Article

Effects of a multicomponent exercise program on upper extremity strength, range of motion, cardiovascular endurance, and adherence in adults with spinal cord injury

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Received: 10th March 2023; Accepted: 3rd September 2024; Published: 10th December 2024

Abstract: This study aimed to examine upper extremity muscle strength, range of motion, and cardiovascular endurance in individuals with spinal cord injury (SCI) with attention paid to accessibility in built structures and adapted equipment that can facilitate exercise attendance and adherence. Eighteen participants were randomly assigned to either the intervention (n = 9) or the control (n = 9) group. Intervention group participants performed the exercise program using adapted weight machines for 75 minutes per session, twice a week for 10 weeks. This study collected measures of feasibility and assessed muscle strength, range of motion, and cardiovascular endurance. The median program attendance rate was 95% (range 80-100%). A linear mixed model showed significant group by time interaction effects in the overall upper extremity muscle strength (Δpost-pre: 61.3 kg, $p < .001$) and shoulder range of motion (Δpost -pre :94.4°, $p = .020$), while insignificant effects on heart rates ($p = .192$). Ten weeks of exercise program in an accessible exercise environment is safe and feasible and could effectively improve upper extremity muscle strength and range of motion.

Keywords: adapted equipment; accessibility; wheelchair users; SCI; physical function

Introduction

Spinal cord injury (SCI) manifests in loss or impairment of motor, sensory, and autonomic functions, with more severe physical deconditioning associated with a higher level of lesion (Tweedy et al., 2017). The onset of SCI negatively impacts muscle strength, cardiorespiratory capacity, and joint range of motion, resulting in a reduction in physical activity and exercise capacity (Nash et al., 2007; Tweedy et al., 2017). Sedentary behaviour and a lack of exercise participation exacerbate secondary conditions in individuals with SCI, such as high incidence of musculoskeletal disorders and cardiovascular disease (Jörgensen et al., 2019; Rodriguez et al., 2021). Moreover, daily use of a wheelchair can result in excessive load on shoulders, which increases the possibility of shoulder and elbow injuries (Alm et al., 2008; Ballinger et al., 2000). Given that body functions and structures are inextricably linked with activity and social participation (World Health Organization, 2001), the physical dysfunction persons with SCI experience could encumber their activities of daily living and social engagement. In turn, people with SCI are at risk for both deteriorated health and attenuated social engagement, eventually impacting their overall quality of life.

Given the deleterious effects of sustaining a SCI, regular exercise participation is highly recommended to manage secondary conditions and promote health (Martin Ginis et al., 2018). Upper extremity exercise is a cornerstone for improving functional independence, physical capacity, and social participation in wheelchair users with SCI (Maher et al., 2017). Upper extremity exercise consists of three core components: aerobic, resistance, and stretching exercise training (American College of Sports Medicine, 2018). Moderate intensity aerobic training has been shown to improve cardiovascular fitness, total daily energy expenditure, and respiratory function in persons with SCI (Tweedy et al., 2017). Resistance training is also a safe and effective modality to improve muscle strength and reduce upper extremity pain in this population (Bizzarini et al., 2005; Tweedy et al., 2017). Shoulder stretching exercises are valuable for wheelchair users with SCI to ameliorate muscle imbalance, prevent joint contractures, and improve range of motion (American College of Sports Medicine, 2018).

Combining these exercise modalities in exercise programs has critical value in addressing a wide range of health outcomes. Multicomponent exercise programs have produced improvements in physical and psychological health outcomes in individuals with SCI. Previous combined aerobic and resistance exercise programs positively affected muscle strength, maximal oxygen intake, and psychological well-being (Hicks et al., 2003; Kim et al., 2019). A combined shoulder resistance and stretching exercise program was found to be useful in preserving shoulder range of motion (García-Gómez et al., 2019). Yet, few studies simultaneously investigated the effects of combined aerobic, resistance, and stretching exercise programs on their specific functional outcomes (i.e., cardiovascular fitness, muscle strength, range of motion). Given the great health potential for multicomponent exercise programs, examination of the multicomponent exercise program including aerobic, resistance, and stretching exercise modalities would provide valuable evidence for people with SCI.

Despite the beneficial effects of exercise, both internal (e.g., lack of energy, time, self-efficacy) and external barriers (e.g., accessibility, transportation, exercise facility) challenge regular exercise participation in this group (Cowan et al., 2013; Kehn & Kroll, 2009). Prominent exercise barriers perceived by people with SCI include accessibility to built structures, adapted equipment, exercise support, and maintenance of motivation (Cowan et al., 2013; Kehn & Kroll, 2009). Previous studies suggested that exercise participation is contingent upon a combination of internal and external factors, indicating that exercise programs should consider both (Cowan et al., 2013; Kehn & Kroll, 2009). Successful adaptation of exercise programs can not only improve targeted health outcomes but also boost adherence (Sánchez-Lastra et al., 2020). It is valuable to investigate the effects of a multicomponent exercise program that considers accessibility in built structures and adapted equipment on health outcomes and adherence for individuals with SCI. Thus, this study aimed to examine varying health outcomes (i.e., upper extremity muscle strength, range of motion, cardiovascular endurance) and adherence in response to the multicomponent exercise program in individuals with SCI.

Materials and Methods

Participants

This study purposively recruited 18 participants through the Seoul SCI Association and social media platforms in South Korea. Eligibility criteria included: (1) male adults between 18 and 65 years old; (2) the onset of SCI greater than 6 months,' and (3) spinal lesion between C5 and L1. Individuals with the following conditions were excluded: (1) pressure ulcers; (2) autonomic dysreflexia; (3) serious cardiovascular disease; (4) uncontrolled hypertension or type 2 diabetes; and (5) musculoskeletal disorder. Participants were screened using the physical activity readiness questionnaire (PAR-Q), and demographic information (name, age, body mass, body height, ASIA scale, years with SCI) was recorded.

The current study obtained approval from the institutional review board of the author's university prior to data collection. All participants gave researchers written informed consent prior to study participation. This study was performed in accordance with the ethical principles set forth in the Declaration of Helsinki.

Multicomponent Exercise Program

The multicomponent exercise program was delivered with specially designed weight machines targeting wheelchair users (RX-Series, Goyang, Korea) in a universally designed building. This building featured environmental supports such as accessible parking, entrances, elevators, bathrooms, shower rooms, and ramps ensuring participants' access to the exercise program. The exercise equipment employed in this study consisted of three types of resistance and two types of aerobic training machines. The adapted machines are designed for participants to perform the exercise training without transferring their wheelchair. A body strap is attached to each adapted weight machine for ensuring postural stability. The resistance machines consist of a 2.5kg interval so that participants easily and safely progress with the exercise intensity. A picture and specific description of the RX-Series is shown in Figure 1. Each participant in the intervention group exercised under the supervision of a research assistant. The research assistants were responsible for giving exercise feedback, ensuring safety, and building favorable rapport for participant attendance and adherence to the program. The research assistants also recorded the types of exercise, repetitions, weight, heart rates, and ratings of perceived exertion (RPE) per set in a daily exercise log. Before the intervention program began, the research assistants were trained on study protocols, exercise prescriptions, and symptoms of SCI. All research assistants were sport science majors (i.e., undergraduates at the author's university) and had foundational knowledge in exercise prescription and promotion.

Figure 1. Adapted equipment specially designed for wheelchair users.

Note. The five specially designed adapted weight machines for wheelchair users. There are three resistance training machines on the left side for the back, chest, and shoulder exercises and two aerobic training machines on the right side.

The multicomponent exercise program was based on the American College of Sports Medicine (ACSM) exercise prescription and the evidence-based exercise guidelines for adults with SCI (American College of Sports Medicine, 2018; Martin Ginis et al., 2018). Participants in the intervention group were provided with the exercise program for 75 minutes per session, two times a week for 10 weeks. The exercise program consisted of 5 minutes of warm-up, followed by 55-60 minutes of the exercise program and 10-15 minutes of cool-down. Each session included resistance exercises, 20 minutes of aerobic training, and passive stretching movements. The overall exercise intensity targeted participants maintaining moderate exercise intensity, which ranged from 12 to 14 on the Borg RPE scale (Borg, 1982). The specific multicomponent exercise program is described in Tables 1 and 2.

Table 1. Description of the multicomponent exercise program.

Characteristics	Components	Details	Duration
Exercise program	Warm-up	Stretching	5 min
	Exercise	(1) Resistance training (RX-Series) - 3 sets for each muscle group (2) Aerobic training (RX-Series) - 4 sets for 500m propulsion	55–60 min
	Cool-down	(3) Passive stretching	10–15 min
Exercise intensity	Resistance training	60% of 1RM, 15 reps per set	
	Aerobic training	40-60% of Target Heart Rate (THR)	1–5 weeks
		60-80% of Target Heart Rate (THR)	6–10 weeks
	Passive stretching	Pain scale ≤ 2	
	Overall intensity	Borg RPE (6-20 scale)	
Exercise frequency	2 sessions per week for 75 minutes		

Note. RPE = Ratings of perceived exertion; THR = Target heart rate; 1RM = one repetition maximum; Participants were provided with hand or body straps for grasping and postural control; Each research assistant supervised the matched participant throughout the program.

Table 2. Specific descriptions of the multicomponent exercise program.

Exercise type	**Exercise A**	**Exercise B**	**Exercise C**
Resistance training	Cable row Chest fly Front raise Dumbbell curl	Lat-pull down Chest press Shoulder press Dumbbell kickback	Cable crossover Under chest fly Lateral raise Dumbbell curl & press
Aerobic training	500m propulsion (Fly-ergometer) 500m propulsion (Shoulder-ergometer)	500m propulsion (Fly-ergometer) 500m propulsion (Shoulder-ergometer)	500m propulsion (Fly-ergometer) 500m propulsion (Shoulder-ergometer)
Passive Stretching	Scapular Stretching 1 Chest Stretching 1 Pulling overhand elbow Externally rotating shoulder	Scapular Stretching 2 Chest Stretching 2 Squeezing back muscles Internally rotating shoulder	Scapular Stretching 1 Chest Stretching 1 Pulling overhand elbow Externally rotating shoulder

Note. All resistance training was provided by adapted equipment except for dumbbell exercises; All passive stretching was performed with research assistants.

The resistance training was designed to strengthen the participants' back, chest, shoulder, and arm muscles. Each resistance training session included three sets of four major muscle groups, including pulling and pushing movements (American College of Sports Medicine, 2018). Participants performed 15 repetitions of each major muscle group exercise per set, achieving the 15 repetitions at 60% of one repetition maximum intensity (1RM) (Bochkezanian et al., 2015; Kraemer & Ratamess, 2004). The resistance training intensity was progressively and individually increased by 2.5kg once the participant successfully completed three sets of 15 repetitions. Hand straps were provided for some participants who had difficulty grasping the weight machines and equipment. Body straps or other forms of accommodation (e.g., exercising one arm at a time) were provided for some participants with postural instability to stabilize during exercise.

The passive stretching program aimed to allow participants with SCI to effectively perform stretching movements with the support of a research assistant. Each session included four types of passive stretches that aimed to activate the posterior muscles (e.g., rhomboids, trapezius), relax the anterior muscles (e.g., anterior deltoid, pectoralis minor, pectoralis major, serratus anterior, coracobrachialis), and facilitate shoulder internal and external rotation for improving shoulder range of motion. Each stretch was held for 15 seconds for three sets, and the intensity was monitored to assure pain scale levels remained under two of the 0–10 pain scale (American College of Sports Medicine, 2018).

Aerobic training (500m propulsion), completed in four bouts, was conducted using a fly-ergometer and shoulder ergometer. The aerobic exercise intensity was monitored and controlled using the Karvonen target heart rate (THR) formula based on each participant' resting heart rate recorded from the baseline assessment. Participants exercised aerobic training within the 40–60% THR in the first five weeks, followed by 60–80% THR from 6 to 10 weeks.

Measures

Adherence and Attendance Rates

Adherence and attendance rates for the multicomponent exercise program were assessed. Adherence rates denote the percentages of withdrawals and completions in both the intervention and control group participants (Smart et al., 2015). The attendance rates represent the percentages of targeted multicomponent exercise sessions completed by intervention group participants who finished the study (Smart et al., 2015).

Upper Extremity Muscle Strength

A hand-held dynamometer (Jtech Medical Industries, UT, USA) was used to measure shoulder and elbow muscle strength. The hand-held dynamometer has been found to be a valid and reliable measure for individuals with SCI in previous studies (Bohannon, 1986; Kim & Lee, 2015; Roy et al., 2009). Participants pushed back the dynamometer as hard as possible for six to seven seconds, two times, in each of the following positions: (1) shoulder extension in the prone position, (2) shoulder flexion while the shoulder is flexed to 90° in the supine position, (3) shoulder abduction and adduction while the shoulder is abducted 90° in the supine position, and (4) elbow flexion and extension with the shoulder abducted 90° and the elbow flexed to 90° in the supine position. The higher strength value from the two trials was recorded for each position and used for final data analyses.

Shoulder Range of Motion

The clinometer application (Plaincode Software Solutions, Stephanskurchen, Germany), a valid and reliable measure, was used to assess participants' shoulder range of motion (Shin et al., 2012; Werner et al., 2014). The measurement sequence was as follows: (1) shoulder flexion in the supine position placing the clinometer proximal to the humerus, (2) shoulder external rotation, then internal rotation, while the elbow is flexed to 90° in the supine position placing the clinometer proximal to the forearm, and (3) shoulder extension in the prone position placing the clinometer proximal to the humerus. The primary researcher measured the range of motion in the supine position followed by the prone position to minimize any movement. Participants were assessed twice in each position, and the higher range of motion value for each position was used for the final data analyses.

Cardiovascular Endurance

Participants performed a submaximal exercise test according to the designed protocol on the fly-ergometer (Goyang, Korea) while maintaining 35 Watts (W) and an intensity of 45–55 strokes per minute (s/m) for 12 minutes. Participants' peak heart rates were measured by a Forerunner 245 (Gramin International Inc, KS, USA) placed on a participant's wrist. This wearable device has been found to be both reliable and valid for assessing heart rates (Gillinov et al., 2017; Støve et al., 2019). Furthermore, participants' perceived exertion was assessed using the Borg RPE every two minutes as an alternative variable for those showing abnormal heart rate response due to sympathetic decentralization (van der Scheer et al., 2018). We calculated the average RPE of each participant for analysis. The submaximal exercise time was recorded after completion of the test. The researcher discontinued the exercise test if participants met one of these criteria: (1) Borg scale of 19 or 20, (2) participants could not follow the designed exercise protocol, (3) participants requested to stop, and (4) participants showed any negative signs or symptoms.

Procedures

This study employed a randomized controlled trial as a pilot study. Participants were randomly assigned to = an intervention (n = 9) or control (n = 9) group using an internet-based random number generator, following the baseline assessment by the first author (M.B). This study employed a stratified randomization technique based on level of injury, as previous studies have found that persons with SCI at or above T6 exhibit higher resting heart rates, autonomic dysregulation/dysreflexia, and limited volume of contractile protein. These factors may lead to significant differences in fitness levels compared to those below T6 (Bresnahan et al., 2019; Jacobs & Nash, 2004). This study collected baseline and follow-up assessments in the same environment where the intervention program was conducted within a 20–22C° temperature. A follow-up assessment was conducted within seven days after the completion of the intervention program. Participants in the control group were asked to maintain their daily activity patterns and routines during the intervention period. An opportunity was provided for control group participants to participate in the same multicomponent exercise program as compensation after the study period. The study procedures were summarized in the CONSORT diagram (Figure 2).

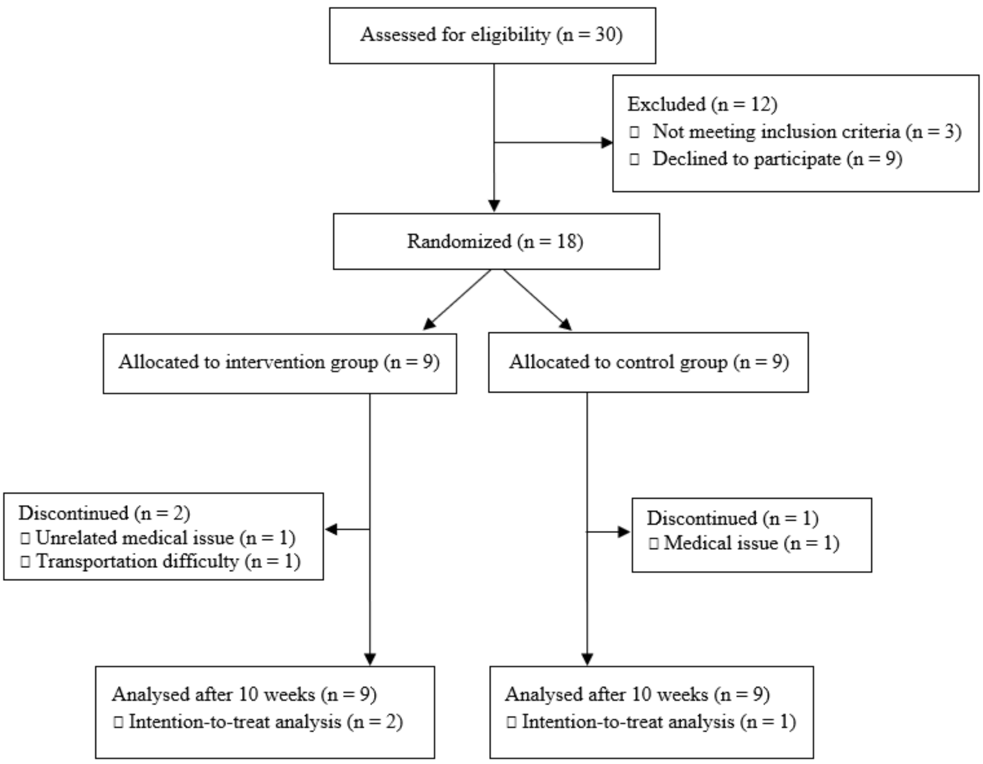

Figure 2. Consolidated standards of reporting trials flowchart diagram of study participation.

Sample Size and Statistical Analysis

For this pilot study, we aimed to recruit nine participants in each group to obtain 80% statistical power to detect intervention effects on muscle strength. G*power software program was employed to estimate a sample size at which two-sided significance level of .05, moderate effect size (Cohen's f = .25), and correlation among groups of .7 were assumed, yielding a total sample size of 18. Baseline and descriptive data between the intervention and control groups were analyzed using independent t-tests. Fisher's exact test was conducted to examine group differences in the level of injury and ASIA grade. To evaluate the effect of multicomponent exercise, an intention-to-treat linear mixed model including all randomized participants in the analysis was performed to assess within-group differences and group by time interactions in upper extremity muscle strength, range of motion, and cardiovascular endurance. Fixed effects in the model included time (e.g., pre-, and post-assessment), groups (e.g., intervention and control), and group by time interaction terms. The advantage of using the linear mixed model is that the model can retain participants with partially missing data. This study calculated effect sizes (Cohen's *d*) for between-group differences using the pooled baseline standard deviation (Morris, 2008). The effect size was interpreted as small ($d > .2$), medium ($d > .5$), and large ($d > .8$). All data analyses were conducted using STATA 17 (STATA Corp., College Station, TX, USA), and the level of significance was set at $p < .05$.

Results

The mean age of participants was 44.6 years old (*SD* = 11.5), and the mean body mass index (BMI) was 24.2 kg/m^2 (*SD* = 4.4). Twelve out of 18 participants were classified as A grade of the American Spinal Cord Injury Association (ASIA), and three participants had ASIA B, C, and D grades each. The remaining participants (n = 3) were not aware of their ASIA grade. For the spinal lesion level, five participants had a cervical injury (C6–C7), twelve participants had a thoracic injury (T3–T12), and one participant had a lumbar injury (L1). Additional characteristics of the participants are shown in Table 3.

Table 3. Demographic information of participants.

	Total (n = 18)		Intervention Group (n = 9)		Control Group (n = 9)		
	M (or n)	SD (or %)	M (or n)	SD (or %)	M (or n)	SD (or %)	*p*-value
Age (years)	44.6	11.5	43.4	11	45.7	12.5	.69
Years w/ SCI	20.1	10.8	17.8	13.2	22.3	7.9	.39
Height (cm)	172.1	6.6	172.6	6.7	171.7	7	.79
Body mass (kg)	71.6	12.7	74.9	9.7	68.3	14.4	.27
BMI (kg/m^2)	24.2	4.4	25.3	4.7	23.1	4.2	.29
Level of injury							.99
T6 or above T6	10	56%	5	56%	5	56%	
Below T6	8	44%	4	44%	4	44%	
ASIA grade							.62
A grade	12	67%	5	56%	7	78%	
Other grades	6	33%	4	44%	2	22%	

Note. Age, years with SCI, height, weight, and BMI are reported as mean and standard deviation; level of injury and ASIA grade are reported as frequency and percentage; BMI = Body Mass Index; SCI = Spinal Cord Injury; ASIA = American Spinal Cord Injury Association.

For demographic information (n = 18), 56% of participants had T6 or above T6 level of injury, and 67% ranged ASIA A grade. There were no significant differences between the intervention and control groups for age, years with SCI, height, weight, and BMI (See Table 1). Intervention and control group participants presented no statistically significant differences in muscle strength, range of motion, and cardiovascular endurance in the baseline except for right shoulder extension (p = .03).

Adherence and Attendance rates

Fifteen participants (intervention group 7, control group 8) completed the baseline and follow-up assessments. Three participants did not fully complete this study; two in the intervention group and one in the control group. Two participants in the intervention group did not complete the follow-up assessments; one withdrew due to an unrelated medical issue, and the other due to the low attendance because of transportation difficulties (seven out of 20 sessions, 35% attendance rate). One participant in the control group had a medical restriction prohibiting the follow-up assessment. The adherence rate of this study was 83% (15 out of 18 participants). The intervention group participants presented a median exercise program attendance rate of 95% (range 80%–00%, M = 92.1%, SD = 8.6). There were no adverse effects reported for intervention group participants during the multicomponent exercise program.

Upper Extremity Muscle Strength

The ten-week multicomponent exercise program significantly improved the total shoulder and elbow muscle group in the intervention group, demonstrating large effect size (Δpost-pre: 61.3 kg, p < .001, d =.9). There were significant group by time interactions between intervention and control groups in all shoulder and elbow muscle strength positions after the intervention program. The intervention group indicated significant improvements in shoulder and elbow muscle strength in all positions. In contrast, this study found that participants in the control group showed a significant decrease in right shoulder extension, right elbow flexion, and left elbow extension positions over 10 weeks. Table 4 provides pre- and post-muscle strength outcomes in both intervention and control groups.

Shoulder Range of Motion

There were significant improvements with large effect size in total shoulder range of motion in the intervention group (Δpost-pre: 94°, p = .02, d = 1.2) following ten weeks of the multicomponent exercise program. Group by time interaction for left shoulder flexion (Δpost-pre: 12.4°, p = .003, d = .5), left shoulder external rotation (Δpost-pre: 12.8°, p = .02, d = .6), and right shoulder external rotation (Δpost-pre: 16.2°, p = .001, d = .8) was significantly different for the intervention group compared to the control group. Notably, the intervention group participants showed within-group differences in all shoulder range of motion positions except for right (p = .08) and left (p = .16) shoulder internal rotations. The participants in the control group did not demonstrate significant shoulder range of motion changes except for left shoulder flexion. All pre- and post-shoulder range of motion outcomes are shown in Table 4.

Cardiovascular Endurance

There were no significant group by time interaction effects in cardiovascular outcomes except for submaximal exercise completion time revealed as medium effect size (Δpost-pre: 3.5 minutes, p = .006, d = .6) after the multicomponent exercise program. Within group analyses revealed that the intervention group participants significantly decreased their average RPE (Δpost-pre: -1.3, p = .046). Specific pre- and post- cardiovascular endurance outcomes are shown in Table 5.

Table 4. Changes in shoulder and elbow muscle strength.

Muscle Strength (kg)	Intervention Group						Control Group						p-value	ES
	Pre		Post		Δ post-pre		Pre		Post		Δ post-pre		Group *Time	d
	M	95% CI (LL, UL)	M	95% CI (LL, UL)	M	95% CI (LL, UL)	M	95% CI (LL, UL)	M	95% CI (LL, UL)	M	95% CI (LL, UL)		
SF-R	19.2	15.7, 22.7	25.0	21.4, 28.6	5.8	4.3, 7.2***	19.7	16.3, 23.3	18.5	14.9, 22.0	-1.3	-2.7, .1	<.001	1.2
SF-L	18.7	15.3, 22.2	25.1	21.5, 28.6	6.3	4.6, 8.0***	18.4	15.0, 21.9	19.3	15.8, 22.8	.9	-.7, 2.4	<.001	1.0
SE-R	14.6	13.2, 16.0	19.7	18.1, 21.3	5.1	3.1, 7.1***	17.1	15.6, 18.6	13.9	12.3, 15.5	-3.2	-5.2, -1.1**	<.001	2.6
SE-L	15.1	13.3, 16.9	19.4	17.4, 21.5	4.3	1.5, 7.1**	15.3	13.4, 17.3	14.3	12.2, 16.4	-1.0	-3.8, 1.8	.008	2.0
SAb-R	15.4	12.2, 18.7	21.8	18.5, 25.2	6.4	4.6, 8.3***	18.4	15.2, 21.6	17.7	14.4, 21.0	-.7	-2.4, 1.1	<.001	.9
SAb-L	15.9	12.9, 18.9	20.8	17.7, 23.9	4.9	2.9, 6.9***	17.0	14.1, 20.0	15.3	12.3, 18.4	-1.7	-3.6, .2	<.001	1.1
SAd-R	20.4	15.6, 25.2	27.0	22.0, 32.0	6.6	3.3, 10.0***	22.9	18.1, 27.7	20.9	16.0, 25.8	-2.0	-5.2, 1.2	<.001	.8
SAd-L	21.5	17.4, 25.6	26.4	22.1, 30.7	4.0	2.3, 7.5***	21.1	16.9, 25.2	20.9	16.7, 25.1	-.2	-2.6, 2.3	.006	.8
EF-R	23.3	18.1, 28.4	28.0	22.7, 33.3	4.7	2.2, 7.2***	27.7	22.6, 32.9	22.9	17.7, 28.1	-4.8	-7.2, -2.4**	<.001	.7
EF-L	20.6	17.0, 24.3	26.3	22.5, 30.0	5.6	3.5, 7.7***	24.0	20.4, 27.7	21.7	18.0, 25.4	-2.4	-4.3, -.4*	<.001	.8
EE-R	19.9	14.9, 24.9	23.7	18.5, 28.8	3.7	.6, 6.9*	19.6	14.6, 24.5	18.8	13.7, 23.8	-.7	-3.8, 2.2	.04	.5
EE-L	20.6	15.7, 25.4	24.5	19.5, 29.4	3.9	1.6, 6.2**	20.4	15.5, 25.2	18.0	13.1, 22.8	-2.4	-4.6, -.2*	<.001	.7
Right Shoulder	69.6	59.5, 79.7	93.2	82.8, 103.7	23.6	17.8, 29.5***	83.1	72.4, 93.9	75.2	64.2, 86.1	-7.9	-13.8, -2.1**	<.001	1.1
Left Shoulder	71.3	61.2, 81.4	91.5	81, 101.9	20.2	14.8, 25.6***	75.6	64.8, 86.3	72.1	61.2, 83.0	-3.4	-8.9, 2.0	<.001	1.1
Right Elbow	43.2	33.3, 53.1	51.6	41.5, 61.7	8.4	3.4, 13.4***	47.3	37.4, 57.2	41.6	31.6, 51.6	-5.7	-10.4, -1.0*	<.001	.5
Left Elbow	41.2	33.2, 49.2	50.6	42.4, 58.8	9.5	5.9, 13***	44.4	36.4, 52.5	39.6	31.5, 47.7	-4.9	-8.2, -1.5**	<.001	.8
Overall strength	225.3	190.9, 259.6	286.6	251.5, 321.7	61.3	45.7, 77.0***	258.1	221.7, 294.5	234.2	197.3, 271.0	-23.0	-39.6, -8.2**	<.001	.9

Note. SF: shoulder flexion, SE: shoulder extension, SAb: shoulder abduction, SAd: shoulder adduction, EF: Elbow flexion, EE: Elbow extension, R: right, L: left; *M*=mean, 95% CI: 95% confidence interval, LL: lower limit, UL: upper limit; statistical symbols (*=$p<.05$, **=$p<.01$, ***=$p<.001$); ES: effect size.

Table 5. Changes in shoulder range of motion and cardiovascular endurance.

	Intervention Group						Control Group						*p*-value	ES
	Pre		Post		Δ post-pre		Pre		Post		Δ post-pre		Group *Time	d
	M	95% CI (LL, UL)	M	95% CI (LL, UL)	M	95% CI (LL, UL)	M	95% CI (LL, UL)	M	95% CI (LL, UL)	M	95% CI (LL, UL)		
Range of Motion (˚)														
SF-R	166 .6	158.6, 174.5	175.9	167.5, 184.2	9.3	3.6, 15.0**	160.8	152.9, 168.7	166.0	157.9, 174.1	5.2	-.1, 10.5	.30	.7
SF-L	155.3	147.2, 163.5	167.8	159.4, 176.2	12.4	8.5, 16.4***	157.4	149.3, 165.6	161.6	153.4, 169.9	4.2	.5, 7.8*	.003	.5
SE-R	35.0	26.4, 43.6	44.5	35.3, 53.7	9.5	2.0, 16.9*	35.4	26.9, 44.0	39.3	30.4, 48.1	3.8	-3.2, 10.9	.28	.2
SE-L	35.6	27.3, 43.9	43.6	34.8, 52.4	8.0	1.4, 14.5*	35.2	26.9, 43.5	38.8	30.3, 47.3	3.6	-2.6, 9.8	.34	.4
SER-R	93.0	85.1, 100.9	105.8	97.0, 114.6	12.8	3.5, 22.1**	97.7	89.7, 105.6	94.7	86.4, 103.0	-3.0	-11.9, 5.9	.02	.6
SER-L	84.8	74.3, 95.3	101.0	90.0, 111.9	16.2	9.6, 22.8***	84.2	73.7, 94.7	84.9	74.2, 95.6	.7	-5.5, 6.9	.001	.8
SIR-R	55.6	45.6, 65.5	68.8	57.5, 80.0	13.2	-1.5, 27.9	55.1	45.2, 65.0	57.1	46.5, 67.6	1.9	-12.2, 16.1	.28	.7
SIR-L	60.0	48.5, 71.5	70.9	58.0, 83.8	10.9	-4.4, 26.3	54.1	42.7, 65.6	55.1	43.0, 67.2	1.0	-13.7, 15.7	.36	1.1
Right RoM	350.1	329.9, 370.3	399.5	376.6, 422.3	49.4	21.0, 77.7**	349.0	328.8, 369.2	361.3	339.9, 382.7	12.3	-14.9, 39.5	.06	1.1
Left RoM	335 .7	307.1, 364.2	382.1	352.1, 412.1	46.4	25.9, 67.0***	331.0	302.5, 359.5	341.1	311.9, 370.3	10.1	-9.2, 29.4	.01	1.1
Overall RoM	685.8	640.6, 730.9	779.7	730.6, 828.9	94.0	38.9, 139.0*	680.0	634.9, 725.1	700.2	653.2, 747.1	20.2	-22.6, 62.9	.02	1.2
Cardiovascular endurance														
HRpeak (bpm)	133.0	114.8,151.2	131.1	110.7, 151.5	-2.0	-24.9, 21.1	133.5	109.3, 157.7	105.4	78.6, 132.3	-28.0	-59.9, 3.8	.19	.8
Average RPE	15.9	14.3, 17.5	14.6	12.9, 16.2	-1.3	-2.6, -.2*	14.9	13.3, 16.6	14.0	12.4, 15	-.9	-2.2, .5	.67	.5
Completion (min)	8.3	6.0, 10.5	11.8	9.4, 14.1	3.5	1.9, 5.1***	9.8	7.3, 10.6	9.9	7.4, 12.3	.1	-1.6, 1.9	.006	.6

Note. SF: shoulder flexion, SE: shoulder extension, SER: shoulder external rotation, SIR: shoulder internal rotation, RoM: range of motion; R: right, L: left; M=mean, 95% CI: 95% confidence interval, LL: lower limit, UL: upper limit; statistical symbols (*=p<.05, **=p<.01, ***=p<.001); ES: effect size.

Discussion

The purpose of this pilot study was to examine the feasibility and effect of the multicomponent exercise program conducted in an accessible exercise environment and with adapted equipment on upper extremity muscle strength, shoulder range of motion, and cardiovascular endurance in adults with SCI. After the exercise program, participants with SCI showed high attendance rates and no adverse events, but relatively low adherence rates. The ten weeks multicomponent program significantly improved upper extremity muscle strength in all shoulder and elbow positions. The shoulder range of motion in the intervention group significantly improved after completing the multicomponent exercise program, although several shoulder positions indicated insignificant effects, including right and left shoulder internal rotation. The peak heart rates and average RPE did not change in response to the multicomponent exercise program, while submaximal exercise completion times improved.

The feasibility results in this study indicate that our 75 minutes, twice a week, ten weeks multicomponent exercise program appears to be feasible. This study showed high attendance rates of 95% and reported no adverse events in the intervention group participants who completed the exercise program. These results align with previous studies reporting that offering adapted equipment, exercise assistance, and feeling of safety could encourage exercise participations and promote participants' motivations in individuals with SCI (Gaspar et al., 2019; Kehn & Kroll, 2009). However, despite the high attendance rates and no adverse events reported, two intervention group participants withdrew from the study due to an unrelated medical issue and transportation difficulty, lowering the adherence rates to 83%. We are aware of the difficulty with access to transportation belonging to a major exercise barrier whose factor, however, could not be handled in this study (Cowan et al., 2013). Although the withdrawal reasons were not directly relevant to the multicomponent exercise program, further studies with a larger sample size should examine whether the multicomponent exercise program retains comparable adherence and attendance rates.

It is noteworthy that our multicomponent exercise program effectively increased muscle strength of shoulder flexor, extensor, abductor, adductor, and elbow flexor and extensor, suggesting overall muscle strength improvements of the upper extremity in adults with SCI. This study finding of increased upper extremity muscle strength is probably because our resistance training was designed based on the predeveloped resistance training protocols and specific exercise guidelines for SCI (American College of Sports Medicine, 2018; Martin Ginis et al., 2018). Bochkezanian and his colleagues (2015) revealed that 50–80% of 1RM with overload adaptations would be an ideal dose for resistance training in SCI populations. This evidence supported the decision of 60% of 1RM exercise intensity in our resistance training exercise protocols. Additionally, our twice per week exercise frequency was sufficient to improve upper extremity muscle strength whose results are in line with previous studies providing the same exercise frequency in this population (Hicks et al., 2003; Nash et al., 2007). Thus, our multicomponent exercise program employing adapted equipment could be an alternative modality to effectively improve muscle strength, extending other resistance training studies that used indoor hand-bike (Kim et al., 2015), elastic bands (Kim et al., 2019), and weight machines in individuals with SCI (Hicks et al., 2003; Nash et al., 2007). Furthermore, this study provided further detailed evidence over previous studies regarding comprehensive muscle strength assessment. Our resistance training increased muscle strength in varying right and left upper-extremity positions. This finding may contribute to the development of tailored resistance training targeting specific major muscle groups important for persons with SCI. We speculate that our variety of resistance training exercises using three types of adapted equipment fostered participant interest and lessened boredom with exercise, which play a critical role in adherence and attendance to exercise programs (American College of Sports Medicine, 2018).

This study found muscle strength decreased in the control group, while range of motion and cardiovascular endurance remained relatively stable over the 10 weeks. Kim et al. (2015) also showed a similar pattern of decreased muscle strength in control group participants over a 6-week period, with participants instructed to maintain their usual activities. This is clinically meaningful for health practitioners to note the importance of regular participation in resistance training to maintain upper extremity muscle strength.

Our combined resistance and stretching training seemed effective in improving the overall range of motion. Considering recent evidence indicating that resistance training showed comparable effects with stretching on range of motion (Afonso et al., 2021; Alizadeh et al., 2023), we cannot determine the superiority of our stretching training over resistance training. The significant improvements in shoulder flexion and shoulder external rotation are expected to ameliorate tightened anterior musculature (Van Straaten et al., 2017). It is noteworthy that the quantitative improvements in left shoulder flexion and external rotation bridged the differences between right and left shoulder range of motion by 28% and 50%, respectively, from the baseline disparities. We can assume that the combination of resistance and passive stretching program in the multicomponent exercise program was effective in balancing right and left shoulder range of motion in addition to the overall improvement of shoulder range of motion. The well-balanced shoulder range of motion could prevent postural changes related to muscle imbalance (García-Gómez et al., 2019). However, there were no statistically significant changes in shoulder internal rotation in the intervention group participants. There are two potential reasons for these findings. First, our passive stretching program may have been relatively insufficient to yield significant changes in shoulder internal rotation range of motion compared to the other shoulder positions. Second, given that shoulder internal rotation was already included in the normal range of motion in the baseline, achieving statistically significant improvements may have been challenging.

Despite the ten weeks of aerobic training, this study did not find significant between-group differences in peak heart rate and RPE. This may be because our aerobic training dose, 20 minutes of moderate exercise intensity, was insufficient to lead to significant improvement in aerobic capacity. Kim et al. (2019) reported that 10-20 minutes of aerobic training three times per week with a maximal heart rate from 65–70% to 80–85% did not reach statistically significant aerobic capacity improvement, whereas 30 minutes of aerobic training at 70% maximal oxygen consumption (VO_{2peak}) three times per week significantly increased aerobic capacity in persons with SCI (Bresnahan et al., 2019). Given that our aerobic training followed minimum aerobic exercise guidelines (i.e., 20 minutes of moderate exercise intensity two times per week), it is recommended that future studies progressively increase both exercise intensity and exercise duration (i.e., 30 minutes of moderate to vigorous exercise intensity three times per week) to successfully achieve cardiorespiratory and cardiometabolic benefit (American College of Sports Medicine, 2018; Martin Ginis et al., 2018). Although significant improvement in exercise completion time was found in our intervention group, we could not exclude the possibility that increased muscle strength contributed to the longer tolerance of the submaximal tests.

Given that the shoulder is an imperative weight-bearing joint for wheelchair users with SCI, improved upper extremity muscle strength and shoulder range of motion found in this study can help individuals with SCI populations to have independent daily lives (Alm et al., 2008; Ballinger et al., 2000). Previous studies reported that improvement in physical functions would result in positive outcomes in the activities of daily living and active wheelchair manipulation (e.g., wheelchair transfer, propulsion, pulling, turning, breaking) that facilitate social participation and physical activity (Alm et al., 2008; Ballinger et al., 2000; Nash et al., 2007). It is expected that strengthened muscle strength and improved range of motion would stabilize shoulder joint muscles and activate scapular movements (e.g., scapular protraction, retraction, elevation, depression) (American College of Sports Medicine, 2018; Kim et al., 2019; Van Straaten et al., 2017). Muscle strength and range of motion is likely to have a preventive effect on shoulder pain and rotator cuff impairment in individuals with SCI (Alm et al., 2008). Therefore, improved physical functioning in response to the multicomponent exercise program may contribute to social participation, functional independence, and daily activities in individuals with SCI.

The limitations of this study include the small number of participants and the fact that only male participants were recruited. Additionally, the dropout of three participants might also affect the study findings, although it was addressed using a specially designed statistical analysis (e.g., a linear mixed model) that compensates for missing data. Thus, the effects of the 10-week exercise program on SCI populations might not be generalized. Additional studies are needed, including female adults with SCI, larger sample sizes, and extended intervention doses, to extend the effectiveness of the multicomponent exercise program. Another limitation was that we only assessed muscle strength, shoulder range of motion, and cardiovascular endurance, limiting the effects of the multicomponent exercise program. Future studies should assess other physiological, functional, and psychological outcomes, such as quality of life, fatigue, activities of daily living, and psychological well-being, to expand the evidence of the multicomponent exercise program on various health-related outcomes. Nevertheless, our study supports the feasibility and health improvements of a multicomponent exercise program, which extends the current evidence of multicomponent exercise for people with SCI (García-Gómez et al., 2019; Hicks et al., 2003; Kim et al., 2019). Furthermore, our study offers evidence of the importance of implementing adaptations and increasing accessibility in exercise programs to ensure both internal and external factors are considered in this population.

Conclusions

Our study suggests that the multicomponent exercise program using adapted equipment in an accessible exercise environment is safe and feasible for individuals with SCI. The 10 weeks resistance and passive stretching training can improve upper extremity muscle strength and shoulder range of motion, while effects of aerobic training remain inconclusive. We suggest future studies design aerobic training with 90 minutes per week of moderate to vigorous aerobic exercise intensity or comparable exercise dose. Effective implementations of multicomponent exercise may prevent deterioration of muscle strength and improve upper extremity physical functions of adults with SCI in the community. Further research efforts should be necessary to strengthen the present study's findings with larger sample sizes and other health-related outcomes.

Perspectives

It is plausible that the exercise environment in our study where peers with SCI exercised together may affect adherence to our exercise program. Given that peers and exercise assistants play important roles influencing exercise participation, future research examining social influence outcomes might provide valuable evidence for long-term exercise participation in people with SCI (Orr et al., 2021; Rocchi et al., 2022). Furthermore, sustainable and accessible community-based exercise programs are crucial for people with disabilities to prevent secondary conditions and promote social interaction (van den Akker et al., 2020; Zanudin et al., 2021). As such, future studies need to address internal and external barriers tailored to targeted populations when developing community-based exercise programs.

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Author Contributions: Conceptualization, M.B, Y.L, and J.J.; Methodology, M.B, Y.L, and J.J.; Formal Analysis, M.B. J.J.; Writing-Original Draft Preparation, M.B.; Writing-Review & Editing, M.B, Y.L, and J.J.

Funding: This research received no external funding.

Availability of data and materials: The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical reasons.

Acknowledgments: We sincerely appreciate Dr. Susan Kasser who helped revise our manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

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