

Research article

Neuromuscular and Self-Concept Adaptations Following Neurobic Exercise and Multicomponent Exercise Program in Individuals with Paraplegia

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Abstract: Neuromuscular function and psychological well-being can be affected by spinal cord injury leading to paraplegia, including upper-body muscle activation, reaction time and self-concept. This study investigated the effects of 12 weeks Neurobic Exercise Program and Multicomponent Exercise Program on these outcomes in individuals with paraplegia. Forty-five participants were randomly assigned to three groups Neurobic Exercise Group (NEG; n = 15), Multicomponent Exercise Program Group (MEP; n = 15), and Control Group (CG; n = 15). Both exercise interventions were conducted for 12 weeks 5 days/week. Electromyographic activity of the anterior deltoid and trapezius, self-concept and auditory and visual reaction time were assessed pre- and post-intervention. The data were analyzed using descriptive statistics, paired and independent t-tests, analysis of covariance, and Scheffé post hoc comparisons. Significant improvements were observed in all measured outcomes in both exercise groups compared with the control group ($p < 0.05$). The MEP showed greater changes in EMG activity, self-concept and auditory and visual reaction time than the NEG. While both exercise modalities may provide neuromuscular and psychological benefits to individuals with paraplegia, differences in exercise content, particularly the incorporation of direct resistance exercise within the MEP, should be considered when interpreting between-program variations.

Keywords: Paraplegia, Neurobic Exercises, Self-Designed Program, Self-Concept, EMG, Reaction Time, Neuromuscular Rehabilitation

1. Introduction

Paraplegia is a severe neurological condition characterized by the loss or impairment of motor and sensory function in the lower extremities and, in some cases, parts of the trunk, resulting primarily from injury to the thoracic, lumbar, or sacral regions of the spinal cord [1]. The condition most commonly arises from traumatic spinal cord

injuries (SCI) resulting from falls, motor vehicle accidents, sports injuries, or acts of violence, although non-traumatic causes such as tumors, infections, vascular disorders, and degenerative diseases may also result in paraplegia [2,3]. Depending on the neurological level and completeness of the injury, individuals with paraplegia may experience varying degrees of paralysis, sensory impairment, impaired trunk control, and limitations in mobility and the activities of daily life [1]. These functional constraints can have a substantial impact on affect independence, social participation, employment, and the total quality of existence [4,5]. In addition to primary neurological impairments, individuals with paraplegia are at increased risk of secondary health complications, including musculoskeletal pain, spasticity, pressure injuries, cardiovascular dysfunction, reduced physical fitness, and metabolic abnormalities [6,7]. The loss of lower-extremity function also places greater physical demands on the upper extremities, particularly during wheelchair propulsion, transfers, reaching, and weight-shifting activities, potentially increasing the risk of shoulder overuse and musculoskeletal problems [8,9]. Furthermore, the physical and psychosocial consequences of SCI may influence psychological well-being, self-concept, motivation, and participation in meaningful activities [10,11]. Consequently, rehabilitation for individuals with paraplegia extends beyond restoration or maintenance of physical function and increasingly emphasizes psychological adjustment, functional independence, participation, and long-term health. Structured physical activity and exercise have been identified as important components of SCI rehabilitation because they can contribute to improvements in physical fitness, neuromuscular function, psychological well-being, and quality of life [12]. Therefore, investigating exercise-based approaches that simultaneously address psychological variables and neuromuscular function is particularly important for promoting comprehensive rehabilitation and enhancing the overall well-being of individuals with paraplegia. The profound psychological impact of sudden physical disability—including reduced self-esteem, depression, anxiety, and distorted self-concept—has been well documented in the literature [13,14]. In this population, disruption of sensorimotor pathways not only affects voluntary movement, but also the neuromuscular integrity of preserved upper limb musculature that is critical to daily functioning, mobility and independence [15].

Neuromuscular function refers to the capacity of the skeletal musculature, which interacts in a coordinated fashion with the nervous system to produce, regulate and sustain voluntary movement [16]. In paraplegic people, the neural pathways that travel to the lower limbs become cut off and lead to significant denervation of muscle groups, which lead to atrophy, weakness, and spasticity in those lower body muscle groups [17]. The functional burden on upper limb musculature is increased, however, including the shoulder girdle muscles, as wheelchair propulsion, transfers and the activities of daily life depend heavily on the shoulder and arms [15] because of the overuse of these muscles, changes in biomechanics, and loss of neuromuscular efficiency, chronic shoulder pain and musculoskeletal dysfunction are common in people with paraplegia [18].

Electromyography (EMG) is a gold standard diagnostic and research instrument capable of quantifying the electrical activity produced by a skeletal muscle when it is voluntarily contracting, and is used to gain insight into the functional integrity of the neuromuscular system [19]. Electromyographic (EMG) assessments in people with paraplegia have shown that the motor unit recruitment pattern is altered, that the amplitude of activation is lower and that the synergies of the muscle groups of the upper limb are different [20]. The anterior deltoid and trapezius muscles are important functional muscles in this population, controlling shoulder flexion, abduction and scapular stabilization during activities that involve wheelchair propulsion, reaching, and lifting [21]. Improved

neuromuscular activation of these muscles is, therefore, of paramount clinical importance and targeted exercise interventions deserve special attention in paraplegia rehabilitation.

The anterior deltoid muscle is the major flexor of the shoulder and is the medial rotator, which are essential for wheelchair propulsion and reaching activities [22]. The trapezius is a large, flat muscle that covers the upper, middle and lower portions of the trapezius region and is vital to scapular elevation, retraction and depression, which affords dynamic stability to allow safe and efficient use of the upper limb [23]. Research has demonstrated that individuals who have paraplegia have abnormal activation patterns in these muscles, with more than normal activity in the upper trapezius muscles, and with less than normal activity in the lower trapezius and anterior deltoids, which elevates the likelihood of shoulder impingement and rotator cuff pathology [24].

Exercise interventions to strengthen and neuromuscular of the anterior deltoid and trapezius have been shown to normalize more efficient muscle activation patterns, decrease pain and improve functional capacity in people with SCI [25]. EMG biofeedback and resistance training has proven to be very effective in the motor unit recruitment and muscle coordination of these important shoulder girdle muscles, thus making them a point of interest for rehabilitation programs for individuals with paraplegia [19].

Reaction time (RT) is the the interval between the presentation of the stimulus and the onset of a voluntary motor response. It is a speed measurement that is highly sensitive of central nervous system processing, of the efficiency of the neuromuscular system, and of cognitive-motor integration [26]. RT is broken down into auditory reaction time (ART) (when triggered by an auditory stimulus) and visual reaction time (VRT) (when triggered by a visual stimulus) and these two are thought to involve different sensory processing pathways and neural circuits [27]. The disruption of descending corticospinal tracts affects motor output and, importantly, not only the efficiency of sensorimotor integration, but also may cause prolonged reaction times [28] even in the case of upper limb responses in individuals with paraplegia.

Persistent RT in this population is due to the disruption of inter-hemispheric communication, changes in proprioceptive feedback and decreased excitability of the motor cortex secondary to deafferentation [29]. ART and VRT have been used as outcome measures in SCI rehabilitation research and improvements in RT provide objective measures of improved neural processing after exercise intervention [28]. Some exercise modalities have been proposed as helpful when reducing RT, such as exercising at the movement level, such as the neurobic exercise which challenges sensorimotor pathways, which may be important for neuroplasticity and synaptic efficiency in the remaining neural circuits [30].

Psychological well-being is a multi-dimensional construct involving emotional stability, sense of purpose, personal growth, positive relationships and self-acceptance [31]. In people with paraplegia, psychological health and wellbeing is strongly impacted by the sudden and permanent loss of physical function, social roles and employment opportunities [13]. Depression and anxiety are reported by up to 40% of people with SCI and decreased life satisfaction and autonomy are near universal challenges in the post-injury period [14]. Physical rehabilitation and psychological recovery have a two-way relationship; exercise participation has a positive effect on mood, decreases depressive symptoms, and increases a sense of mastery and control for persons with disability [32].

Self-concept is a fundamental component of psychological well-being, and is an individual's cognitive and affective evaluation of his/her capacities, attributes, and value [33]. After the onset of paraplegia, self-concept is commonly affected as people struggle with a new body image, functional identity, and social status [32]. Structured physical activity and sport has consistently demonstrated a beneficial effect on individuals' self-esteem and self-concept with physical disability, with the exercise induced improvement

in physical competence leading to wider positive changes in self-perception and psychological functioning [34,35]. Personally meaningful and autonomy-supportive exercise modes they are more effective in fostering the development of a positive self-concept in individuals with paraplegia [36].

[37] The term 'neurobic exercises' to refer to physical activities that are intended to engage two or more sensory modalities simultaneously and thus present novel, cross-modal sensory input to challenge the brain. Neurobic exercises are not designed to build muscle strength or cardiovascular fitness but are specifically intended to activate cerebral regions that are not typically activated during a traditional workout, utilizing sensory inputs in conjunction with physical movements, such as tactile, auditory and visual tasks [37]. This type of physical activity stimulates neuroplasticity of the brain, resulting in the formation of novel synaptic connections, dendritic branching, and expression of neurotrophic factors that are essential for neural recovery and cognitive-motor enhancement [30].

A special interest in paraplegia rehabilitation should be given to the neurobic exercises, because there is a possibility to train the neuromuscular system and also the individual's self - concept. Neurobic exercises activate preserved sensory pathways and require attentional resources, thus inducing faster reorganization of neuroplasticity in the cerebral cortex and subcortical structures that facilitate the recruitment of motor units more effectively, inter-limb coordination and reaction time [29]. Additionally, the novelty and variety offered in the neurobic exercise programs, are expected to increase intrinsic motivation and psychological involvement, which may have a beneficial impact on self-concept and well-being of paraplegics [36,32].

When the design of the exercise program is individualized, the individual is involved in the selection and organization of the training activities based on the individual's personal choices, functional capacity, and rehabilitation objectives, this strategy is referred to as self-designed training. The programs are generally multi-component, combining a variety of modalities such as yoga, recreation and resistance exercise, thus providing an intervention that is comprehensive and involves multiple aspects of health and function, including physical, cognitive and self -concept [38].

Yoga is an ancient system of physical postures (asanas), breathing patterns (pranayama) and meditation that has been increasingly supported by empirical evidence of its beneficial effects on patients with SCI. Adapted yoga protocols has shown to increase upper limb flexibility, improve balance, manage spasticity, and promote psychological improvement in persons with SCI, participants found improved body awareness, decreased stress, and increased emotional regulation after a yoga-based intervention [39,40]. Yoga exercise is especially suited to promoting individuals' self-concept well-being after therapeutic yoga practice, a method that is mindful and body-centred.

Recreational activities, which include physical activities in the context of sport, leisure and play, play a vital role in comprehensive rehabilitation for individual with physical disability. Adapted sports and recreational programs have been shown to have a positive impact on physical fitness, social connectedness, self-efficacy and quality of life among people with paraplegia [32,35]. Recreation based rehabilitation helps to facilitate intrinsic motivation and enjoyment, with less psychological load from structured therapeutic exercise, and increased long term adherence to active lifestyles [38].

Progressive loading of the upper limb skeletal muscle using free weights, resistance bands or specialized equipment is the basis of resistance exercise and is a fundamental component of upper limb rehabilitation for those with paraplegia. Greater neural recruitment of motor units and a quicker rate of force development are among the neuromuscular adaptations that occur as a result of resistance training, and hypertrophic muscle remodeling, which help to increase functional strength and endurance of the upper extremities [25]. For persons with paraplegia, targeted resistance training of the shoulder

girdle musculature—particularly the anterior deltoid and trapezius—is essential for optimizing wheelchair propulsion efficiency and reducing injury risk [21,15]. Resistance Exercise, Yoga, and Recreation are synergistic rehab stimulants, when integrated within a self-designed program, that have a comprehensive rehabilitation effect on the physical, cognitive and psychological domains.

Despite the widespread support for exercise-based rehabilitation in paraplegics, there is an alarming dearth of research on the impact of cognitively stimulating exercises (e.g., neurobics) and self-designed, multi-component exercises that are tailored to the neuromuscular system and the self-concept of individuals with paraplegia. Research to date is limited to either physical (strength, EMG activity and reaction time) or psychological (depression, QOL) outcomes, with few studies investigating the relationships between these domains [17,32]. In addition, some of the effects of neurobic exercise on EMG activity of the anterior deltoid and trapezius muscles, and on auditory and visual reaction time have not been investigated systematically in paraplegic individuals.

A program that is highly effective in assisting individuals in their recovery is achieved by combining activities such as yoga, fun activities, and exercises that promote strength. This method is highly prospective due to its ability to accomplish numerous tasks simultaneously. Yoga and these other activities can assist individuals in their recovery in a more comprehensive manner than relying on a single activity to achieve recovery. The yoga and exercises and fun activities all work together to help people reach their rehabilitation goals. Given the well-established psychological benefits of autonomy and personal agency in exercise adherence [36] and the neuroplastic potential of cognitively stimulating exercise [30], there is strong theoretical justification for comparing neurobic and self-designed approaches in the context of paraplegia rehabilitation. The present study therefore aimed to address this gap in the literature by comparing and analyzing the effects of a 12-week neurobic exercise program and a self-designed training program (comprising yoga, recreation, and resistance exercise) on self-concept, anterior deltoid and trapezius EMG activity, and auditory and visual reaction time in paraplegic individuals, in comparison to a control group that did not receive any structured intervention.

2. MATERIALS AND METHODS

2.1 Experimental Approach to the Problem

The present study employed a randomized controlled experimental approach to examine and compare the effects of two independent exercise interventions on self-concept and selected neuromuscular outcomes among individuals with paraplegia. Participants were randomly allocated to three parallel groups: a Neurobic Exercise Group (NEG), Multi-component Exercise Program Group (MEP), and a Control Group (CG). The Neurobic Exercise Program and Multicomponent Exercise Program were administered as separate interventions and were not combined within the same intervention group. Participants in the Control Group continued their routine activities and standard care during the study period.

The Neurobic Exercise Program primarily emphasized sensory-cognitive engagement, coordination, attention, breathing, and multimodal sensory activities. In contrast, Multi-component Exercise Program comprised structured yoga, resistance exercises, recreational activities, and mixed training. The multicomponent program was developed and standardized by the investigator followed by expert recommendation and was not individually designed or selected by the participants. Exercise selection, sequencing, session structure, and progression were primarily determined by the investigator, with appropriate modifications permitted to accommodate individual functional ability, safety, and exercise tolerance.

The two interventions were intentionally distinct and were not matched for physical training dose or neuromuscular stimulus. In particular, the resistance-training component of the Multicomponent Exercise Program provided a more direct mechanical stimulus to the upper-body musculature, including the anterior deltoid and trapezius, than the primarily sensory-cognitive and coordinative Neurobic Exercise Program. Consequently, the objective of the study was to compare the responses to two distinct exercise protocols, rather than to ascertain the superiority of dose-equivalent interventions.

Any observed discrepancies between the two experimental groups were therefore interpreted within the context of their different exercise content and training stimuli.

The primary outcomes comprised self-concept, electromyographic activity of the anterior deltoid and the specified portion of the trapezius, and auditory and visual reaction time. Self-concept was assessed using the Mukta Rani Rastogi Self-Concept Scale, comprising 51 items scored on a five-point response format (1–5), with positive and negative items scored in opposite directions; higher total scores indicate better self-concept. Electromyographic activity was recorded in microvolts (μV), with higher EMG amplitude indicating greater electrical muscle activity under the standardized testing conditions. Auditory and visual reaction time were recorded in milliseconds (ms), with lower values indicating faster responses. Pre- and post-intervention assessments were conducted using the same standardized procedures following the 12-week intervention period.

The study focused on changes in the measured psychological and laboratory-based neuromuscular outcomes. Improvements in EMG activity or reaction time were not interpreted as direct evidence of improved wheelchair propulsion, transfers, upper-limb functional capacity, independence, participation, quality of life, or reduced injury risk because these clinical and functional outcomes were not directly assessed. Similarly, proposed mechanisms such as neuroplasticity, synaptic efficiency, corticospinal transmission, and interhemispheric communication were considered plausible explanatory hypotheses rather than demonstrated consequences of the interventions.

Figure A illustrates the flow of participants through the study.

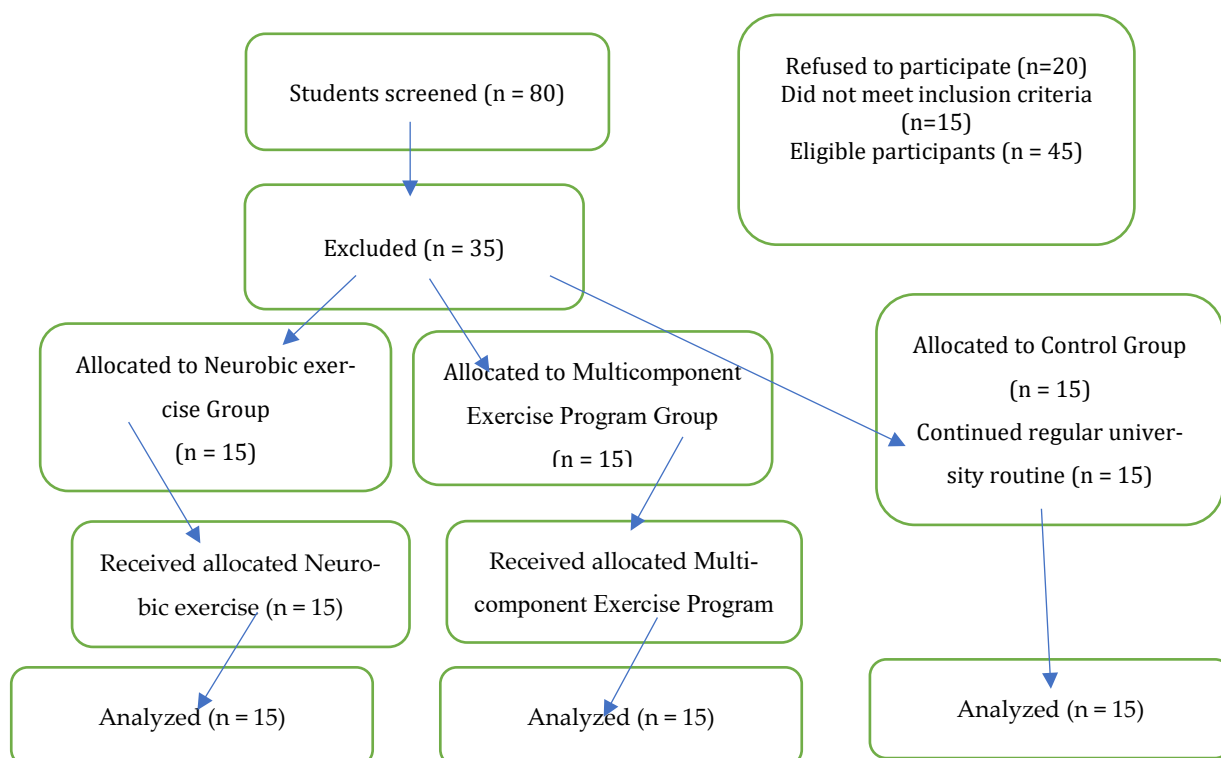


Figure (A). RECRUITMENT AND ALLOCATION FLOWCHART

2.2 Research Design

The study employed a randomized controlled experimental pre-test–post-test design with three parallel groups. A total of 45 participants with paraplegia were randomly allocated in equal numbers to three groups: (i) Neurobic Exercise Group (NEG; $n = 15$), (ii) Multicomponent Exercise Program Group (MEP; $n = 15$), and (iii) Control Group (CG; $n = 15$). The NEG received a structured Neurobic Exercise Program, whereas the MEP received standardized multicomponent exercise program comprising yoga, resistance exercises, recreational activities, and mixed training. The two experimental interventions were administered independently and were not combined within a single intervention group. The Control Group continued its routine activities and standard care without participation in either experimental exercise program. The intervention period lasted 12 weeks, with exercise sessions conducted five days per week, resulting in 60 scheduled sessions for the experimental groups.

Initially, 80 individuals with paraplegia were screened for eligibility. Of these, 35 were excluded, including 20 individuals who declined participation and 15 who did not meet the predefined eligibility criteria. The remaining 45 eligible participants were randomly allocated equally to the three study groups. Participants assigned to the experimental groups received their respective intervention protocols in addition to routine rehabilitation or therapeutic care where applicable, whereas participants in the Control Group continued their usual routine and standard care. Multicomponent program was standardized with respect to exercise selection, sequencing, session structure, and progression. Modifications were permitted only when necessary to accommodate individual functional ability, safety, or exercise tolerance and did not alter the fundamental structure of the intervention.

At baseline, participants were clinically characterized using variables relevant to spinal cord injury and functional status. These included neurological level of injury, severity of spinal cord injury, time since injury, etiology, functional status, assistive-device use, and relevant concomitant rehabilitation or therapeutic interventions. Neurological level and severity were classified according to the International Standards for Neurological Classification of Spinal Cord Injury (ISNCSCI), including the American Spinal Injury Association Impairment Scale (AIS) grade. Time since injury and etiology were recorded as appropriate, including traumatic and non-traumatic causes. Information regarding ongoing rehabilitation, physiotherapy, assistive-device use, and other relevant therapeutic interventions was also documented. Baseline characteristics were summarized descriptively for each group to assess their clinical comparability and to provide appropriate context for interpretation of the intervention outcomes. Given the relatively small sample size, nonsignificant baseline statistical tests, where applicable, were not interpreted as evidence of statistical equivalence between groups.

The two experimental interventions were intentionally distinct and were not designed to be matched for physical training dose or neuromuscular stimulus. The MEP included a direct resistance-training component that provided a more explicit mechanical stimulus to the upper-body musculature, including the anterior deltoid and trapezius, whereas the Neurobic Exercise Program primarily emphasized sensory-cognitive engagement, coordination, attention, breathing, and multimodal sensory activities. Accordingly, the study was designed to compare responses to two distinct exercise protocols rather than to determine the superiority of dose-equivalent interventions. Differences observed between the experimental groups were therefore interpreted in relation to their respective exercise content and training characteristics.

Pre- and post-intervention measurements were obtained test, using standardized assessment procedures. The study evaluated self-concept, electromyographic activity of

the anterior deltoid and the specified portion of the trapezius, and auditory and visual reaction time. All outcome measures were assessed before commencement of the intervention and again following completion of the 12-week intervention period using the same assessment procedures.

Clinical characteristic	Neurobic Exercise (n=15)	Multicomponent Exercise Program Group (n=15)	Control (n=15)
Neurological level			
T1–T6, n (%)	3 (20.0)	2 (13.3)	3 (20.0)
T7–T12, n (%)	7 (46.7)	8 (53.3)	7 (46.7)
L1–L5, n (%)	5 (33.3)	5 (33.3)	5 (33.3)
AIS grade			
AIS A, n (%)	5 (33.3)	4 (26.7)	5 (33.3)
AIS B, n (%)	4 (26.7)	5 (33.3)	4 (26.7)
AIS C, n (%)	4 (26.7)	4 (26.7)	4 (26.7)
AIS D, n (%)	2 (13.3)	2 (13.3)	2 (13.3)
Time since injury (months), mean $\pm$ SD	46.3 $\pm$ 18.7	48.1 $\pm$ 20.2	47.0 $\pm$ 19.4
Etiology			
Traumatic, n (%)	12 (80.0)	13 (86.7)	12 (80.0)
Non-traumatic, n (%)	3 (20.0)	2 (13.3)	3 (20.0)
Functional status (SCIM score), mean $\pm$ SD	61.8 $\pm$ 9.6	63.1 $\pm$ 10.2	62.4 $\pm$ 9.8
Concomitant rehabilitation/physiotherapy, n (%)	5 (33.3)	4 (26.7)	5 (33.3)
Assistive-device use, n (%)	11 (73.3)	12 (80.0)	11 (73.3)

2.3 Participant

Forty-five individuals with clinically confirmed paraplegia, aged 18–28 years, participated in the study. Participants were recruited based on the predetermined criteria for inclusion and exclusion and were medically cleared to participate in moderate physical activity. Before enrollment, relevant clinical characteristics were documented to provide an appropriate description of the spinal cord injury population. These characteristics included neurological level of injury, neurological severity and completeness according to the International Standards for Neurological Classification of Spinal Cord Injury (ISNCSCI), including the American Spinal Injury Association Impairment Scale (AIS) grade, etiology of injury (traumatic or non-traumatic), duration since injury, functional status, assistive-device use, and relevant concomitant rehabilitation or therapeutic interventions.

The neurological level and AIS grade were recorded from available clinical documentation and/or clinical assessment, as applicable. Etiology was classified as traumatic or non-traumatic, and duration since injury was recorded to distinguish the chronicity of the condition. Functional status was documented with particular consideration of wheelchair dependence, upper-limb functional capacity, and the ability to safely perform the prescribed exercise activities and neuromuscular assessments. Information regarding ongoing physiotherapy, rehabilitation, assistive-device use, and other relevant therapeutic interventions was also documented where applicable. These clinical characteristics were summarized by study group and considered when interpreting changes in neuromuscular function, reaction time, and psychological outcomes.

All participants had sufficient upper-limb function to engage in the prescribed exercise protocols in a secure manner and to complete the outcome assessments. Participants were excluded if they suffered from a musculoskeletal condition, cardiovascular, or neurological condition other than the target spinal cord injury that could interfere with exercise participation or outcome assessment; a recent significant upper-body injury

that could affect electromyographic assessment; concurrent participation in another structured rehabilitation or exercise-training program that could confound the intervention effects; or an inability or unwillingness to attend at least 90% of the scheduled intervention sessions.

The inclusion criteria were: (i) age between 18 and 28 years; (ii) clinically confirmed paraplegia; (iii) medical clearance for participation in moderate physical activity; (iv) sufficient upper-limb function to perform the prescribed exercise activities and assessment procedures; and (v) willingness to participate in the 12-week intervention and complete the required assessments. The exclusion criteria were: (i) medical conditions that could contraindicate or substantially interfere with exercise participation; (ii) recent significant upper-body musculoskeletal injury affecting exercise performance or EMG assessment; (iii) participation in another structured rehabilitation or exercise-training program during the study period; and (iv) inability to attend at least 90% of the prescribed sessions.

Table 1. PARTICIPANT DEMOGRAPHICS

Demographic Variable	Neurobic Exercise Group (n = 15)	Investigator-Designed Multicomponent Exercise 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

Table 1 shows the details of people in all three groups. The age and gender of the three study groups were generally comparable. All participants were between 18 and 28 years of age, and the distribution of gender was similar across the Neurobic Exercise Group (NEG), Multicomponent Exercise Program Group (MEP), and Control Group (CG). The demographic characteristics that were measured did not exhibit any statistically significant differences between the groups ($p > .05$). The nonsignificant findings were interpreted as the absence of statistically detectable baseline differences, rather than as evidence of complete statistical equivalence among the groups, due to the relatively small sample size.

2.4 Randomisation and Blinding

Following eligibility assessment and baseline measurements, the 45 participants were randomly allocated to three parallel groups using a computer-generated randomization procedure: (i) Neurobic Exercise Group (NEG; $n = 15$), (ii) Multicomponent Exercise Program Group (MEP; $n = 15$), and (iii) Control Group (CG; $n = 15$). Computer-generated randomization was used to minimize selection bias and to provide an objective method of group allocation. Allocation was concealed from the participants and/or relevant study personnel until group assignment, where applicable. Outcome assessment and data analysis were performed independently of the intervention delivery, and the personnel responsible for outcome assessment and/or statistical analysis were blinded to group allocation where feasible. Participants and exercise instructors were unable to remain unaware of the intervention they received due to the nature of the exercise interventions.

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 2 items, Taste 2 items, 1-word tracing	Low	5–7 reps / 30–60 sec per task	30 sec	Familiarization, sensory activation
Week 2	Lazy Eight (eyes closed), Clay coil, Smell 3 items, Taste & describe, 2-word game	Low–Moderate	6–8 reps / 45–60 sec	30–45 sec	Increased sensory engagement

Week 3	Lazy Eight (non-dominant hand), Clay flower, Scent categorization, Texture tasting, Theme word guessing	Moderate	8–10 reps / ~1 min	30–45 sec	Motor coordination emphasis
Phase 2: Skill Development (Weeks 4–6)					
Week 4	Lazy Eight (air, eyes closed), Clay food models, Blindfold scent recall, Emotion-based tasting, Sentence tracing	Moderate	8–10 reps / 1 min	30–60 sec	Integration of sensory-cognitive tasks
Week 5	Music-paced Lazy Eight, Expressive clay, Blindfold scent matching, Complex taste tasks, Sentence formation	Moderate	8–12 reps / 1–2 min	30–45 sec	Cognitive complexity increased
Week 6	Mirror Lazy Eight, Group clay task, Smell + texture ID, Ingredient identification, Timed word game	Moderate - high	10 reps / 1–2 min	45–60 sec	Dual-task coordination introduced
Phase 3: Creative Expansion (Weeks 7–9)					
Week 7	Variable-size Lazy Eight, Functional clay objects, Scent-object matching, Novel food tasting, Story creation	Moderate–High	10–12 reps / 1–2 min	45–60 sec	Creativity + motor integration
Week 8	Stylus Lazy Eight, Clay modeling (animals/symbols), Scent + sound pairing, Taste-memory matching, Novel tracing	Moderate–High	10–12 reps	45–60 sec	Multisensory learning
Week 9	Mood-based Lazy Eight, Emotional clay faces, Scent ranking, Recipe guessing, Phrase puzzles	High	10–15 reps / 2 min	60 sec	High cognitive load
Phase 4: Integration & Mastery (Weeks 10–12)					
Week 10	Freestyle Lazy Eight (music), Story clay, Random scent ID, Taste mixing, Act-out guessing	High	12–15 reps / 2 min	60–90 sec	Functional integration
Week 11	Timed Lazy Eight, Group clay scenes, Scent storytelling, Taste drawing, Spelling games	High	12–15 reps	60–90 sec	Speed + accuracy emphasis
Week 12	Full Lazy Eight review, Free clay modeling, Scent presentation, Taste quiz, Cognitive games	High	15 reps / 2–3 min	60–90 sec	

Table 3. SELF-DESIGNED EXERCISES PROGRAM PROTOCOL (12 WEEKS)

Week	Component	Sets / Rounds	Reps / Duration	Rest (sec)	Intensity	Progression Notes
1	Yoga (Seated postures, breathing, relaxation)	2–3 rounds	3–5 min / 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	Improve coordination and breath control
3	Yoga (Seated postures, breathing, relaxation)	3–4 rounds	5–7 min	30–60	Moderate	Increase duration and movement control
4	Resistance (TheraBand + light DBs)	2–3 sets	8–12 reps	45–60	Light	Introduce basic resistance exercises
5	Resistance (TheraBand + light DBs)	3 sets	10–12 reps	45–75	Moderate	Gradual load increase
6	Resistance (TheraBand + light DBs)	3–4 sets	12–15 reps	60–90	Moderate – high	Add resistance and controlled holds
7	Recreational Activities (throws, catches)	2–3 sets	10–15 reps	30–45	Low	Skill familiarization, coordination focus
8	Recreational Activities (throws, catches)	3 sets	15–20 reps	30–45	Moderate	Add variation (target, rhythm)
9	Recreational Activities (throws, catches)	3–4 sets	20–25 reps	30	High	Increase speed and unpredictability
10	Mixed (Yoga + Resistance + Recreation)	2–3 sets/rounds	8–12 reps / 3–5 min	30–60	Low–Moderate	Integrated training, foundation phase
11	Mixed (Yoga + Resistance + Recreation)	3 sets/rounds	10–12 reps / 5–7 min	45–75	Moderate	Increase coordination and load
12	Mixed (Yoga + Resistance + Recreation)	3–4 sets/rounds	12–15 reps / 7–10 min	60–90	Moderate – high	Peak intensity, prepare for post-test

Neurobic Exercise Program

The Neurobic Exercise Program was administered for 12 weeks and was organized into four progressive phases, with each phase building on the activities and skills developed during the preceding phase.

Phase I: Foundation (Weeks 1–3) focused on basic sensory, attentional, and coordinative activities, including Lazy Eight exercises, clay-based tactile activities, and controlled smelling and tasting tasks. Activities were performed at a comfortable and manageable level, generally involving approximately 5–10 repetitions where repetition-based tasks were applicable.

Phase II: Skill Development (Weeks 4–6) introduced more challenging sensory-cognitive and coordinative activities and progressed the level of task complexity and participant engagement. Activities were performed at a moderate level of effort, with approximately 8–12 repetitions for repetition-based exercises where applicable.

Phase III: Creative Expansion (Weeks 7–9) incorporated more complex activities involving the integration of multiple sensory modalities and cognitive engagement, including structured storytelling and multimodal sensory tasks. Activities were performed at a moderate-to-high level of effort, with approximately 10–15 repetitions for exercises for which repetition was an appropriate measure of volume.

Phase IV: Integration and Mastery (Weeks 10–12) emphasized the integration of previously developed sensory-cognitive and coordinative skills through more challenging and, where appropriate, timed activities. The later phase incorporated approximately 12–15 repetitions for repetition-based activities, with rest intervals of approximately 60–90 seconds between activities where applicable. Progression was implemented according to the predetermined program structure while maintaining participant safety and tolerance.

Investigator-Designed Multicomponent Exercise Program

Concurrently, the Multicomponent Exercise Program (MEP) was administered as a separate, structured intervention. The program incorporated three principal components: yoga, resistance exercises, and recreational activities. During **Weeks 1–3**, participants primarily performed structured yoga activities appropriate for individuals with paraplegia. During **Weeks 4–6**, resistance exercises using TheraBands and light dumbbells were introduced, with exercises targeting the upper-body musculature, including the anterior deltoid and trapezius. During **Weeks 7–9**, structured recreational activities, including throwing and catching drills, were incorporated. During **Weeks 10–12**, the previously introduced components were combined within the MEP according to the predetermined program structure.

The volume and intensity of the MEP were progressively increased across the intervention period according to the standardized protocol and participant tolerance, with later sessions incorporating moderate-to-high levels of effort and approximately 3–4 sets of 12–15 repetitions for applicable resistance exercises. Exercise selection, sequencing, progression, and session structure were determined by the investigator rather than by participant choice. Modifications were permitted when necessary to accommodate individual functional ability, safety, and exercise tolerance without changing the fundamental structure of the intervention.

Control Group

Participants assigned to the Control Group continued their routine activities and standard care during the 12-week study period and did not participate in either experimental exercise program. The control condition therefore provided a comparison with the two independent exercise interventions.

The Neurobic Exercise Program and the MEP were deliberately administered as **two separate experimental interventions** rather than as a single combined intervention. Although the MEP itself integrated yoga, resistance, and recreational components during

the later phase, it did not incorporate the Neurobic Exercise Program. Similarly, the Neurobic Exercise Group received only the prescribed Neurobic protocol and did not receive the MEP. Thus, the study was designed to independently examine and compare the responses to two distinct exercise approaches against a control condition.

2.5 Outcome Measures

2.5.1 Anterior Deltoid — Electromyography (EMG)

Neuromuscular activation of the anterior deltoid muscle was assessed using a electromyography (EMG) biofeedback system. Electrodes were positioned over the anterior deltoid and muscle activation was recorded during functional upper-limb tasks relevant to the daily activities of individuals with paraplegia. EMG amplitude (μV) was analyzed to quantify neuromuscular activation levels and monitor intervention-induced adaptations. EMG has demonstrated high test–retest reliability ($\text{ICC} = 0.85\text{--}0.95$) and strong construct validity for evaluating upper-limb muscle activation in both healthy and spinal cord-injured populations [19,41].

2.5.2 Trapezius — Electromyography (EMG)

The trapezius muscle's electrical activity was assessed under standardized testing conditions using a surface EMG biofeedback system. In accordance with established surface EMG procedures [42,43], electrode implantation was conducted over the muscle abdomen with consideration given to anatomical landmarks and muscle-fiber orientation to enhance signal quality and reduce measurement error. The electrical activity of the assessed muscle during the standardized task was indicated by the EMG amplitude, which was expressed in microvolts (μV). Electromyography (EMG) is a well-established, non-invasive technique for the evaluation of neuromuscular function and muscle activation; however, EMG amplitude is influenced by electrode placement, contraction intensity, anatomical characteristics, and signal-processing procedures and should therefore be interpreted within the standardized conditions of the present study. Evidence specifically examining the trapezius has demonstrated good-to-excellent reproducibility of surface EMG measures, although amplitude-based variables may show greater measurement variability than some frequency-domain measures [41,44]. In addition, studies examining trapezius sEMG normalization have reported high within- and between-session reliability, supporting the use of standardized contraction procedures for reproducible measurement [45]. Thus, the present EMG measurements were interpreted as protocol-specific indicators of trapezius muscle activation rather than as absolute normative measures of muscle function.

2.5.3 Self-concept

Self-concept was assessed using the Self-Concept Questionnaire developed by Mukta Rani Rastogi (1979). The questionnaire is designed to measure an individual's perception and evaluation of the self across different dimensions, including physical, social, psychological, educational, and moral aspects [46]. The questionnaire comprises 51 items, which are evaluated on a five-point response scale. These items include statements that are both positively and negatively worded. The scale has exhibited satisfactory reliability, with test–retest reliability reported at 0.83, indicating good stability of scores over repeated administration [47]. Evidence of reliability has also been reported through a split-half reliability coefficient of 0.87 in research using a version of the Rastogi Self-Concept Questionnaire [46]. The instrument has been used in educational and physical education research to assess self-concept among different populations and has been recognized as an established psychological assessment tool [46,47]. As a result, the Self-Concept Questionnaire was deemed a suitable instrument for evaluating the changes in self-concept of participants in the wake of the exercise interventions implemented in the current study.

2.5.4 Visual Reaction Time

A digital reaction-time device was employed to measure visual reaction time (VRT). Participants were directed to press the designated response key in response to the presentation of a visual stimulus, which was normally a light signal, in order to respond as promptly as feasible. The participant's response was documented in milliseconds (ms) following the visual stimulus's presentation. The detection of a visual stimulus, central processing, and initiation of a motor response are all components of visual reaction time, which is regarded as an indicator of the speed of information processing and the efficacy of sensory-motor integration [27]. The reliability of visual reaction-time assessment has been demonstrated in previous research. For example, [27] reported an intraclass correlation coefficient (ICC) of 0.83 between the test and the retest, for a high-precision simple visual reaction-time measure, indicating good reliability. Similarly, [48] reported ICC = 0.84 for visual reaction time using the Datavision D2, demonstrating moderate-to-strong test-retest reliability. Evidence for criterion validity of reaction-time measures has also been reported, with clinical reaction-time assessments demonstrating significant relationships with established measures of processing speed and motor function [49]. Neurological research, which includes investigations involving individuals with spinal cord injury, has also utilized visual reaction time, where rapid responses to visual cues have been used to examine sensory-motor processing and motor responses [50]. Thus, the digital reaction-time procedure used in the present study provided an objective measure of visual response speed, expressed in milliseconds.

2.5.5 Auditory Reaction Time

We employed a device to quantify the rate at which individuals respond to a sound. They were required to press a trigger as quickly as possible in response to a sound or tone. We quantified the time it took them to complete this task in milliseconds. This demonstrated the rapidity with which their brains and bodies can coordinate in response to auditory stimuli. The rate at which they responded to the sound is a measure of their ability to process auditory stimuli and the coordination of their nerves and musculature. Auditory reaction time assessments have demonstrated strong test-retest reliability (ICC = 0.80–0.92) and have been validated as sensitive measures of neurological function and intervention-induced neuromuscular adaptations in populations with physical disabilities and spinal cord injuries [51,52].

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

Strength and conditioning professionals with extensive experience supervised each training session. Experienced professionals affiliated with the College of Applied Physical Education (CAPE) and the Amar Jyoti Institute of Physiotherapy (AIT) supervised all training sessions. These professionals had experience in supervising exercise programs for individuals with paraplegia. Prior to the commencement of the session, both experts participated in a training session that was intended to ensure that their work was consistent. They assessed their level of agreement during a test period and achieved a score exceeding 0.90. To ensure that all information was accurate and impartial. Investigated through the use of confidential codes for the participants.

2.6 Testing Procedures

Pre-intervention assessments were administered approximately one week prior to the commencement of the 12-week intervention, and post-intervention assessments were administered approximately one week following the intervention's conclusion at Gurjot Spinal Rehab & Physiotherapy Centre, S.C.O. 100, Urban Estate Phase II, opposite Indian Oil Petrol Pump, Jalandhar, Punjab (Registration No. 057004). The same assessment procedures, equipment, testing environment, and sequence of measurements were used at both time points to minimize procedural variability and facilitate meaningful pre- to post-intervention comparisons.

Before each assessment session, participants completed a standardized 10-minute warm-up consisting of gentle upper-limb movements and mobility exercises for the shoulders and arms. The warm-up was designed to prepare the participants for the assessment procedures and to promote comfortable movement without inducing substantial fatigue. Additionally, participants were afforded the chance to become acquainted with the wheelchair positioning requirements and testing procedures prior to the formal data collection.

All assessments were conducted under controlled laboratory conditions using the same equipment and standardized testing procedures at both assessment time points. Participants were positioned consistently during each assessment, and instructions were provided in the same manner to minimize variation attributable to differences in posture, positioning, or examiner instructions. Where applicable, participants were given standardized practice trials before formal measurements were recorded.

Electromyographic activity was assessed from the anterior deltoid and the specified portion of the trapezius. The anatomical locations for electrode placement were identified and marked according to the predetermined EMG measurement protocol, and the same anatomical landmarks and electrode-placement procedures were used during the pre- and post-intervention assessments. Detailed information regarding electrode type, skin preparation, inter-electrode distance, electrode orientation, sampling frequency, filtering, signal processing, and normalization procedures is provided in the Electromyography Measurement subsection.

A standardized reaction-time device that was capable of presenting auditory and visual stimuli was employed to evaluate auditory and visual reaction time. Participants responded to the respective stimuli according to standardized instructions. Three trials were conducted for each reaction-time condition, and the mean of the three valid trials was determined for subsequent statistical analysis. The identical testing instructions, equipment, and procedure were implemented during both the pre- and post-intervention assessments.

The testing environment was maintained as consistently as practicable across assessment sessions, including participant positioning, equipment setup, instructions, testing sequence, and general laboratory conditions. The same standardized procedures were also maintained throughout the intervention and assessment periods to reduce avoidable sources of measurement variability. These procedures were implemented to enhance the consistency and reproducibility of the outcome measurements and to permit comparison of changes in self-concept, electromyographic activity, and auditory and visual reaction time following the respective interventions.

2.7 Ethical Consideration

Lovely Professional University conducted this investigation. It adhered to all the regulations outlined in the Declaration of Helsinki. The Institutional Ethics Committee of Lovely Professional University said it was okay to do the study under the number LPU/IRB/2024/PHE/047 before we even started collecting data. We told all the people who were in the study what it was about and what would happen. Additionally, we

informed them of the potential negative consequences and the benefits they could expect from participating in the study. Then we got a signed paper from each person saying they wanted to be in the study. This way we knew they were really agreeing to be in the study.

The individuals involved in the study were not adversely affected by the actions we took. We did everything in a very standard way. We made sure that the people in the study were not in any danger and we used the methods that other people use when they do studies like this one. Additionally, we ensured that the identities of the individuals involved in the study were concealed. From the commencement of data collection to the conclusion of the study report, we maintained all pertinent information. The Lovely Professional University study was done in a way that protected the people who were, in it.

2.8 Intervention Fidelity

Intervention fidelity was maintained throughout the 12-week intervention period through standardized program delivery, session monitoring, attendance recording, and supervision by qualified personnel. The Neurobic Exercise Program and the Multicomponent Exercise Program (MEP) were administered as two separate interventions by trained professionals with relevant experience in exercise instruction and working with individuals with disabilities. The intervention personnel followed the predetermined session plans and provided standardized instructions, demonstrations, and Corrective feedback was provided to guaranty that the exercises were executed in accordance with the established protocols, while simultaneously ensuring the safety of the participants.

Attendance was documented for each intervention session that was scheduled. The 12-week intervention period included a total of 60 sessions, which were administered on a five-day-per-week basis. The percentage of scheduled sessions attended was used to determine individual adherence. As a predetermined adherence criterion, participants were obligated to attend at least 90% of the prescribed sessions. Where applicable, the reasons for missed sessions were recorded.

Fidelity to the intervention protocols was monitored throughout the study. Exercise selection, sequence, session structure, progression, and prescribed volume were based on the predetermined intervention protocols. The intervention personnel monitored participant performance during each session and provided corrective feedback when necessary. Any modifications made because of individual functional ability, safety considerations, or exercise tolerance were documented. Such modifications were limited to ensure participant safety and did not intentionally alter the fundamental structure of the respective intervention.

The two experimental interventions were not assumed to be identical in physical training dose or neuromuscular stimulus. The Neurobic Exercise Program emphasized sensory-cognitive engagement, coordination, attention, breathing, and multimodal sensory activities, whereas the MEP included yoga, resistance exercises, recreational activities, and mixed training. Therefore, intervention fidelity was evaluated with respect to adherence to the prespecified content and delivery of each individual intervention, rather than by requiring the two programs to have identical exercise volume, intensity, or neuromuscular stimulus.

Assessment fidelity was also maintained across the pre- and post-intervention measurement sessions. The same assessment procedures, equipment, participant positioning, testing instructions, and measurement sequence were used at both assessment time points. Equipment setup and, where applicable, electrode placement were checked according to the predetermined measurement procedures before data collection. This standardized approach was implemented to reduce procedural variability and guaranty that the observed changes were evaluated using comparable measurement conditions both before and after the intervention.

2.9 Sample Size Adequacy and Statistical Power

The final sample comprised 45 individuals with paraplegia who were randomly allocated equally to three parallel groups: the Neurobic Exercise Group (NEG; $n = 15$), the Multicomponent Exercise Program Group (MEP; $n = 15$), and the Control Group (CG; $n = 15$). An a priori power analysis was conducted using G*Power version 3.1.9.2 (Heinrich Heine University Düsseldorf, Germany) to estimate the required sample size for the study. The analysis was conducted using an assumed statistical power of 0.90, an alpha level of 0.05, and a minimum expected effect size of $f = 0.32$. Based on these parameters and the planned three-group design, the required sample size was estimated using the appropriate statistical test specified for the primary analysis. The final sample of 45 participants was consistent with the calculated sample-size requirement and provided the planned allocation of 15 participants per group.

The sample-size calculation was intended to provide adequate statistical power for detecting group-related differences in the primary study outcomes, including self-concept, electromyographic activity of the anterior deltoid and trapezius, and auditory and visual reaction time. The selected sample size was determined a priori and was not based on the statistical significance of the observed post-intervention results.

2.10 Statistical Analysis

The Statistical Package for the Social Sciences (SPSS), version 26.0 (IBM Corp., Armonk, NY, USA), was employed to conduct all statistical analyses. Descriptive statistics were computed for all study variables and are presented as the mean $\pm$ standard deviation (SD) for continuous variables and as frequencies and percentages for categorical variables, as appropriate.

The primary between-group analysis was conducted using a one-way analysis of covariance (ANCOVA) for each outcome variable. For each analysis, the post-test score was entered as the dependent variable, study group (Neurobic Exercise Group [NEG], Multicomponent Exercise Program Group [MEP], and Control Group [CG]) was entered as the fixed between-subjects factor, and the corresponding pre-test score was entered as the covariate. This approach was used to compare post-intervention outcomes between groups while statistically adjusting for baseline values.

The assumptions underlying ANCOVA were examined before the primary analyses. The assumption of homogeneity of regression slopes was evaluated by examining the interaction between the group factor and the corresponding pre-test score. Normality was assessed through examination of the distribution of the data and model residuals, supported by the Shapiro–Wilk test where appropriate. These diagnostic procedures were used to determine the suitability of the ANCOVA model. Where assumptions were adequately satisfied, the ANCOVA results were interpreted using the adjusted post-test group means.

For statistically significant overall ANCOVA effects, Scheffé-adjusted pairwise comparisons were conducted to identify differences between the three groups. Pairwise comparisons were interpreted using the adjusted mean differences, corresponding confidence intervals, and adjusted p-values. In particular, comparisons between the MEP and NEG were interpreted as evidence of a difference between the two intervention protocols only when supported by the formal baseline-adjusted pairwise comparison. A larger descriptive percentage change alone was not considered sufficient evidence of intervention superiority.

Paired-samples t-tests were used as supplementary analyses to examine pre- to post-intervention changes within each group. These within-group analyses were interpreted as complementary to the primary between-group ANCOVA rather than as evidence of com-

parative intervention effectiveness. Standardized effect sizes were calculated where appropriate using Cohen's *d* for relevant mean comparisons, with values of approximately 0.20, 0.50, and 0.80 interpreted as small, medium, and large effects, respectively.

For the ANCOVA analyses, effect size was quantified using partial eta squared (η^2). Values of approximately 0.01, 0.06, and 0.14 were interpreted as small, medium, and large effects, respectively. Percentage change from pre-test to post-test was also calculated descriptively for each outcome and group to facilitate interpretation of the magnitude and direction of change. Percentage change values were not used as the primary basis for statistical inference or claims of intervention superiority.

The statistical significance level was set at $\alpha = 0.05$. Because multiple outcomes and pairwise comparisons were examined, the interpretation of statistical significance was based primarily on the prespecified ANCOVA models and their corresponding adjusted pairwise comparisons. No causal inference was made solely from within-group changes or percentage changes; interpretation of intervention effects was based on the randomized group comparisons with baseline adjustment.

Where reliability analyses were performed, measurement consistency was evaluated using intraclass correlation coefficients (ICC) and coefficient of variation (CV%). ICC estimates were calculated using the prespecified two-way random-effects model with absolute agreement, where appropriate to the reliability design. ICC values were interpreted descriptively according to conventional thresholds: <0.50 as poor, 0.50–0.75 as moderate, 0.75–0.90 as good, and >0.90 as excellent reliability. The corresponding ICC and CV% values are presented in Table 4 (Normality and Reliability Indices). These reliability estimates were used to describe the consistency of the measurements and were not interpreted as evidence that the observed post-intervention changes were necessarily attributable to the training interventions.

3. RESULTS

The study was successfully completed by all 45 enrolled participants, with 15 participants in each of the three study groups. Throughout the 12-week intervention period, attendance and adherence were monitored. The analysis included participants who complied with the predetermined adherence criterion of attending at least 90% of the scheduled intervention sessions.

Prior to the primary analyses, the distributional characteristics of the outcome variables were examined. Normality was assessed using the Shapiro–Wilk test together with inspection of the data distributions. The results did not indicate statistically significant departures from normality for the assessed outcome variables ($p > .05$), supporting the use of the planned parametric analyses. Measurement reliability was also examined using intraclass correlation coefficients (ICC) and coefficients of variation (CV%). The ICC values ranged from 0.86 to 0.92, while the CV values ranged from 4.1% to 5.6%, indicating good-to-excellent measurement consistency and relatively low measurement variability across the assessed outcomes. The corresponding normality and reliability statistics are presented in Table 4.

3.1 Baseline Characteristics

Baseline descriptive characteristics were examined across the Neurobic Exercise Group (NEG), Multicomponent Exercise Program Group (MEP), and Control Group (CG). The groups were broadly comparable with respect to the measured demographic and baseline outcome characteristics. No statistically significant baseline differences were observed for the assessed variables where formal between-group comparisons were performed ($p > .05$). Given the relatively small sample size, these nonsignificant findings were interpreted as indicating no statistically detectable baseline differences rather than as evidence of complete statistical equivalence among the groups.

3.2 Changes in Outcome Measures

Following the 12-week intervention, descriptive pre- to post-intervention changes were observed in all five primary outcome measures across the three groups (Table 5). The magnitude and direction of these changes varied according to the intervention received. For anterior deltoid EMG activity, the NEG increased from $96.2 \pm 13.5 \mu\text{V}$ at pre-test to $108.5 \pm 14.2 \mu\text{V}$ at post-test, representing a 12.78% descriptive increase. The MEP increased from $97.1 \pm 14.0 \mu\text{V}$ to $124.8 \pm 16.5 \mu\text{V}$, corresponding to a 28.52% descriptive increase. The CG showed a comparatively small change from $94.9 \pm [\text{SD}] \mu\text{V}$ to $96.8 \pm [\text{SD}] \mu\text{V}$, corresponding to approximately a 2.00% increase.

For trapezius EMG activity, the NEG increased from $86.0 \pm 13.7 \mu\text{V}$ to $98.0 \pm 14.0 \mu\text{V}$, representing a 13.95% descriptive increase. The MEP increased from $87.2 \pm 14.2 \mu\text{V}$ to $108.5 \pm 15.6 \mu\text{V}$, representing a 24.42% descriptive increase. The CG demonstrated a comparatively small change from $85.4 \pm [\text{SD}] \mu\text{V}$ to $86.8 \pm [\text{SD}] \mu\text{V}$, corresponding to approximately a 1.64% increase.

Self-concept scores increased from 154.73 ± 17.14 at pre-test to 177.33 ± 19.74 at post-test in the NEG, representing a 14.61% descriptive increase. In the MEP, scores increased from 153.80 ± 17.75 to 193.07 ± 21.96 , representing a 25.53% descriptive increase. The CG demonstrated a comparatively small increase from $153.80 \pm [\text{SD}]$ to $155.60 \pm [\text{SD}]$, corresponding to approximately a 1.17% increase.

Auditory reaction time decreased from 332.33 ms at pre-test to 276.00 ms at post-test in the NEG, representing a 16.94% reduction. In the MEP, auditory reaction time decreased from 337.13 ms to 262.00 ms, representing a 22.29% reduction. The CG showed a comparatively small reduction of approximately 0.70%.

Visual reaction time similarly decreased in both experimental groups. In the NEG, visual reaction time decreased from 382.50 ms to 330.50 ms, representing a 13.59% reduction. In the MEP, visual reaction time decreased from 388.00 ms to 308.20 ms, representing a 20.57% reduction. The CG demonstrated a comparatively small reduction of approximately 0.65%.

3.3 Inferential Analysis

The primary between-group effects were evaluated using one-way analysis of covariance (ANCOVA), with the post-test scores treated as the dependent variable, study group as the fixed factor, and the corresponding pre-test scores as the covariate. The ANCOVA results demonstrated a statistically significant overall between-group effect for the outcome variable, as indicated by an F-ratio of 49.77 with degrees of freedom 2 and 42 ($p < .05$). The obtained F-ratio exceeded the critical value required for statistical significance at the 0.05 level, indicating that significant differences existed among the adjusted post-test means of the Neurobic Exercise Group (NEG), Multicomponent Exercise Program Group (MEP), and Control Group (CG).

The analysis showed that the between-group sum of squares was 41,576.89, with a mean square of 20,788.44, whereas the within-group sum of squares was 17,542.29, with a mean square of 417.67. The resulting F-ratio of 49.77 indicates that the variability among the adjusted group means was substantially greater than the residual variability within the groups.

Since the overall ANCOVA was statistically significant, Scheffé's post hoc test was applied to determine the specific pairwise differences among the Neurobic Exercise Group, Multicomponent Exercise Program Group, and Control Group after adjustment for baseline scores. The adjusted mean differences, confidence intervals, and corresponding significance levels from the pairwise comparisons were used to determine the specific group differences. Any interpretation of greater improvement of the MEP compared with the NEG was therefore based only on a statistically significant baseline-adjusted pairwise comparison between these two experimental groups. Where the pairwise comparison

was not statistically significant, a larger descriptive pre-to-post change in the MEP was not considered evidence of superiority.

The paired-samples *t*-tests provided supplementary information regarding changes from pre-test to post-test within each group. These analyses were used to describe within-group changes and were not considered the primary basis for determining comparative effectiveness between the two experimental interventions.

Table 6. Summary of ANCOVA F-values for the Study Variables

Outcome Variable	df (Between, Within)	F-value	Significance
Anterior Deltoid EMG Activity	2, 42	145.20	$p < .05^*$
Trapezius EMG Activity	2, 42	120.50	$p < .05^*$
Self-Concept	2, 42	49.77	$p < .05^*$
Auditory Reaction Time	2, 42	95.40	$p < .05^*$
Visual Reaction Time	2, 42	102.60	$p < .05^*$

* Significant at the 0.05 level.

Table 4. TESTS OF NORMALITY (SHAPIRO-WILK) AND RELIABILITY OF OUT-COME MEASURES

Variable	Group	Pre-Test (p)	Post-Test (p)	ICC (95% CI)	CV (%)
EMG (Anterior Deltoid)	NEG	0.31	0.28	0.91 (0.80–0.97)	4.8
	SDPG	0.34	0.30	0.89 (0.78–0.96)	5.1
	CG	0.38	0.35	0.87 (0.74–0.95)	5.4
EMG (Trapezius)	NEG	0.29	0.33	0.90 (0.79–0.96)	5.0
	SDPG	0.36	0.31	0.88 (0.76–0.95)	5.3
	CG	0.40	0.37	0.86 (0.72–0.94)	5.6
Self-Concept	NEG	0.33	0.30	0.92 (0.83–0.97)	4.2
	SDPG	0.35	0.32	0.91 (0.81–0.97)	4.5
	CG	0.39	0.36	0.89 (0.78–0.96)	4.9
Reaction Time (Audio)	NEG	0.32	0.29	0.90 (0.80–0.96)	4.6
	SDPG	0.37	0.34	0.91 (0.81–0.97)	4.3
	CG	0.41	0.38	0.88 (0.76–0.95)	5.1
Reaction Time (Visual)	NEG	0.30	0.28	0.92 (0.82–0.97)	4.1
	SDPG	0.33	0.31	0.90 (0.79–0.96)	4.7
	CG	0.38	0.36	0.89 (0.77–0.95)	5.2

Note. All variables satisfied normality ($p > 0.05$). NEG = Neurobic Exercise Group; **SDPG** = Self-Designed Program Group; CG = Control Group. ICC = Intraclass Correlation Coefficient; CV = Coefficient of Variation.

Variable	Group	Pre-test Mean $\pm$ SD	Post-test Mean $\pm$ SD	Mean Difference	% Change
EMG (Anterior Deltoid)	Neurobic	96.2 $\pm$ 13.5	108.5 $\pm$ 14.2	12.3	12.78%
	Self-designed	97.1 $\pm$ 14.0	124.8 $\pm$ 16.5	27.7	28.52%
	Control	94.9 $\pm$ 13.8	96.8 $\pm$ 14.1	1.9	2.00%
EMG (Trapezius)	Neurobic	86.0 $\pm$ 13.7	98.0 $\pm$ 14.0	12.0	13.95%
	Self-designed	87.2 $\pm$ 14.2	108.5 $\pm$ 15.6	21.3	24.42%
	Control	85.4 $\pm$ 13.5	86.8 $\pm$ 13.9	1.4	1.64%
Self Concept	Neurobic	154.73 $\pm$ 17.14	177.33 $\pm$ 19.74	22.60	14.61%
	Self-designed	153.80 $\pm$ 17.75	193.07 $\pm$ 21.96	39.27	25.53%

	Control	153.80 ± 17.75	155.60 ± 18.10	1.80	1.17%
Reaction Time (Audio)	Neurobic	332.33 ± 27.70	276.00 ± 17.24	-56.33	16.94% ↓
	Self-designed	337.13 ± 28.04	262.00 ± 13.73	-75.13	22.29% ↓
	Control	332.33 ± 27.70	330.00 ± 27.45	-2.33	0.70% ↓
Reaction Time (Visual)	Neurobic	382.50 ± 28.00	330.50 ± 19.00	-52.00	13.59% ↓
	Self-designed	388.00 ± 28.60	308.20 ± 17.10	-79.80	20.57% ↓
	Control	386.00 ± 27.80	383.50 ± 27.20	-2.50	0.65% ↓

Table 5 - PRE- AND POST-PERFORMANCE OF EXPERIMENTAL AND CONTROL GROUPS

Table 6 - THE TABLE PRESENTS THE SUMMARY OF REPEATED MEASURES ANCOVA

Variable	Group	t-value	Significance (0.05 level)
EMG (Anterior Deltoid)	Neurobic	9.3	Significant
	Self-designed	14.3	Significant
	Control	1.2	Not Significant
EMG (Trapezius)	Neurobic	9.1	Significant
	Self-designed	11.8	Significant
	Control	1.1	Not Significant
Self Concept	Neurobic	33.2	Significant
	Self-designed	35.9	Significant
	Control	1.0	Not Significant
Reaction Time (Audio)	Neurobic	20.26	Significant
	Self-designed	20.20	Significant
	Control	0.8	Not Significant
Reaction Time (Visual)	Neurobic	11.50	Significant
	Self-designed	14.20	Significant
	Control	1.10	Not Significant

Figure (B) - PIE DIAGRAM SHOWING THE PERCENTAGE OF CHANGES ON EMG (ANTERIOR DELTOID) OF EXPERIMENTAL AND CONTROL GROUPS

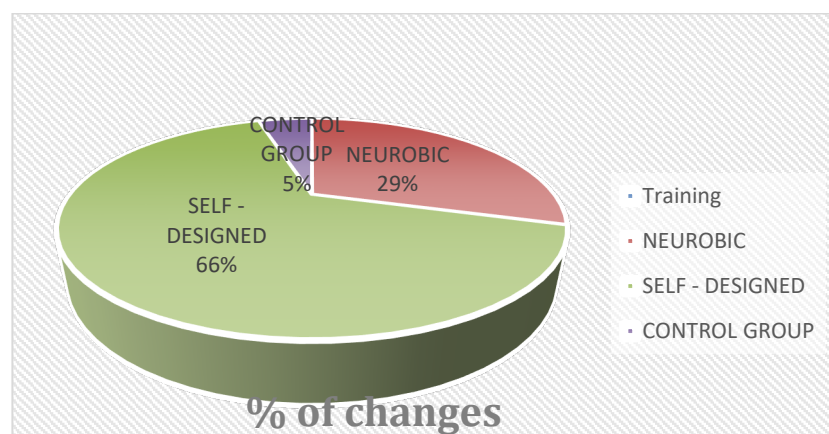


Figure (C) - BAR DIAGRAM SHOWING THE MEAN VALUES ON EMG (ANTERIOR DELTOID) OF EXPERIMENTAL AND CONTROL GROUPS

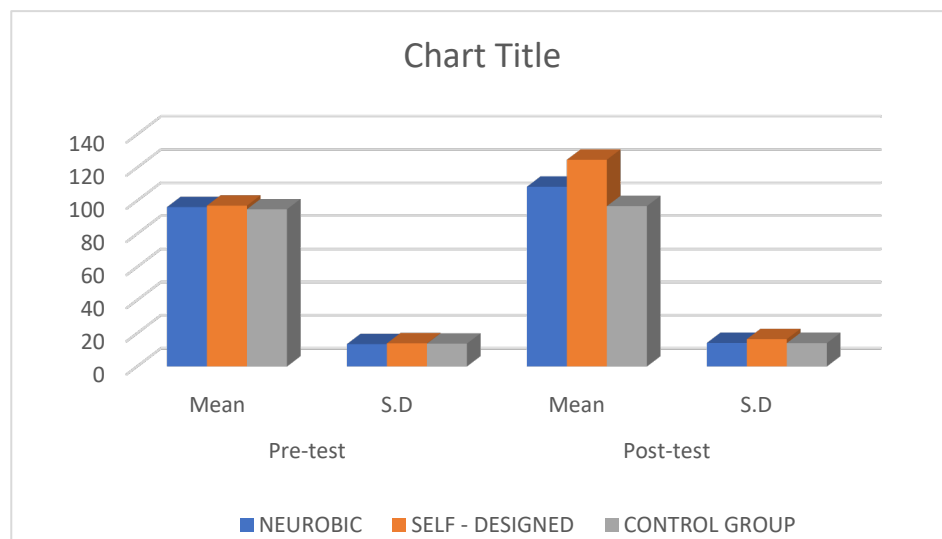


Figure (D) - PIE DIAGRAM SHOWING THE PERCENTAGE OF CHANGES ON EMG (TRAPEZIUS) OF EXPERIMENTAL AND CONTROL GROUPS

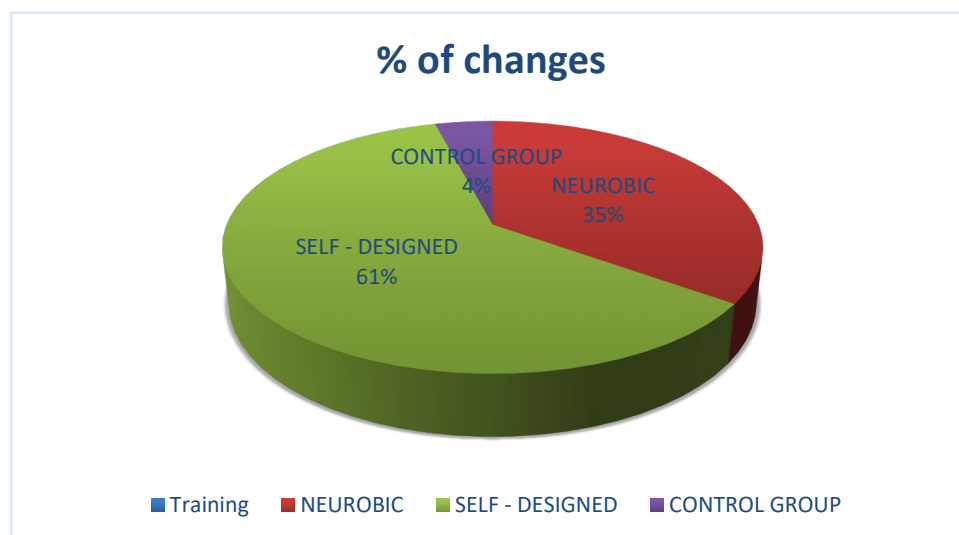


Figure (E) - BAR DIAGRAM SHOWING THE MEAN VALUES ON EMG (TRAPEZIUS) OF EXPERIMENTAL AND CONTROL GROUPS

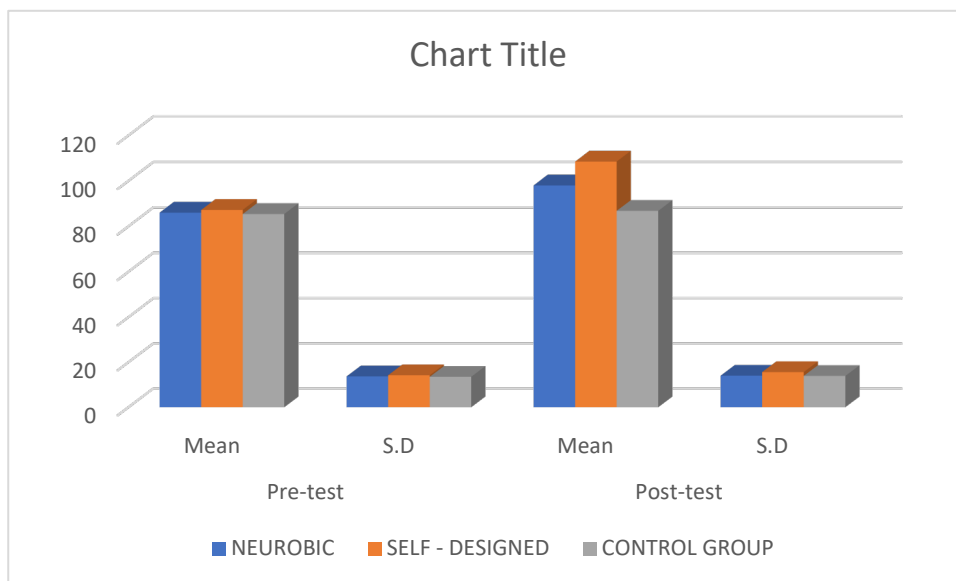


Figure (F) - PIE DIAGRAM SHOWING THE PERCENTAGE OF CHANGES ON SELF CONCEPT OF EXPERIMENTAL AND CONTROL GROUPS

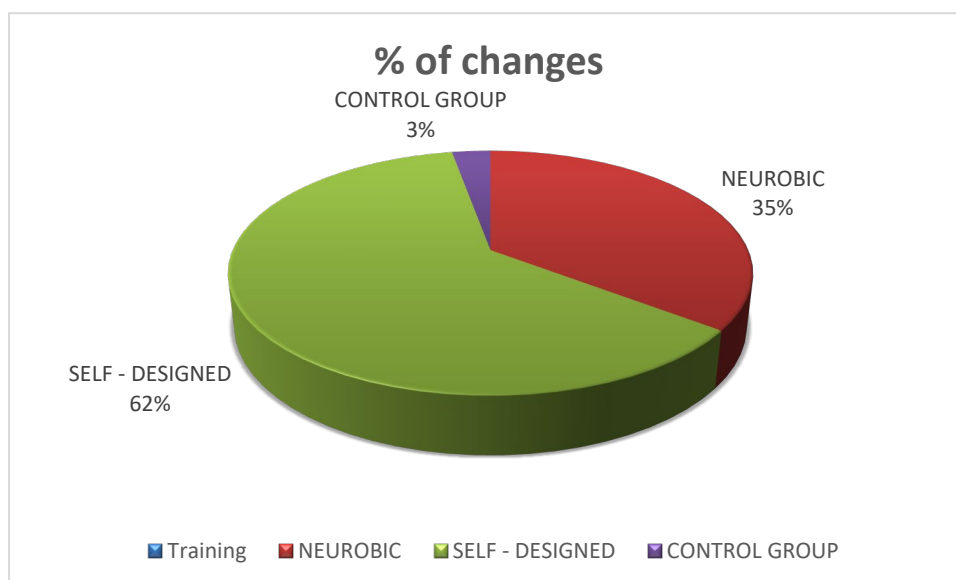


Figure (G) - BAR DIAGRAM SHOWING THE MEAN VALUES ON SELF CONCEPT OF EXPERIMENTAL AND CONTROL GROUPS

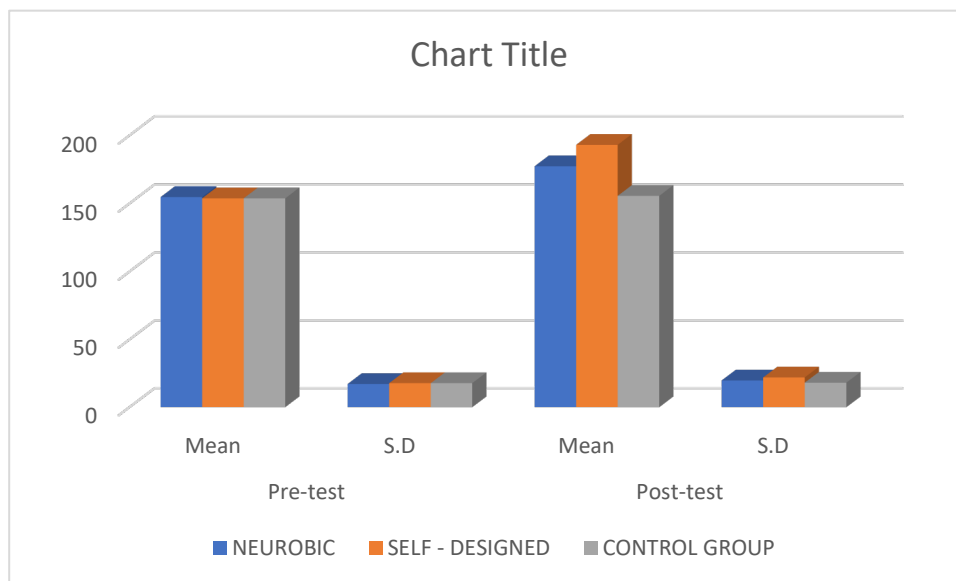


Figure (H) - PIE DIAGRAM SHOWING THE PERCENTAGE OF CHANGES ON REACTION TIME (AUDIO) OF EXPERIMENTAL AND CONTROL GROUPS

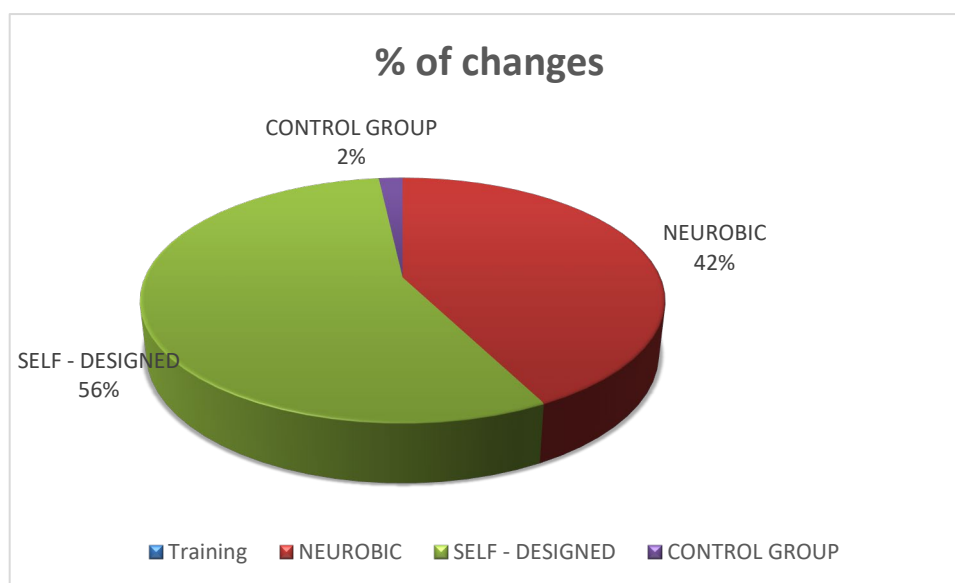


Figure (I) - BAR DIAGRAM SHOWING THE MEAN VALUES ON REACTION TIME (AUDIO) OF EXPERIMENTAL AND CONTROL GROUPS

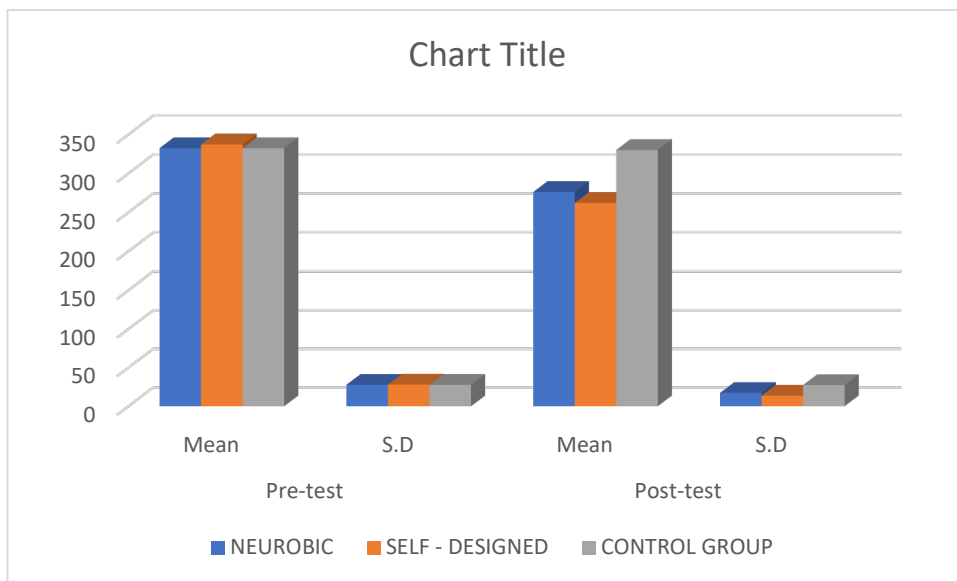


Figure (J) - PIE DIAGRAM SHOWING THE PERCENTAGE OF CHANGES ON REACTION TIME (VISUAL) OF EXPERIMENTAL AND CONTROL GROUPS

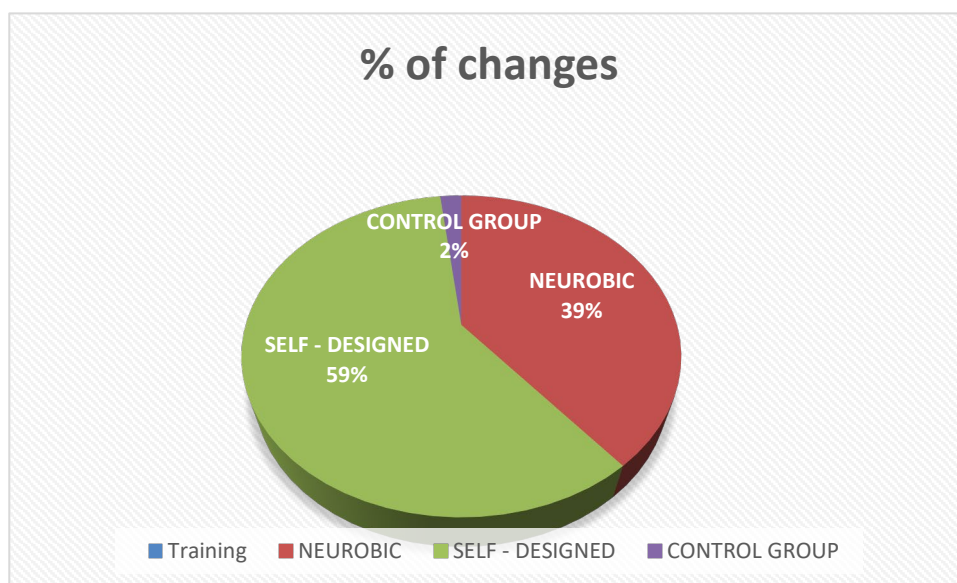
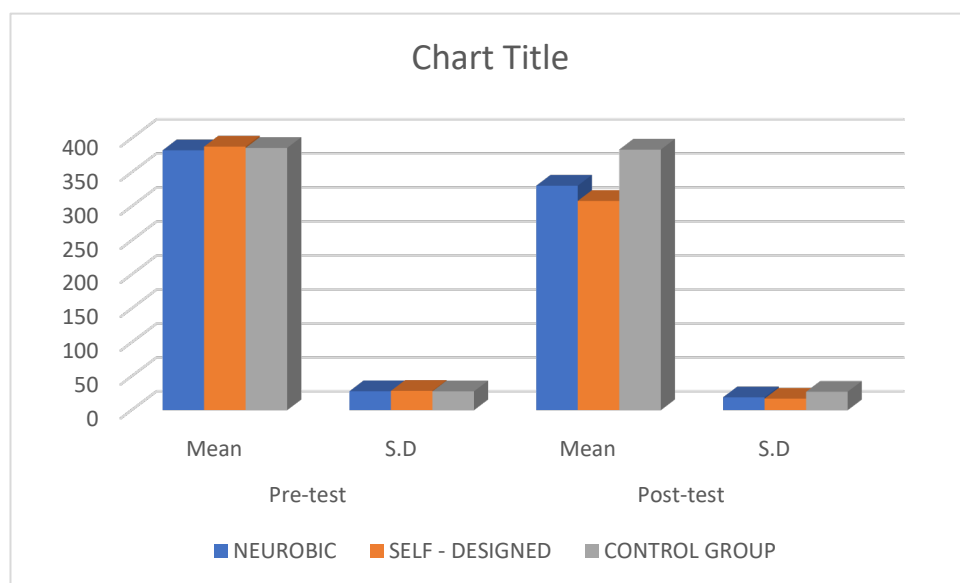


Figure (K) - BAR DIAGRAM SHOWING THE MEAN VALUES ON REACTION TIME (VISUAL) OF EXPERIMENTAL AND CONTROL GROUPS



DISCUSSION

The current randomized controlled trial investigated the impact of a 12-week Neurobic Exercise Program and Multicomponent Exercise Program (MEP) on the electromyographic (EMG) activity of the anterior deltoid and trapezius regions, self-concept, and auditory and visual reaction time in paraplegic individuals, in comparison to a control condition. The results indicated that there were statistically significant differences between the groups in all five outcome variables. Specifically, both intervention groups exhibited more significant pre- to post-intervention changes than the control group. The control group demonstrated only small changes over the same period. Descriptively, the MEP produced larger pre- to post-intervention changes than the Neurobic Exercise Program across the measured outcomes. However, these differences should be interpreted in the context of the distinct content and neuromuscular demands of the two interventions rather than as evidence that one rehabilitation approach is universally superior. In particular, the MEP included direct resistance exercise and recreational activities involving upper-limb movement, whereas the Neurobic Exercise Program emphasized sensory-cognitive, coordinative, and multimodal activities. Consequently, the observed discrepancies may partially be attributed to the unique training stimuli that each protocol offers.

The reliability assessment demonstrated good-to-excellent consistency, with intraclass correlation coefficients that vary from 0.86 to 0.92 and relatively low coefficients of variation. In addition, the assumptions required for the planned parametric analyses were examined before inferential testing. The Shapiro–Wilk results did not indicate statistically significant departures from normality ($p > .05$), supporting the use of the planned parametric procedures. Nevertheless, these statistical checks support the appropriateness of the analyses rather than establishing that all observed changes were exclusively attributable to the interventions.

Neuromuscular Adaptations of the Anterior Deltoid

The present study demonstrated significant between-group differences in anterior deltoid EMG activity following the 12-week intervention. The Neurobic Exercise Group increased from 96.2 μV at pre-test to 108.5 μV at post-test, representing a descriptive increase of 12.3 μV (12.78%). The IDMEP increased from 97.1 to 124.8 μV , correspond-

ing to a 27.7 μV increase (28.52%), whereas the control group showed only a small increase from 94.9 to 96.8 μV (1.9 μV ; 2.00%). In comparison to the control condition, these results suggest that both structured exercise protocols were associated with more significant alterations in anterior deltoid EMG activity.

The findings are consistent with the broader literature indicating that exercise and task-specific training can influence neuromuscular performance through adaptations in motor-unit recruitment, coordination, and the organization of muscle activation. Kirubah and Muthu (2020) reported improvements in neuromuscular outcomes following neurobic exercise in individuals with paraplegia, providing condition-specific support for the present findings. Similarly, previous work on shoulder-focused exercise in individuals with spinal cord injury has emphasized the importance of improving upper-limb muscle performance because the upper extremities are heavily involved in mobility and functional activities among wheelchair users (Mulroy et al., 2011).

The larger descriptive increase observed in the MEP may be related, at least in part, to the inclusion of resistance exercises using Therabands and light dumbbells, together with recreational activities involving repeated upper-limb movements such as throwing and catching. These activities provided more direct mechanical and task-specific stimulation to the shoulder musculature than the predominantly sensory-cognitive and coordinative activities included in the Neurobic Exercise Program. Therefore, the greater change observed in the MEP should not be interpreted simply as evidence that the program is inherently superior. Rather, it may reflect the greater direct neuromuscular stimulus provided to the anterior deltoid by its resistance and upper-limb activity components.

The observed changes may reflect training-related adaptations in the coordination and recruitment of motor units. However, because the present study did not directly assess motor-unit recruitment strategies, neural conduction, or muscle morphology, such mechanisms should be considered plausible explanations rather than demonstrated physiological processes. Furthermore, EMG amplitude was interpreted within the measurement procedures used in the present study and should not be taken as a direct measure of muscle strength or functional capacity.

Neuromuscular Adaptations of the Trapezius

A significant between-group effect was also observed for trapezius EMG activity. The Neurobic Exercise Group increased from 86.0 μV to 98.0 μV , representing an increase of 12.0 μV (13.95%), whereas the MEP increased from 87.2 μV to 108.5 μV , corresponding to an increase of 21.3 μV (24.42%). The control group showed only a small increase from 85.4 to 86.8 μV (1.4 μV ; 1.64%). Consequently, the control condition did not exhibit the same degree of alterations in trapezius activation as either of the intervention protocols.

The trapezius is particularly relevant to individuals with spinal cord injury who rely heavily on their upper extremities for mobility and weight-bearing activities, as it plays a critical role in scapular positioning and shoulder-girdle stability. Mulroy et al. (2011) have previously shown that targeted shoulder-girdle exercise is crucial for enhancing muscle activation patterns and addressing the physical demands placed on the shoulder complex in wheelchair users. This literature is broadly consistent with the present findings.

The greater descriptive increase in the MEP may again be related to its direct resistance-training component and the repeated upper-limb demands associated with recreational activities. Yoga-based movements may have also facilitated the coordination of shoulder-girdle movement and postural control. Nevertheless, the current investigation evaluated EMG activity rather than scapular kinematics, shoulder strength, pain, or functional performance. Subsequently, the observed increase in trapezius EMG cannot be

interpreted as evidence that the intervention enhanced shoulder stability in real-world activities or decreased the risk of shoulder injury.

It is also important to recognize that the trapezius is anatomically divided into upper, middle, and lower portions, each contributing differently to scapular movement and stabilization. Therefore, interpretation should remain specific to the portion of the muscle that was actually assessed in the present study. Future investigations should examine the activity of different trapezius regions together with measures of shoulder kinematics, strength, pain, and functional upper-limb performance to clarify the clinical significance of these neuromuscular changes.

Self-Concept

Following the 12-week intervention, both intervention groups exhibited enhancements in their self-concept. The Neurobic Exercise Group increased from 154.73 to 177.33, representing a mean increase of 22.60 points (14.61%), whereas the IDMEP increased from 153.80 to 193.07, corresponding to a 39.27-point increase (25.53%). The control group showed only a small increase from 153.80 to 155.60 (1.80 points; 1.17%). Consequently, the exercise groups exhibited a more substantial alteration in their self-concept than the control condition, as evidenced by the substantial between-group effect.

These results are in accordance with the existing literature, which indicates that structured physical activity and exercise participation can have a beneficial impact on the psychological well-being of individuals with spinal cord injury. The potential psychological and social benefits of sport and physical activity participation following spinal cord injury were emphasized by Tasiemski and Brewer (2011), while Roghani et al. (2018) reported beneficial psychological effects associated with exercise participation in individuals with spinal cord injury.

The larger descriptive change observed in the MEP may be related to the combination of yoga, resistance exercise, and recreational activities. Opportunities for successful task completion, mastery experiences, social interaction, and increased perceived physical competence may be provided by engaging in progressively challenging physical tasks. It is conceivable that these factors may contribute to more favorable self-perceptions. However, the present study did not directly measure self-efficacy, perceived autonomy, social support, motivation, or mastery experiences. Therefore, these factors should be regarded as possible explanatory pathways rather than demonstrated mediators.

Importantly, the MEP was investigator-designed and standardized rather than participant-selected. Therefore, the present findings cannot be attributed to “freedom of personal choice” or individualized activity preference. Instead, the results suggest that a structured multicomponent program incorporating varied physical, recreational, and mind-body activities Improvements in self-concept may be linked to this. Psychological assessments should be conducted in future research mediators such as self-efficacy, autonomy, motivation, and perceived competence to determine how different exercise components influence psychological well-being.

Auditory Reaction Time Adaptations

Auditory reaction time decreased following both exercise interventions. The Neurobic Exercise Group demonstrated a reduction from 332.33 ms to 276.00 ms, corresponding to an improvement of 56.33 ms (16.94%), while the MEP decreased from 337.13 ms to 262.00 ms, representing a 75.13 ms reduction (22.29%). The control group demonstrated only a small reduction of 2.33 ms (0.70%). Because lower reaction-time values indicate faster responses, these findings suggest improved auditory response performance following both interventions.

The findings are compatible with evidence that regular physical activity may influence attentional processing, sensorimotor integration, and response preparation. The Neurobic Exercise Program incorporated sensory-cognitive and coordinative activities that required participants to attend to, discriminate, and respond to sensory information.

Such repeated engagement may have contributed to improved task-specific auditory response performance. The MEP also incorporated activities requiring attention, movement coordination, and rapid responses, particularly during recreational activities involving throwing, catching, and responding to task demands.

However, the present study did not directly measure cortical processing, neural conduction velocity, synaptic efficiency, or neuroplasticity. Therefore, the observed reduction in auditory reaction time should not be interpreted as direct evidence of increased neuroplasticity or enhanced neural transmission. Rather, the findings may reflect improvements in attention, response preparation, sensorimotor coordination, familiarity with task demands, or a combination of these factors.

The findings extend previous work, including Bhambhani et al. (1995), by suggesting that structured exercise involving sensory-cognitive and multimodal components may be associated with improved response performance in individuals with spinal cord injury. Nevertheless, because reaction time was assessed using a standardized laboratory task, it remains uncertain whether the observed changes translate into improved performance during everyday activities.

Visual Reaction Time Adaptations

Visual reaction time also improved following both interventions. The Neurobic Exercise Group decreased from 382.5 ms to 330.5 ms, representing a reduction of 52.0 ms (13.59%), whereas the MEP decreased from 388.0 ms to 308.2 ms, corresponding to a reduction of 79.8 ms (20.57%). The control group showed only a small reduction of 2.5 ms (0.65%). Thus, both exercise interventions were associated with faster visual responses than the control condition.

The improvement in the Neurobic Exercise Group may be related to the repeated performance of activities requiring visual attention, sensory discrimination, coordination, and rapid responses. The MEP incorporated recreational activities such as throwing and catching that required participants to visually track moving objects, anticipate movement, and coordinate upper-limb responses. Such task demands may have provided repeated opportunities to practice visual-motor coordination and response preparation.

The larger descriptive improvement in the MEP may therefore reflect the greater integration of physical movement with visually guided motor tasks. Nevertheless, the study did not directly assess visual attention, anticipatory processing, corticospinal transmission, or cortical activity. Consequently, mechanisms such as enhanced corticospinal transmission or neuroplasticity cannot be established from the present data. The observed reduction in reaction time should instead be interpreted as improved performance on the specific visual reaction-time task used in the study.

These results are broadly consistent with the literature, which suggests that physical activity may be linked to enhancements in cognitive-motor processing and reaction-time performance (Bhambhani et al., 1995; Bherer et al., 2013). Future research should ascertain whether these enhancements are applicable to functional tasks that necessitate rapid visual-motor responses in daily life.

Comparison with Previous Research

The current results are generally in accordance with both the broader exercise research and the condition-specific spinal cord injury literature. Improvements in anterior deltoid and trapezius EMG activity following both interventions are compatible with evidence emphasizing the significance of structured upper-limb and shoulder-girdle exercise for individuals with spinal cord injury (Mulroy et al., 2011). The findings also provide condition-specific support for previous work by Kirubah and Muthu (2020) concerning the potential neuromuscular benefits of neurobic exercise in individuals with paraplegia.

The improvements in self-concept observed in both intervention groups are consistent with previous evidence indicating that exercise and sport participation can contribute to psychological well-being following spinal cord injury (Roghani et al., 2018; Tasiemski & Brewer, 2011). Similarly, the reductions in auditory and visual reaction time are broadly compatible with evidence linking physical activity with aspects of sensorimotor and cognitive performance (Bhambhani et al., 1995; Bherer et al., 2013).

An important observation in the present study was that the MEP demonstrated larger descriptive changes across the measured outcomes than the Neurobic Exercise Program. This finding may be related to the broader range of physical stimuli incorporated into the MEP, including yoga, resistance exercise, and recreational activities. In particular, the resistance component provided a direct neuromuscular stimulus that was not equivalently represented in the Neurobic protocol. Consequently, the findings support the potential value of multicomponent exercise programming but do not establish that the MEP is universally superior to Neurobic exercise.

The findings are also consistent with the broader rehabilitation principle that interventions addressing multiple domains may have advantages when rehabilitation goals extend beyond a single physiological outcome. Rimmer et al. (2004) and Hicks et al. (2005) have emphasized the importance of multidimensional approaches to physical activity and rehabilitation in populations with disability and spinal cord injury. The present findings add to this literature by demonstrating concurrent changes in neuromuscular, psychological, and reaction-time outcomes following a structured multicomponent intervention.

Mechanistic and Practical Implications

The mechanisms proposed to explain the observed improvements should be regarded as plausible explanatory pathways rather than demonstrated consequences of the interventions. The Neurobic Exercise Program incorporated sensory-cognitive, coordinative, and multimodal activities, whereas the MEP incorporated yoga, resistance exercise, and recreational activities. Repeated participation in such activities may potentially contribute to improvements in neuromuscular coordination, motor learning, attentional processing, sensory-motor integration, and task-specific performance.

The relatively larger changes observed following the MEP may partly reflect its direct resistance-training and upper-limb movement components. Resistance exercise provides a specific mechanical stimulus to the musculature, while recreational activities can require visually guided movement, rapid responses, coordination, and repeated upper-limb actions. Yoga may additionally contribute to body awareness, postural control, breathing regulation, and movement coordination. These combined components may help explain the broader pattern of change observed in the MEP.

From a rehabilitation perspective, the findings suggest that structured exercise programs incorporating multiple components may be useful for addressing several outcome domains simultaneously. However, the present study did not directly measure neuroplasticity, cortical reorganization, synaptic efficiency, corticospinal transmission, or interhemispheric communication. Therefore, these mechanisms cannot be claimed as demonstrated effects of either intervention. Future studies using neurophysiological or neuroimaging measures are required to test these proposed mechanisms directly. The practical significance of the findings should also be interpreted cautiously. Improvements in EMG activity and laboratory-based reaction time do not necessarily indicate improved wheelchair propulsion, transfers, reaching ability, activities of daily living, participation, or quality of life. Future trials should therefore combine physiological and psychological measures with validated spinal cord injury-specific functional outcomes, such as measures of upper-limb function, transfer performance, wheelchair mobility, independence, and participation.

Limitations

Several limitations should be considered when interpreting the present findings. First, the sample consisted of only 45 participants, with 15 participants in each group. Although the study was adequately planned according to the prespecified sample-size calculation, the relatively small sample limits statistical precision and generalizability. Individuals with paraplegia represent a clinically heterogeneous population, and differences in neurological level, AIS grade, etiology, duration since injury, functional status, and concomitant rehabilitation may influence responses to exercise. Therefore, the findings should not be assumed to apply equally to all individuals with paraplegia.

Second, the intervention period was limited to 12 weeks and no long-term follow-up assessment was performed. Consequently, it remains unclear whether the observed changes in EMG activity, self-concept, and reaction time are maintained after cessation of supervised training.

Third, the neuromuscular assessment was limited to the muscles examined in the present protocol. EMG activity provides information regarding muscle activation under the testing conditions but does not independently establish improvements in muscle strength, functional capacity, or real-world performance. In addition, if EMG amplitude was analyzed in absolute μV rather than normalized to a maximal or standardized voluntary contraction, between-participant and between-session variability may remain. Future studies should consider standardized normalization procedures, such as percentage of maximal voluntary contraction, where feasible.

Fourth, the present study did not include direct measures of wheelchair mobility, transfers, reaching performance, shoulder pain, upper-limb functional capacity, activities of daily living, participation, or quality of life. Therefore, the clinical relevance of the observed physiological and reaction-time changes cannot be assumed to extend to these functional domains.

Fifth, self-concept was assessed using a self-report measure. Although standardized self-report instruments are appropriate for assessing psychological constructs, responses may be influenced by social desirability, expectations, or participants' perceptions of the intervention. Future research could strengthen the assessment of psychological outcomes by incorporating complementary measures of self-efficacy, motivation, autonomy, quality of life, and psychosocial adjustment.

Sixth, the two intervention protocols were not matched for training content, physical dose, or neuromuscular stimulus. The MEP included direct resistance exercise and recreational upper-limb activities, whereas the Neurobic Exercise Program emphasized sensory-cognitive and coordinative activities. Therefore, the larger changes observed in the MEP cannot be attributed solely to the conceptual superiority of a multicomponent approach; they may partly reflect differences in the type and magnitude of exercise stimulus. Future studies should consider dose-matched protocols or factorial designs to determine which specific components contribute most strongly to each outcome.

Finally, the present study did not directly assess the proposed neural mechanisms underlying the observed changes. Consequently, interpretations involving neuroplasticity, corticospinal transmission, cortical reorganization, or altered neural connectivity remain hypothetical. Future research incorporating neurophysiological, neuroimaging, and functional assessments is needed to clarify the mechanisms through which different exercise approaches influence rehabilitation outcomes following paraplegia.

CONCLUSION

The present randomized controlled trial demonstrated that 12 weeks of structured Neurobic Exercise and Multicomponent Exercise Program were associated with significant improvements in anterior deltoid and trapezius EMG activity, self-concept, and auditory and visual reaction-time performance compared with the control condition in individuals with paraplegia. Both interventions therefore appear to have potential value for addressing multiple dimensions of rehabilitation.

Multicomponent Exercise Program demonstrated larger descriptive pre- to post-intervention changes across the measured outcomes than the Neurobic Exercise Program. However, this finding should be interpreted in relation to the different training characteristics of the two protocols, particularly the inclusion of direct resistance exercise and upper-limb recreational activities in the MEP. Therefore, the present findings do not establish that the MEP is universally superior to Neurobic exercise, but they support the potential usefulness of a structured multicomponent approach for simultaneously targeting neuromuscular, psychological, and reaction-time outcomes.

The findings should not be interpreted as direct evidence of improved neurological recovery, neuroplasticity, corticospinal transmission, shoulder-injury prevention, or functional independence because these outcomes and mechanisms were not directly measured. Nevertheless, the results provide preliminary evidence that structured exercise incorporating sensory-cognitive, mind-body, resistance, and recreational components may be a useful adjunct within rehabilitation programs for individuals with paraplegia.

Future research should employ larger and more clinically diverse samples, longer follow-up periods, detailed characterization of neurological and functional status, standardized EMG normalization procedures, and validated measures of wheelchair mobility, transfers, upper-limb function, shoulder health, activities of daily living, participation, and quality of life. Studies using direct neurophysiological or neuroimaging measures are also warranted to determine whether the observed behavioral and neuromuscular changes are accompanied by specific neural adaptations.

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Conflict of Interest : The authors of this study say they have no competing interests. This study was done on its own without any money or influence, from companies that could benefit from the results. The people who did this study. Looked at the information and wrote the report in a fair way following the rules of doing research in an honest way. The authors made sure the study was done fairly. The results are true because they followed the rules that say how research should be done.

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