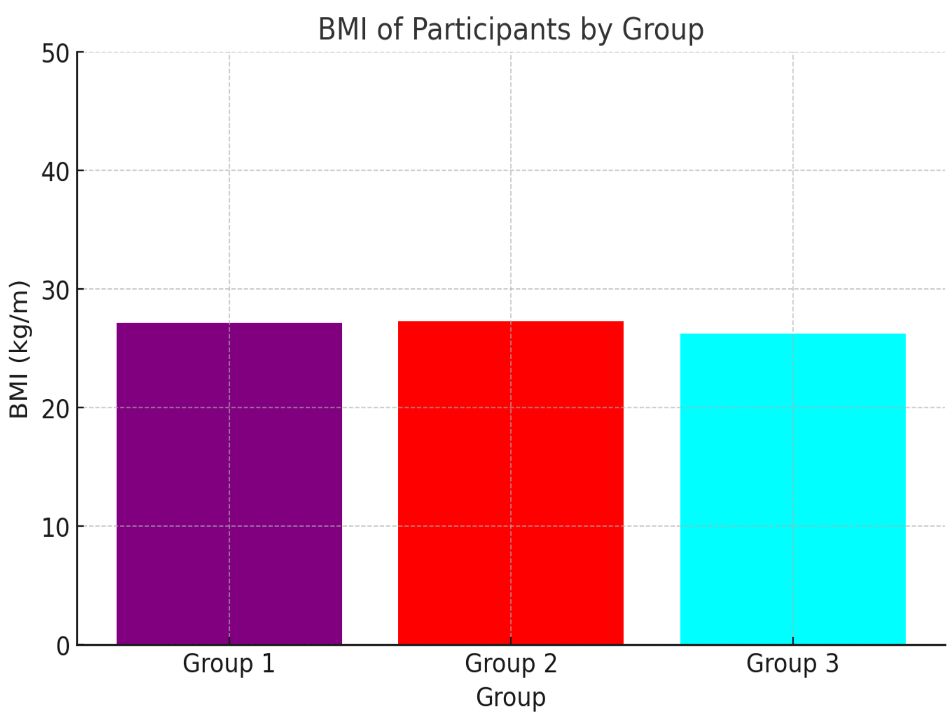


Figure 3 BMI of Participants by Group

The BMI of participants was evenly distributed across the groups, reflecting a consistent baseline for body composition. Group 1 had a mean BMI of 27.13 ± 3.233 kg/m², Group 2 recorded 27.31 ± 2.945 kg/m², and Group 3 had a slightly lower mean BMI of 26.26 ± 2.235 kg/m². These values indicate that all groups were within a similar BMI range, reducing the likelihood of BMI influencing study outcomes.

Table 1: Demographics statistics

Demographics	GROUP 1, n=9 Mean (SD)	GROUP 2 n=9 Mean (SD)	GROUP 3 n=9 Mean (SD)
Male, n(%)	5 (57.1)	6 (71.4)	5 (57.1)
Female, n(%)	4 (42.9)	3 (28.6)	4 (42.9)
Married, n(%)	4(57.1)	5 (71.4)	4 (57.1)
NLOI C6, n(%)	4(57.1)	3(42.9)	4(57.1)
NLOIC7, n(%)	3(42.9)	4(57.1)	3(42.9)
ASIA A, n(%)	2(28.6)	2(28.6)	2(28.6)
ASIA B, n(%)	1(14.3)	2(28.6)	1(14.3)
ASIA C, n(%)	3(42.9)	2(28.6)	2(28.6)
ASIA D, n (%)	1(14.3)	2(28.6)	2(28.6)

NLOI: Neurological level of injury, ASIA: American Spinal Injury Association impairment scale

The demographic characteristics were well-balanced across the groups. Male participants comprised 57.1% in Groups 1 and 3, and 71.4% in Group 2, while females accounted for 42.9% in Groups 1 and 3, and 28.6% in Group 2. Married participants made up 57.1% in Groups 1 and 3, and 71.4% in Group 2. Neurological level of injury (NLOI) C6 was observed in 57.1% of participants in Groups 1 and 3 and 42.9% in Group 2, whereas NLOI C7 was seen in 42.9% in Groups 1 and 3 and 57.1% in Group 2. ASIA A classification accounted for 28.6% of participants in all groups, ASIA B was 14.3% in Groups 1 and 3 and 28.6% in Group 2, ASIA C was 42.9% in Group 1 and 28.6% in Groups 2 and 3, and ASIA D was 14.3% in Group 1 and 28.6% in Groups 2 and 3. These results reflect the comparable distribution of clinical and demographic features among the groups.

Table 2: - Between-group analysis (one-way ANOVA Test)

VARIABLE	GROUP 1 n=9	GROUP 2 n=9	GROUP 3 n=9	p- value
	Right and left-hand grip strength			
Right Pre	0.1429(0.243)	0.857(1.864)	0.717(0.1889)	0.351
Right Post	11.500(2.327)	6.285(1.4100)	4.000(1.414)	0
Left Pre	0.714(0.1219)	0.107(0.196)	0.035(0.094)	0.658
Left Post	10.500(2.126)	5.571(1.389)	3.585(1.315)	0
	Right and left-hand lateral pinch grip			
Right Pre	0.000(0.000)	0.000(0.000)	0.000(0.000)	-
Right Post	2.064(0.645)	0.4071(1.880)	0.000(0.000)	0
Left Pre	0.000(0.000)	0.000(0.000)	0.000(0.000)	-

VARIABLE	GROUP 1 n=9	GROUP 2 n=9	GROUP 3 n=9	p- value
Left Post	1.750(0.6123)	0.3071(0.159)	0.000(0.000)	0
GRASSP right and left-hand sensibility				
Right Pre	19.714(5.707)	17.142(8.783)	17.142(8.783)	0.783
Right Post	22.285(2.927)	20.571(4.720)	18.857(6.414)	0.441
Left Pre	19.7143(5.707)	17.142(8.783)	17.142(8.783)	0.783
Left Post	22.285(2.927)	20.571(4.720)	17.142(1.511)	0.288
GRASSP tool right and left-hand prehension performance				
Right Pre	0.00(0.00)	0.00(0.00)	0.00(0.00)	-
Right Post	20.71(3.45)	5.71(1.88)	4.28(1.88)	0
Left Pre	0.00(0.00)	0.00(0.00)	0.00(0.00)	-
Left Post	17.85(3.93)	5.00(0.00)	4.28(1.88)	0
SCIM self-care and mobility				
SCIM self-care Pre	0.00(0.00)	0.00(0.00)	0.00(0.00)	-
SCIM self-care Post	20.71(3.45)	5.714(1.88)	4.28(1.88)	0
SCIM mobility Pre	0.00(0.00)	0.00(0.00)	0.00(0.00)	-
SCIM mobility Post	17.85(3.93)	5.00(0.00)	4.28(1.88)	0

The one-way ANOVA analysis demonstrated significant improvements in hand grip strength, lateral pinch grip strength, and functional outcomes in Group 1 compared to Groups 2 and 3. Post-intervention right-hand grip strength in Group 1 was 11.500 ± 2.327, significantly higher than 6.285 ± 1.410 in Group 2 and 4.000 ± 1.414 in Group 3 ($p < 0.05$). Left-hand grip strength in Group 1 also improved to 10.500 ± 2.126, compared to 5.571 ± 1.389 in Group 2 and 3.585 ± 1.315 in Group 3 ($p < 0.05$). Lateral pinch grip strength showed the highest gains in Group 1, with post-intervention values of 2.064 ± 0.645 on the right and 1.750 ± 0.612 on the left, whereas Groups 2 and 3 showed minimal or no improvement ($p < 0.05$). Functional independence assessed by the SCIM tool revealed substantial gains in Group 1, with post-intervention self-care scores of 20.71 ± 3.45 and mobility scores of 17.85 ± 3.93, significantly outperforming Groups 2 and 3 ($p < 0.05$). Sensibility measured by the GRASSP tool showed slight improvements across all groups but without significant intergroup differences.

Table 3: - Within-group analysis (paired-sample t-test)

VARIABLE	GROUP 1 n=9	GROUP 2 n=9	GROUP 3 n=9	p-value
Right and left-hand grip strength				
Right hand grip strength (Pre,Post)	11.35(2.26)	-5.42(2.97)	-3.92(1.30)	0.000

VARIABLE	GROUP 1 n=9	GROUP 2 n=9	GROUP 3 n=9	p-value
Left hand grip strength (Pre,Post)	10.42(10.42)	-5.46 (1.38)	-3.55(1.24)	0.001
Right and left-hand lateral pinch grip				
Right hand lateral pinch grip (Pre,Post)	-2.06 (0.64)	-.407(.18)	-.407(.18)	0.001
Left hand lateral pinch grip (Pre,Post)	-1.75 (0.612)	-.307(.159)	-.307(.159)	0.002
GRASSP right and left-hand sensibility				
GRASSP right hand sensibility (Pre,Post)	-2.57(3.20)	-3.42(4.72)	-1.71(2.92)	0.078
GRASSP left-hand sensibility (Pre,Post)	-2.57(3.20)	-3.42(4.72)	-1.71(2.92)	0.783
GRASSP tool right and left-hand prehension performance				
Right prehension performance (Pre,Post)	-20.71(.450)	-5.71(1.88)	-4.28(1.88)	0.00
Left prehension performance (Pre,Post)	17.85(3.93)	-5.71(1.88)	-4.28(1.88)	0.001
SCIM self-care and mobility				
SCIM self-care (Pre,Post)	-8.14(3.02)	-2.57(2.76)	-.571(1.51)	0.04
SCIM mobility (Pre,Post)	-.571(1.51)	-7.71(2.56)	-2.71(1.60)	0.00

The within-group analysis using paired-sample t-tests revealed significant improvements in grip strength, lateral pinch grip, prehension performance, and SCIM scores, particularly in Group 1. Post-intervention right-hand grip strength increased by 11.35 ± 2.26 in Group 1, compared to reductions of -5.42 ± 2.97 and -3.92 ± 1.30 in Groups 2 and 3 ($p = 0.000$). Left-hand grip strength in Group 1 improved by 10.42 ± 10.42, outperforming Groups 2 (-5.46 ± 1.38) and 3 (-3.55 ± 1.24, $p = 0.001$). Lateral pinch grip strength showed significant gains in Group 1, with improvements of -2.06 ± 0.64 (right) and -1.75 ± 0.612 (left), compared to minimal changes in Groups 2 and 3 ($p < 0.01$). Prehension performance improved notably in Group 1, with right-hand gains of -20.71 ± 0.450, significantly exceeding the improvements in Groups 2 (-5.71 ± 1.88) and 3 (-4.28 ± 1.88, $p = 0.001$). SCIM scores for self-care and mobility also showed significant improvements in Group 1, with self-care increasing by -8.14 ± 3.02 and mobility by -0.571 ± 1.51, whereas Groups 2 and 3 demonstrated less improvement ($p < 0.05$). Sensory function improvements were less pronounced, with no statistically significant differences observed.

DISCUSSION

The integration of functional electrical stimulations (FES) and motor priming exercises (MPE), designed as task-oriented bimanual hand function training, demonstrated significant improvements in tenodesis action among participants. These improvements included enhanced grip strength, lateral pinch grip, prehension performance, and quality of life. The combined FES and MPE intervention had a bilateral impact on grip and lateral pinch strength, even though the focus was primarily on task-related training rather than strength-building. While FES alone led to statistically significant gains in grip strength and lateral pinch grip, it did not yield comparable results in prehension performance or dexterity. The findings underscored the greater efficacy of combining FES with MPE over FES or conventional exercise therapy (CET) alone, emphasizing the role of targeted interventions in improving functional outcomes in individuals with chronic spinal cord injuries (SCI) (21).

These findings are consistent with the concept of cortical priming, as participants with the most chronic SCI exhibited significant bilateral improvements with FES and MPE intervention. Peripheral nerve stimulation has been shown to activate the somatosensory cortex, and previous research indicates that the corticomotor system is more powerfully engaged during power grip exercises (21). The mutually excitatory connections between the motor and sensory cortices suggest that interventions enhancing corticomotor activity could improve precision grip over power grip (6, 22). Despite the involvement of the somatosensory cortex in task-related movements, the current study found no significant changes in sensory function, a finding consistent with prior research (23). Unlike studies exploring transcranial direct current stimulation and aerobic exercise in stroke rehabilitation, this study focused on bimanual task-oriented hand training for SCI, demonstrating a task-specific enhancement in corticomotor excitability, particularly in the dominant hand.

The study was strengthened by its task-oriented approach, which emphasized functional recovery and practical applications for daily tasks. The findings suggested that combining FES with MPE improved ipsilateral hemispheric excitability compared to exercise alone, with effects evident in descending corticomotor pathways. However, several limitations were identified. Participant withdrawals and protocol fidelity posed challenges, resulting in dropouts. Furthermore, the absence of objective measures of corticospinal excitability, such as electromyography (EMG) or neuroimaging, limited the understanding of underlying neural mechanisms. The lack of precision in evaluating corticomotor activation also reduced the depth of mechanistic insights.

Nevertheless, the study provided evidence that FES combined with MPE is an effective and clinically available method for improving grip strength and functional hand use in individuals with cervical SCI. This approach enhances motor recovery while mitigating long-term secondary complications. Precision grip, critical for daily activities, showed promising improvements with these methods, enabling patients to achieve greater independence and quality of life.

To further validate these findings, future studies should adopt longitudinal designs to assess the sustained effects of FES and MPE interventions. The inclusion of quantitative measures, such as EMG and ultrasonic imaging, would provide deeper insights into neuroplasticity and corticospinal activation. These advancements could refine rehabilitation protocols, ensuring more precise and effective outcomes for individuals with SCI.

Recent advancements in spinal cord injury (SCI) rehabilitation highlight the benefits of combining functional electrical stimulation (FES) with motor priming exercises (MPE). A study by Fawaz et al. (2019) demonstrated that FES paired with real repetitive transcranial magnetic stimulation (rTMS) significantly improved hand function compared to FES with sham rTMS in chronic cervical SCI patients. Enhanced outcomes, including gains in hand function tests and corticomotor excitability, suggest that cortical priming techniques, such as rTMS, can optimize the neuroplastic and functional benefits of FES. These findings complement the current study, underscoring the potential for integrating advanced neuromodulation strategies with task-oriented FES and MPE to maximize recovery in SCI patients (24).

CONCLUSION

The findings of this study emphasize the critical importance of precision grip force for performing everyday tasks, particularly in individuals with cervical-level spinal cord injuries. The combination of motor priming exercises and functional electrical stimulation proved to be an effective rehabilitation approach for enhancing grip strength and functional hand use. These methods, being clinically accessible, have the potential to stimulate corticomotor activation, supporting long-term functional recovery and reducing the risk of secondary complications. By improving hand function, these interventions can significantly enhance the ability of patients to achieve daily goals, fostering greater independence and improving the quality of life for individuals living with spinal cord injuries.

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AUTHOR CONTRIBUTIONS

Author	Contribution
Laraib Noor	Substantial Contribution to study design, analysis, acquisition of Data Manuscript Writing Has given Final Approval of the version to be published
Binash Afzal	Substantial Contribution to study design, acquisition and interpretation of Data Critical Review and Manuscript Writing Has given Final Approval of the version to be published
Tarab Rasool	Substantial Contribution to acquisition and interpretation of Data Has given Final Approval of the version to be published
Fatima Shafaqat Ali	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published
Asfoora Azmat	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published
Muhammed Shahwaiz	Substantial Contribution to study design and Data Analysis Has given Final Approval of the version to be published
Ramsha Umar	Contributed to study concept and Data collection Has given Final Approval of the version to be published
Hafiza Motia Tabassum	Writing - Review & Editing, Assistance with Data Curation
Urooj Manzoor	Writing - Review & Editing, Assistance with Data Curation

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