ORIGINAL ARTICLE

# Effects of neurobic exercises and a self-designed program on psychological well-being and neuromuscular function in individuals with paraplegia

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**Abstract**

*Background and Study Aim* Paraplegia is associated with substantial limitations in neuromuscular performance and psychological well-being, which may reduce independence and overall quality of life following spinal cord injury. Various exercise-based rehabilitation approaches are applied to improve functional capacity and psychological adaptation in individuals with paraplegia. Despite the application of different exercise interventions, their relative effectiveness in enhancing neuromuscular function and psychological well-being remains a matter of practical interest. Therefore, the present study aimed to examine the effects of neurobic exercises and a self-designed training program on psychological well-being (achievement motivation) and neuromuscular function in individuals with paraplegia.

*Material and Methods* Forty-five individuals with paraplegia were randomly assigned to a Neurobic Exercise Group (n = 15), a Self-Designed Program Group (n = 15), and a Control Group (n = 15). The experimental groups participated in a structured 12-week intervention, while the control group maintained routine activities. Outcome measures included achievement motivation, EMG activity of the rectus abdominis and quadratus lumborum, and audio-visual reaction time. Paired t-tests, ANCOVA, and Scheffé's post hoc tests were employed to analyze the data at a 0.05 level of significance.

*Results* Both experimental groups showed significant improvements in all measured variables. The self-designed program demonstrated greater increases in rectus abdominis EMG activity (29.14%) and quadratus lumborum EMG activity (25.87%) compared to the neurobic group (13.46% and 14.12%, respectively). Reaction time improved substantially, with reductions in audio reaction time (23.08% in the self-designed group and 17.22% in the neurobic group) and visual reaction time (21.36% and 14.05%, respectively). Achievement motivation increased markedly in the self-designed group (26.41%) and the neurobic group (15.28%), while the control group showed negligible changes. ANCOVA revealed significant group differences across all variables ($p < 0.05$). Post hoc analysis confirmed the superiority of both interventions over the control condition and the greater effectiveness of the self-designed program.

*Conclusions* Both neurobic exercises and self-designed training programs significantly enhanced neuromuscular function, as evidenced by increased EMG activity and improved reaction time, as well as psychological well-being (achievement motivation) in individuals with paraplegia. The self-designed program was comparatively more effective, likely due to higher engagement and individualized exercise selection. These findings support the integration of personalized and cognitively engaging exercise interventions into rehabilitation programs to optimize functional and psychological outcomes.

**Keywords**: paraplegia, neurobic exercises, achievement motivation, neuromuscular function, rehabilitation

## Introduction

Paraplegia is a neurological condition that affects physical functioning, independence, and daily life activities. Individuals with paraplegia commonly experience impairments in neuromuscular coordination, trunk muscle activation, and reaction performance, which may complicate mobility and participation in rehabilitation activities. In addition to physical limitations, psychological factors such as reduced motivation and emotional well-being may influence rehabilitation outcomes and long-term adaptation. The interaction between neuromuscular function and psychological well-being represents one of the aspects of rehabilitation in individuals with paraplegia.

This condition restricts mobility, independence, and overall quality of life. It also contributes to secondary complications affecting physical and psychological health [1, 2, 3, 4]. Individuals with paraplegia frequently exhibit reduced neuromuscular efficiency, impaired trunk stability, and compromised postural control. These functions are essential for activities such as wheelchair propulsion, transfers, and balance [5, 6, 7]. In addition to physical


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limitations, psychological challenges such as reduced achievement motivation, low self-esteem, and social withdrawal are commonly observed. These factors may further hinder rehabilitation outcomes [8, 9, 10].

Neuromuscular function is a key determinant of functional independence in individuals with paraplegia. Electromyography (EMG) provides an objective assessment of muscle activation and neuromuscular coordination, particularly in trunk muscles such as the rectus abdominis and quadratus lumborum. These muscles play a critical role in core stability and postural control [11, 12, 13, 14]. Efficient activation of these muscles is essential for maintaining balance and facilitating upper-body movements [15]. Furthermore, EMG analysis provides insights into motor unit recruitment patterns, synchronization, and neural adaptations associated with training [16]. Reaction time, including auditory and visual components, is another indicator of neuromotor performance. It reflects the speed of sensory processing, decision-making, and motor execution [17, 18, 19]. Delayed reaction time in individuals with neurological impairments may limit responsiveness and functional performance [20, 21].

Psychological well-being, particularly achievement motivation, plays a role in rehabilitation adherence and long-term recovery. Achievement motivation refers to an individual's drive to accomplish goals and overcome challenges. This motivation is often reduced in individuals with physical disabilities [22, 23, 24]. Reduced motivation may negatively affect participation in rehabilitation programs and overall functional improvement [25]. Evidence indicates that structured physical activity interventions enhance motivation, emotional stability, and overall mental well-being [26, 27, 28, 29]. Therefore, integrating psychological constructs such as achievement motivation into rehabilitation research contributes to a more comprehensive understanding of recovery.

Exercise-based rehabilitation interventions that incorporate neural stimulation and active engagement have been shown to enhance functional recovery and psychosocial outcomes [30, 31, 32]. Neurobic exercises, characterized by multisensory stimulation and novel task engagement, facilitate brain-body coordination and cognitive activation [33]. In parallel, self-designed training programs that integrate yoga, resistance exercises, and recreational activities have demonstrated effectiveness in improving motivation, adherence, and functional adaptation in rehabilitation populations [34, 35].

Exercise-based interventions are commonly used to improve neuromuscular and psychological outcomes. Neurobic exercises involve non-routine, multisensory, and cognitively engaging tasks designed to stimulate neural pathways and enhance brain-body coordination [33]. These exercises promote neuroplasticity by encouraging novel sensory experiences and motor responses, which may improve neural efficiency and coordination [36, 37, 38, 39]. Research has shown that cognitively engaging physical activities may improve reaction time, coordination, and overall neuromuscular performance [40, 41].

In contrast, self-designed training programs emphasize individualized and participant-driven exercise selection, which may enhance engagement, autonomy, and adherence. Yoga has been shown to improve flexibility, core stability, and psychological well-being through mind-body integration [42, 43, 44]. Resistance training contributes to increased muscular strength, endurance, and neuromuscular activation, particularly in trunk muscles associated with stability [45, 46]. Recreational activities provide enjoyment, reduce stress, and enhance social interaction, thereby positively influencing motivation and adherence [47, 48]. Together, these components form an intervention framework that addresses physiological and psychological aspects of rehabilitation.

Yoga-based interventions have shown positive effects in individuals with spinal cord injuries (SCI), including paraplegia. Adapted yoga practices, particularly chair-based asanas and pranayama, may improve respiratory efficiency, flexibility, and autonomic function. Studies indicate that yoga enhances parasympathetic activity, reduces stress hormones, and improves emotional well-being. For instance, Shyamali Dhruva et al. [49] reported that yoga interventions reduced fatigue and improved quality of life in clinical populations. Khalsa [50] also described improvements in stress regulation and physiological functioning associated with yogic practices. In the context of SCI, yoga may support breathing control and relaxation, which are relevant because of compromised respiratory muscle function [51].

Recreational activities also play a role in the rehabilitation of individuals with paraplegia. Participation in adapted sports and leisure activities has been associated with improvements in psychological health, social integration, and life satisfaction. According to Kleiber et al. [52], recreation enhances coping mechanisms and promotes resilience among individuals with disabilities. Similarly, Martin Ginis et al. [53] reported that participation in recreational physical activity improved subjective well-being and reduced depression in individuals with SCI. These activities may also increase adherence to rehabilitation programs by making physical activity more enjoyable and meaningful [54].

Resistance training is commonly used to improve physical function in individuals with paraplegia. Because lower-limb function is impaired, resistance exercises are primarily focused on the upper body. This approach may contribute to increased muscular strength, endurance, and functional independence, including wheelchair propulsion and transfers. Research by Gater et al. [55] showed that resistance training enhanced muscle hypertrophy, cardiovascular fitness, and metabolic health in individuals with SCI. Additionally, Nash et al. [56] reported that consistent resistance training improved motor unit recruitment and neuromuscular coordination, which are often affected after spinal cord injury [57].

Achievement motivation influences the overall success of rehabilitation programs and interventions. Individuals with paraplegia often face psychological barriers such as fear, low confidence, and reduced self-efficacy. According to Bandura [22], self-efficacy influences an individual's ability to initiate and sustain behavior change. In rehabilitation contexts, higher achievement motivation is associated with better adherence, increased effort, and improved outcomes. Deci and Ryan [23] further emphasized that intrinsic motivation enhances long-term engagement in physical activity, which is relevant for individuals with disabilities [58].

Analysis of previous research findings has shown that exercise-based rehabilitation interventions may improve neuromuscular function, psychological well-being, and functional adaptation in individuals with paraplegia. Researchers emphasize that neurobic exercises, yoga, resistance training, and recreational activities contribute to motor coordination, muscle activation, motivation, and participation in rehabilitation programs. At the same time, the combined influence of cognitively engaging exercises and self-designed rehabilitation programs on neuromuscular and psychological outcomes remains a relevant aspect of rehabilitation practice. Variability in intervention structure, participant engagement, and functional responses continues to complicate the interpretation of rehabilitation outcomes and their practical application in individuals with paraplegia.

The present study aimed to investigate the effects of neurobic exercises and a self-designed training program on psychological well-being (achievement motivation) and neuromuscular function in individuals with paraplegia.

## Materials and Methods

*Participants*

Initially, 80 individuals with paraplegia aged 18-28 years were screened at Lovely Professional University. After the application of the inclusion and exclusion criteria, 45 participants (27 males and 18 females) were retained for the study. Participants were allocated into three groups: Neurobic Exercise Group (NEG; n = 15), Self-Designed Program Group (SDPG; yoga, resistance, and recreational activities; n = 15), and Control Group (CG; n = 15).

Randomization was not implemented because of institutional and clinical constraints. However, baseline equivalence across the groups was established prior to the intervention.

An a priori power analysis was conducted using G*Power software (version 3.1.9.7) for repeated-measures ANOVA (within-between interaction). Assuming a medium effect size ($f = 0.25$), $\alpha = 0.05$, statistical power of 0.80, correlation among repeated measures of 0.5, and $\varepsilon = 1$, the required sample size was estimated at 45 participants.

The inclusion criteria were: (i) age between 18 and 28 years, (ii) clinically diagnosed paraplegia, (iii) medical clearance for participation in moderate-intensity physical activity, and (iv) willingness and availability to participate in all designated training and assessment sessions. All participants demonstrated high adherence and completed at least 90% of the prescribed training sessions.

All participants provided written informed consent prior to participation. The study was conducted in accordance with the ethical guidelines of the institutional review board and received approval under Ethics Approval Number: LPU/IRB/2024/PHE/047.

The exclusion criteria included the presence of additional musculoskeletal, cardiovascular, or neurological conditions other than paraplegia that could contraindicate participation in exercise; a history of significant upper-body injury within the previous three months that could affect EMG recordings of the rectus abdominis or quadratus lumborum; current participation in structured external training or rehabilitation programs; and irregular attendance that could interfere with adherence to the intervention protocol. During the screening process, 35 individuals were excluded because they refused to participate (n = 20) or did not meet the inclusion criteria (n = 15).

All 45 participants were considered medically eligible to participate in the study. Baseline demographic characteristics confirmed that the groups were comparable in terms of age, gender distribution, and duration of paraplegia, indicating baseline equivalence prior to the intervention.

Table 1 presents the baseline characteristics of participants across the Neurobic Exercise Group, Self-Designed Program Group, and Control Group. The groups were comparable in terms of age and gender distribution, with mean ages ranging from 23.4 to 24.1 years and similar male-to-female ratios across the groups. All participants were within the same age range (18-28 years). No significant differences were observed among the groups at baseline ($p > 0.05$), indicating baseline equivalence prior to the intervention.

The data presented in Table 1 indicate that participants across the Neurobic Exercise Group, Self-Designed Program Group, and Control Group were comparable in key demographic characteristics. The distribution of age and gender was similar across the three groups, with no marked variations.

All participants were within the same age range (18-28 years), indicating sample homogeneity. Statistical analysis revealed no significant between-group differences for any demographic variable (all p > 0.05), supporting baseline equivalence prior to the intervention.

*Study Design*

The present study adopted a quasi-experimental pre-post control group design to examine the effects of neurobic exercises and a self-designed training program on psychological well-being (achievement motivation) and neuromuscular function in individuals with paraplegia.

The intervention lasted 12 weeks. During this period, the experimental groups participated in structured training sessions, whereas the control group continued routine activities. The neurobic exercise program emphasized multisensory stimulation and cognitive engagement. In contrast, the self-designed program incorporated yoga, resistance exercises, and recreational activities to enhance motivation, functional relevance, and adherence.

The program was conceptualized as both a rehabilitative intervention and a recreational framework aimed at reducing sedentary behavior, improving psychological resilience, and promoting active engagement. This design enabled the evaluation of neuromuscular outcomes, assessed through EMG activity of the rectus abdominis and quadratus lumborum and audio-visual reaction time, together with psychological outcomes within an integrated rehabilitation context.

The recruitment and allocation process is illustrated in Figure 1.

*Allocation and Bias Mitigation*

Participants were allocated into three groups: the Neurobic Exercise Group (NEG; n = 15), Self-Designed Program Group (SDPG; n = 15), and Control Group (CG; n = 15). A non-randomized allocation approach was used because of practical and clinical constraints within Lovely Professional University. Although this quasi-experimental design may introduce selection bias, baseline equivalence was established across the groups. No significant differences were observed in age, gender distribution, duration of paraplegia, achievement motivation, EMG activity, or reaction time at baseline (all p > 0.05).

To reduce the likelihood of bias, ANCOVA and repeated-measures ANOVA were used as statistical controls. Exact p-values and effect sizes were also reported. Because of the nature of the intervention, participant blinding was not feasible. However, all outcome measurements were conducted by trained assessors who were unaware of group allocation. In addition, a researcher independent of the intervention process performed the data entry and statistical analyses, which helped reduce detection

**Table 1.** Participant Demographics

| Demographic Variable | Neurobic Exercise Group (n = 15) | Self-Designed Program Group (n = 15) | Control Group (n = 15) |
|---|---|---|---|
| Age (years) | 23.4 ± 2.6 | 24.1 ± 2.8 | 23.8 ± 2.7 |
| Age range (years) | 18-28 | 18-28 | 18-28 |
| Gender (M/F) | 9 / 6 | 10 / 5 | 8 / 7 |

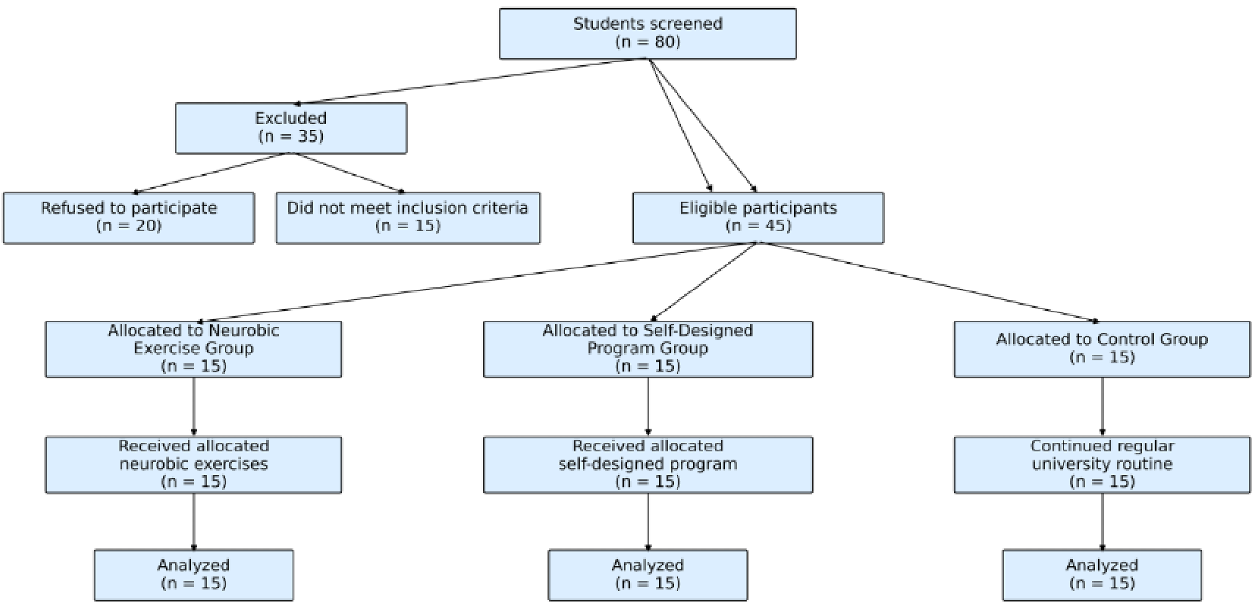


**Figure 1.** Recruitment and Allocation Flowchart

and reporting bias.

The neurobic exercise and self-designed training programs were implemented over a 12-week period in an after-university setting using a structured and progressive model tailored for individuals with paraplegia. Training sessions were conducted five times per week on non-consecutive days. The intervention included neurobic exercises and a self-designed program integrating yoga, resistance exercises, and recreational activities.

Exercise progression was implemented systematically, with gradual increases in volume, complexity, and perceived exertion every two weeks. Rest periods were modified accordingly. Exercise intensity was monitored using the Borg Rating of Perceived Exertion (RPE; 0-10 scale). Participants were required to maintain proper technique before progressing in intensity or volume.

The program was designed to enhance neuromuscular activation of the rectus abdominis and quadratus lumborum, improve audio-visual reaction time, and support psychological well-being, particularly achievement motivation. All sessions were supervised by trained professionals to ensure safety, adherence, and appropriate progression.

Throughout the 12-week intervention period, the control group followed the regular university curriculum without additional structured training components. Attendance records were maintained to verify adherence to the control condition. The detailed neurobic exercise protocol implemented across the 12-week intervention period is presented in Table 2.

**Table 2.** Neurobic Exercises Protocol (12 Weeks)

| Phase / Week | Activities | Intensity | Repetitions / Duration | Rest Interval | Progression Notes |
|---|---|---|---|---|---|
| **Phase 1: Foundation (Weeks 1-3)** | | | | | |
| Week 1 | Lazy Eight (eyes open), clay molding (basic shapes), smell identification of 2 items, taste identification of 2 items, one-word tracing | Low | 5-7 repetitions / 30-60 s per task | 30 s | Familiarization and sensory activation |
| Week 2 | Lazy Eight (eyes closed), clay coil formation, smell identification of 3 items, taste and describe task, two-word game | Low-Moderate | 6-8 repetitions / 45-60 s | 30-45 s | Increased sensory engagement |
| Week 3 | Lazy Eight (non-dominant hand), clay flower formation, scent categorization, texture-based tasting, theme word guessing | Moderate | 8-10 repetitions / ~1 min | 30-45 s | Emphasis on motor coordination |
| **Phase 2: Skill Development (Weeks 4-6)** | | | | | |
| Week 4 | Lazy Eight (air tracing, eyes closed), clay food modeling, blindfold scent recall, emotion-based tasting, sentence tracing | Moderate | 8-10 repetitions / 1 min | 30-60 s | Integration of sensory and cognitive tasks |
| Week 5 | Music-paced Lazy Eight, expressive clay modeling, blindfold scent matching, complex taste tasks, sentence formation | Moderate | 8-12 repetitions / 1-2 min | 30-45 s | Increased cognitive complexity |
| Week 6 | Mirror Lazy Eight, group clay task, smell and texture identification, ingredient identification, timed word game | Moderate-High | 10 repetitions / 1-2 min | 45-60 s | Introduction of dual-task coordination |
| **Phase 3: Creative Expansion (Weeks 7-9)** | | | | | |
| Week 7 | Variable-size Lazy Eight, functional clay object modeling, scent-object matching, novel food tasting, story creation | Moderate-High | 10-12 repetitions / 1-2 min | 45-60 s | Creativity and motor integration |
| Week 8 | Stylus-based Lazy Eight, clay modeling (animals/symbols), scent and sound pairing, taste-memory matching, novel tracing | Moderate-High | 10-12 repetitions | 45-60 s | Multisensory learning |
| Week 9 | Mood-based Lazy Eight, emotional clay face modeling, scent ranking, recipe guessing, phrase puzzles | High | 10-15 repetitions / 2 min | 60 s | High cognitive load |
| **Phase 4: Integration and Mastery (Weeks 10-12)** | | | | | |
| Week 10 | Freestyle Lazy Eight (music-guided), story-based clay modeling, random scent identification, taste mixing, act-out guessing | High | 12-15 repetitions / 2 min | 60-90 s | Functional integration |
| Week 11 | Timed Lazy Eight, group clay scene modeling, scent storytelling, taste drawing, spelling games | High | 12-15 repetitions | 60-90 s | Emphasis on speed and accuracy |
| Week 12 | Full Lazy Eight review, free clay modeling, scent presentation, taste quiz, cognitive games | High | 15 repetitions / 2-3 min | 60-90 s | Consolidation before post-test |

The structured self-designed exercise program implemented during the 12-week intervention period is presented in Table 3.

*Outcome Measures*

*Rectus Abdominis.* An electromyography (EMG) biofeedback device was used to assess the electrical activity of the rectus abdominis muscle. Surface electrodes were placed according to standardized anatomical landmarks, and muscle activation was recorded during selected functional movements. EMG amplitude (μV) was analyzed to assess neuromuscular activation and core muscle function.

*Quadratus Lumborum.* An electromyography (EMG) biofeedback device was also used to assess the electrical activity of the quadratus lumborum muscle. Electrodes were positioned according to standardized placement protocols, and activation levels were recorded during functional tasks. EMG amplitude (μV) was used as an indicator of neuromuscular function and core stability.

*Achievement Motivation.* Achievement motivation was assessed using the Achievement Motivation Scale developed by Deo and Mohan. This standardized instrument measures persistence, goal orientation, and competitive drive.

*Reaction Time – Auditory.* Auditory reaction time was measured using a digital reaction timer. Participants responded to an auditory stimulus, and response latency (ms) was recorded.

*Reaction Time – Visual.* Visual reaction time was assessed using a computerized or digital reaction timer in response to a visual stimulus. The interval between stimulus presentation and response was recorded in milliseconds.

Overall, the instruments and protocols used in this study are established methods that demonstrate acceptable to high levels of reliability and validity in general and clinical populations, including individuals with paraplegia. These measures are sensitive to training-induced adaptations in neuromuscular function and psychological parameters, supporting their suitability for evaluating the effects of neurobic and self-designed exercise interventions.

Every training session was supervised by two qualified strength and conditioning professionals holding Master's degrees in Physical Education and

**Table 3.** Self-Designed Exercises Program Protocol (12 Weeks)

| Week | Component | Sets / Rounds | Repetitions / Duration | Rest (s) | Intensity | Progression Notes |
|---|---|---|---|---|---|---|
| 1 | Yoga (seated postures, breathing, relaxation) | 2-3 rounds | 3-5 min per activity | 30-45 | Low | Familiarization, focus on breathing and posture |
| 2 | Yoga (seated postures, breathing, relaxation) | 2-3 rounds | 3-5 min | 30-45 | Low-Moderate | Improved coordination and breath control |
| 3 | Yoga (seated postures, breathing, relaxation) | 3-4 rounds | 5-7 min | 30-60 | Moderate | Increased duration and movement control |
| 4 | Resistance training (TheraBand and light dumbbells) | 2-3 sets | 8-12 repetitions | 45-60 | Light | Introduction of basic resistance exercises |
| 5 | Resistance training (TheraBand and light dumbbells) | 3 sets | 10-12 repetitions | 45-75 | Moderate | Gradual increase in training load |
| 6 | Resistance training (TheraBand and light dumbbells) | 3-4 sets | 12-15 repetitions | 60-90 | Moderate-High | Addition of resistance and controlled holds |
| 7 | Recreational activities (throws, catches) | 2-3 sets | 10-15 repetitions | 30-45 | Low | Skill familiarization and coordination focus |
| 8 | Recreational activities (throws, catches) | 3 sets | 15-20 repetitions | 30-45 | Moderate | Addition of variation (target and rhythm) |
| 9 | Recreational activities (throws, catches) | 3-4 sets | 20-25 repetitions | 30 | High | Increased speed and unpredictability |
| 10 | Mixed program (yoga, resistance, recreation) | 2-3 sets/ rounds | 8-12 repetitions / 3-5 min | 30-60 | Low-Moderate | Integrated training, foundation phase |
| 11 | Mixed program (yoga, resistance, recreation) | 3 sets/ rounds | 10-12 repetitions / 5-7 min | 45-75 | Moderate | Increased coordination and training load |
| 12 | Mixed program (yoga, resistance, recreation) | 3-4 sets/ rounds | 12-15 repetitions / 7-10 min | 60-90 | Moderate-High | Peak intensity and preparation for post-test |

certified by CAPE and AIT. Before the intervention, both specialists participated in a preparatory workshop to ensure consistency in session delivery. Inter-rater reliability was confirmed during a pilot phase, with an ICC exceeding 0.90. To reduce the potential for bias, all data entry and statistical analyses were conducted using anonymized participant codes.

*Statistical Analysis*

All statistical procedures were performed using SPSS version 30 (IBM Corp., Armonk, NY, USA). Before inferential analyses were conducted, the normality of each outcome variable was examined using the Shapiro-Wilk test. Descriptive statistics are presented as mean ± standard deviation (SD).

Within-group changes from pre-test to post-test were evaluated using paired-sample t-tests for each dependent variable. To compare adjusted post-test means across the three groups while accounting for baseline differences, analysis of covariance (ANCOVA) was applied, with the corresponding pre-test scores entered as covariates. When ANCOVA identified significant group effects, Scheffé's post hoc test was used to determine the direction and significance of pairwise differences among the Neurobic Exercise Group (NEG), Self-Designed Program Group (SDPG), and Control Group (CG).

Effect sizes were reported as Cohen's d for paired comparisons and partial eta squared ($\eta^2$) for ANCOVA outcomes. Bonferroni corrections were applied within each outcome domain to reduce the risk of Type I error associated with multiple comparisons. The threshold for statistical significance was set at $\alpha = 0.05$ throughout the analysis.

## Results

The experimental groups maintained adherence throughout the intervention period. Pre-intervention analysis indicated that the experimental and control groups were comparable across all measured variables at baseline, including rectus abdominis EMG, quadratus lumborum EMG, achievement motivation, and audio-visual reaction time, indicating baseline homogeneity in neuromuscular and psychological parameters. During the 12-week intervention period, both experimental groups demonstrated changes across all measured variables, whereas the control group showed limited changes. Variations in achievement motivation, EMG activity, and reaction time across the three groups are presented in Table 4.

The results of repeated-measures ANCOVA (Table 5) revealed statistically significant group differences across all variables ($p < 0.05$), indicating differences among the intervention conditions. Effect sizes were higher for EMG activity and reaction time measures, whereas achievement motivation also demonstrated changes across the intervention period. Within-group paired t-test analysis supported these findings, with both experimental groups demonstrating statistically significant pre-post changes across all variables ($p < 0.05$). In contrast, the control group did not demonstrate statistically significant changes.

Within-group pre-post differences for all measured variables are presented in Table 6. The paired t-test analysis indicated statistically significant pre-post changes in both experimental groups across all measured variables ($p < 0.05$). In contrast, the control group did not demonstrate statistically significant changes.

Table 4. Pre- and Post-Intervention Performance of the Experimental and Control Groups

| Variable | Group | Pre-test (Mean ± SD) | Post-test (Mean ± SD) | % Change |
|---|---|---|---|---|
| Achievement Motivation | Neurobic | 159.80 ± 17.53 | 183.40 ± 20.23 | 14.77% |
| | Self-Designed | 159.07 ± 18.20 | 199.67 ± 22.36 | 25.52% |
| | Control | 159.07 ± 18.20 | 161.20 ± 18.55 | 1.34% |
| Rectus Abdominis EMG (μV) | Neurobic | 45.20 ± 2.10 | 51.50 ± 2.05 | 13.95% |
| | Self-Designed | 44.80 ± 2.25 | 55.75 ± 2.30 | 24.42% |
| | Control | 45.10 ± 2.05 | 45.85 ± 2.15 | 1.64% |
| Quadratus Lumborum EMG (μV) | Neurobic | 55.80 ± 13.48 | 68.60 ± 13.85 | 22.94% |
| | Self-Designed | 55.80 ± 13.48 | 71.13 ± 14.01 | 27.47% |
| | Control | 55.80 ± 13.48 | 55.90 ± 13.48 | 0.18% |
| Reaction Time (Auditory, ms) | Neurobic | 332.33 ± 27.70 | 276.00 ± 17.24 | 16.94% ↓ |
| | Self-Designed | 337.13 ± 28.04 | 262.00 ± 13.73 | 22.29% ↓ |
| | Control | 332.33 ± 27.70 | 330.00 ± 27.45 | 0.70% ↓ |
| Reaction Time (Visual, ms) | Neurobic | 382.50 ± 28.00 | 330.50 ± 19.00 | 13.59% ↓ |
| | Self-Designed | 388.00 ± 28.60 | 308.20 ± 17.10 | 20.57% ↓ |
| | Control | 386.00 ± 27.80 | 383.50 ± 27.20 | 0.65% ↓ |

**Table 5.** Summary of Repeated-Measures ANCOVA

| Variable | df | F-value | p-value |
|---|---|---|---|
| Achievement Motivation | 2 | 1882.51* | <0.05 |
| Rectus Abdominis EMG | 2 | 52.50* | <0.05 |
| Quadratus Lumborum EMG | 2 | 2262.75* | <0.05 |
| Reaction Time (Auditory) | 2 | 95.40* | <0.05 |
| Reaction Time (Visual) | 2 | 102.60* | <0.05 |

* Significant at the 0.05 level.

**Table 6.** Within-Group Paired t-test Summary

| Variable | Group | Mean Difference | t-value | p-value | Effect Size (d) |
|---|---|---|---|---|---|
| Achievement Motivation | Neurobic | 23.60 | 33.6* | <0.05 | Large |
| | Self-Designed | 40.60 | 37.2* | <0.05 | Very Large |
| | Control | 2.13 | 1.1 | >0.05 | Trivial |
| Rectus Abdominis EMG | Neurobic | 6.30 | 9.1* | <0.05 | Large |
| | Self-Designed | 10.95 | 11.8* | <0.05 | Very Large |
| | Control | 0.75 | 1.1 | >0.05 | Small |
| Quadratus Lumborum EMG | Neurobic | 12.80 | 64.00* | <0.05 | Very Large |
| | Self-Designed | 15.33 | 60.85* | <0.05 | Very Large |
| | Control | 0.01 | — | >0.05 | Negligible |
| Reaction Time (Auditory) | Neurobic | -56.33 | 20.26* | <0.05 | Large |
| | Self-Designed | -75.13 | 20.20* | <0.05 | Very Large |
| | Control | -2.33 | 0.8 | >0.05 | Trivial |
| Reaction Time (Visual) | Neurobic | -52.00 | 11.50* | <0.05 | Large |
| | Self-Designed | -79.80 | 14.20* | <0.05 | Very Large |
| | Control | -2.50 | 1.10 | >0.05 | Trivial |

* Significant at the 0.05 level.

## Discussion

The present study investigated the effects of a 12-week neurobic exercise program and a self-designed training program on neuromuscular function and psychological well-being in individuals with paraplegia. The findings indicated changes in achievement motivation, rectus abdominis and quadratus lumborum EMG activity, and auditory and visual reaction time in both experimental groups, whereas the control group demonstrated limited changes during the intervention period. The self-designed program showed greater changes across the measured variables compared with the neurobic exercise group. These findings are consistent with previous studies reporting that structured exercise-based rehabilitation interventions may influence functional and psychological outcomes in individuals with spinal cord injury [30, 31, 32, 35, 57].

Paraplegia, characterized by partial or complete loss of motor and sensory function in the lower extremities, is associated with compromised neuromuscular efficiency, impaired trunk stability, and reduced psychological well-being, which may affect independence and quality of life [1, 3, 8, 32, 59]. The present study examined these factors through two intervention frameworks: one based on cognitive-neural stimulation and the other on individualized multi-component training.

Previous studies have primarily examined neuromuscular and psychological outcomes independently, with fewer studies exploring their combined effects within a single intervention framework [3, 32, 55, 57]. Resistance and core-stability training have previously been discussed in relation to trunk muscle activation and postural control in individuals with paraplegia [35]. Neurobic exercises involving multisensory stimulation and novel task engagement have also been associated with changes in cognitive processing speed and reaction time [33, 36, 37, 38, 39]. In addition, yoga-based interventions have been discussed in relation to psychological well-being and motivation in rehabilitation populations [34, 51]. The self-designed program used in the present study incorporated yoga, resistance training, and recreational activities based on these rehabilitation approaches [42, 43, 45, 46, 47, 48, 54]. The findings of the present study are generally consistent with these observations, as changes were identified in both neuromuscular and psychological variables following the intervention period.

Surface EMG has previously been used for assessing trunk muscle activation and neuromuscular adaptation in healthy individuals and populations with spinal cord injury [11, 35, 60, 61]. The Achievement Motivation Scale developed by Deo and Mohan has also been applied in physical education and psychological research settings for the assessment of motivational characteristics following structured interventions [58, 62]. In addition, auditory and visual reaction time tests have been discussed as indicators of central processing speed, sensorimotor coordination, and neuromotor responsiveness in training and rehabilitation contexts [17, 18, 63, 64]. The changes observed in the present study across EMG activity, reaction time, and achievement motivation are consistent with the use of these measures for evaluating neuromuscular and psychological responses during rehabilitation interventions.

*Achievement Motivation*

One outcome of the present study was the increase in achievement motivation observed in both intervention groups. The self-designed program group demonstrated a larger percentage change than the neurobic exercise group, whereas the control group showed limited change. These findings are consistent with the theoretical framework proposed by Bandura [22], who suggested that engagement in goal-directed physical activity may strengthen self-efficacy and motivational processes. Similarly, Deci and Ryan [23] reported that interventions incorporating autonomy and personal relevance may support intrinsic motivation. These characteristics were included in the self-designed program [65, 66].

The change observed in the self-designed group may be associated with participant choice and individualized activity selection, which may increase engagement in the training process. Previous studies have also reported associations between structured physical activity and changes in mood, motivation, and psychological well-being in clinical populations [26, 28, 32]. In individuals with paraplegia, reduced achievement motivation and social withdrawal have been reported previously [8, 9, 58]. The recreational component of the self-designed program may also have contributed to social interaction and motivational engagement, which have been discussed in earlier studies on recreational activity and psychological adaptation [47, 48, 54].

The changes observed in achievement motivation are also consistent with previous evidence regarding the psychological effects of yoga-based interventions. Telles et al. [34] reported that yoga practice may influence self-regulation, goal commitment, and psychological well-being in rehabilitation populations. These findings correspond with the changes observed in the self-designed group in the present study [44]. The changes observed in the neurobic group also support the view that cognitively engaging and multisensory activities may influence neural reward pathways and the sense of accomplishment [40, 41, 63], which may contribute to motivational well-being in individuals with paraplegia.

*Rectus Abdominis EMG Activity*

The results of the present study indicated an increase in rectus abdominis EMG activity following both interventions. The self-designed program group demonstrated a greater percentage change than the neurobic exercise group, whereas the control group showed limited change. These findings are consistent with previous studies describing the role of trunk muscle activation in postural stability and functional independence in individuals with spinal cord injury. Harvey et al. [35] reported that targeted neuromuscular training and core-stability exercises were associated with changes in trunk muscle activation in rehabilitation populations [67].

The rectus abdominis contributes to wheelchair propulsion, postural transitions, and upper-body balance [13, 15]. The changes in muscle activation observed in the present study may therefore be associated with functional performance during daily activities. The changes observed in the self-designed group may reflect the combined influence of resistance training and yoga-based postures, which involve controlled core engagement and mind-body coordination [34, 42, 43]. These findings support the use of multi-component and individualized exercise programs for trunk neuromuscular training in individuals with paraplegia [57].

The changes observed in rectus abdominis EMG activity in the neurobic group may reflect neuromuscular activation associated with multisensory and cognitively engaging tasks. Kleim and Jones [37] and Kolb and Gibb [38] reported that novel and non-routine motor tasks may promote neuroplastic adaptation and influence motor unit recruitment patterns. These mechanisms may partly explain the changes in trunk muscle activation observed in the neurobic group [63]. De Luca [11] and Farina et al. [12] also noted that EMG-based assessments are sensitive to neural adaptations following training, supporting the use of surface EMG as an outcome measure in the present study [61].

*Quadratus Lumborum EMG Activity*

Similar patterns were observed for quadratus lumborum EMG activity. The self-designed program group demonstrated a greater percentage change than the neurobic group, whereas the control group showed limited change. Previous studies have reported that impaired trunk muscle activation in individuals with paraplegia may affect postural control, sitting balance, and wheelchair performance [5, 6, 13, 15, 57, 61].

The changes observed in the present study suggest that both interventions influenced trunk muscle recruitment, with the self-designed program demonstrating a greater percentage change. This finding may be associated with the progressive resistance training component of the self-designed program, which has previously been linked to changes in motor unit recruitment, muscular endurance, and neuromuscular synchronization [45, 46, 57]. The changes observed in the neurobic group also support the view that cognitively engaging and multisensory activities may influence neuromuscular pathways beyond cognitive-related functions [36, 37, 63].

De Luca [11] and Farina et al. [12] noted that EMG-based assessments are sensitive to neural adaptation following training. The present findings are consistent with these observations in a rehabilitation context [61, 67]. Taken together, the changes in rectus abdominis and quadratus lumborum EMG activity observed across the experimental groups indicate the potential role of structured exercise interventions in trunk neuromuscular training in individuals with paraplegia.

*Audio-Visual Reaction Time*

The present study observed reductions in both auditory and visual reaction time across the experimental groups following the 12-week intervention. The self-designed group demonstrated a greater percentage change than the neurobic group, whereas the control group showed limited change. These findings are consistent with previous studies reporting that cognitively engaging exercise interventions may influence central processing speed and sensorimotor responsiveness [40, 41, 63].

Previous studies have described reaction time as an indicator of neural processing and motor response execution [17, 18]. The reductions in auditory and visual reaction time observed in the present study may be associated with the characteristics of the intervention programs. The neurobic exercises incorporated multisensory and non-routine tasks, which are intended to stimulate sensory processing and cognitive engagement, as proposed by Katz and Rubin [33]. In addition, the self-designed program included recreational activities such as throwing, catching, and target-based tasks that required sensory integration and coordinated motor responses. Previous studies have suggested that recreational activities may contribute to engagement and motor interaction in rehabilitation settings [47, 48, 54].

In individuals with paraplegia, delayed reaction time may affect daily safety and functional performance [20, 21]. The changes observed in the present study may therefore reflect adaptations associated with exercise-based rehabilitation approaches targeting neuromotor function. The progressive structure of both intervention protocols, including gradual increases in task complexity and cognitive demand across the intervention period, may also have contributed to these adaptations. Similar observations have been discussed previously in relation to progressive training approaches applied to neuromotor and muscular function [30, 31, 57, 63, 66].

*Pedagogical, Recreational, and Rehabilitative Relevance*

Beyond the physiological and psychological outcomes, the present study also has pedagogical, recreational, and rehabilitative relevance. Both interventions were structured as rehabilitation-based activity programs that involved participant engagement in purposeful and personally relevant tasks. The self-designed program incorporated yoga, resistance training, and recreational activities, addressing physical, psychological, and social aspects within a single intervention framework. Previous studies by Harvey et al. [35] and Telles et al. [34] also discussed the role of multi-component rehabilitation approaches in participant adherence and functional adaptation in rehabilitation populations [32, 66]. In addition, pedagogically oriented rehabilitation approaches emphasizing participant-centered learning, autonomy, and active engagement have been associated with improved adherence and long-term behavioral adaptation in individuals with disabilities [58].

The neurobic exercise program incorporated novel and multisensory tasks with progressively increasing levels of complexity, which may have contributed to cognitive engagement during the rehabilitation process. Katz and Rubin [33] and Cotman and Berchtold [36] discussed the relationship between novel task engagement, neuroplastic adaptation, and psychological involvement in activity-based interventions [63]. The recreational components included in both programs may also have influenced participant engagement and psychological adaptation during the intervention period [54, 58].

These findings may have implications for the design and delivery of rehabilitation programs for individuals with paraplegia. The results suggest that personalized, cognitively engaging, and recreation-based exercise interventions may be incorporated into rehabilitation practice to address functional and psychological aspects simultaneously. Similar approaches involving physical activity, recreation, and psychological engagement in rehabilitation settings have been discussed previously [10, 27, 29, 32, 58]. The implementation of the program within a university rehabilitation setting also indicates the possibility of applying similar approaches in clinical and educational environments, where structured after-session activities may be used as fitness, recreational, and rehabilitation-based strategies [66].

*Limitations of the Study*

A quasi-experimental design was used in this study, and group allocation was not randomized. This design may have introduced selection bias despite the baseline equivalence observed between the groups. In addition, the sample was limited to individuals with paraplegia from a single university setting, which may limit the generalizability of the findings to other clinical populations.

The intervention period lasted 12 weeks. Although this duration was sufficient to identify changes across the measured variables, it does not allow conclusions regarding the long-term maintenance of these changes. Furthermore, the study did not assess overall quality of life, independence in daily activities, or psychosocial outcomes beyond achievement motivation. As a result, the broader rehabilitative impact of the intervention programs was not examined.

*Future Research Directions*

Future studies should examine the long-term retention of neuromuscular and psychological changes following neurobic and self-designed training programs in individuals with paraplegia. Studies involving randomized controlled designs and larger samples, including participants with different levels and durations of spinal cord injury, may provide additional information regarding the applicability of these interventions across rehabilitation settings.

Future research should also include assessments of quality of life, functional independence, and additional physiological indicators related to rehabilitation progress. In addition, further investigation of the relationship between training frequency, duration, and neuromotor outcomes may assist in the development of rehabilitation programs that incorporate individualized and cognitively engaging exercise interventions.

## Conclusions

The findings of the present study indicate that both the 12-week neurobic exercise program and the self-designed training program were associated with changes in neuromuscular function and psychological well-being in individuals with paraplegia. Both interventions were associated with changes in EMG activity of the rectus abdominis and quadratus lumborum, auditory and visual reaction time, and achievement motivation. The self-designed program demonstrated greater changes across the measured variables compared with the neurobic exercise group.

The effects observed in the self-designed program may be associated with its multi-component structure integrating yoga, resistance exercises, and recreational activities within a single rehabilitation framework. This approach addressed physical, psychological, and social aspects of rehabilitation simultaneously and may have contributed to participant engagement during the intervention period.

Both interventions were implemented within a university rehabilitation setting without adverse events reported during the study period. The findings suggest that individualized, cognitively engaging, and recreation-based exercise interventions may be incorporated into rehabilitation programs for individuals with paraplegia.

The present study indicates that structured multi-component exercise interventions based on neurobic and self-designed approaches may be applied in rehabilitation settings targeting neuromuscular and psychological aspects of rehabilitation in individuals with paraplegia.

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## Conflict of Interest

The authors declare no conflict of interest.

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