2024, Retos, 58, 138-146

Circuit Training Improves Physiological Conditions Among Wheelchair Basket Players
El Entrenamiento en Circuito Mejora las Condiciones Fisiológicas entre los Jugadores de Baloncesto en Silla de Ruedas

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Abstract. The utilization of a wheelchair exclusively has a profound impact on an individual's musculoskeletal, metabolic, and cardiorespiratory functions. Various programs focusing on physical activity intervention have proven to effectively enhance these physiological responses in wheelchair users. Nevertheless, there has been a limited number of studies investigating the impact of a circuit training physical activity adaptive program on improving these parameters in wheelchair basketball participants. Therefore, the primary aim of this research was to evaluate and identify alterations in cardiorespiratory fitness and musculoskeletal strength among wheelchair basketball players following a circuit training intervention. The study involved 36 male wheelchair basketball athletes with spinal cord injuries aged between 19 and 26 years. They were divided into an experimental group participating in a circuit training program [EG, n = 18], and a control group undergoing exclusively aerobic upper-body exercise training [CG, n = 18]. Anthropometric measurements and the 12-minute wheelchair propulsion distance test, which evaluates the maximal oxygen uptake (VO_2max), were conducted for all participants at the commencement and conclusion of the training period. The results demonstrated a significant interaction between Time and Group for the 12-minute wheelchair propulsion distance variable, indicating a notable improvement in the intervention group ($p < 0.001$). Conversely, no significant changes were observed in the control group. Hence, the findings suggest that incorporating circuit training exercises into the daily training regimen can have a substantial positive influence on the cardiorespiratory fitness and musculoskeletal strength of wheelchair basketball players.
Key words: physiology; exercise; sport; spinal cord injuries; cardiorespiratory fitness.

Resumen. La utilización exclusiva de una silla de ruedas tiene un profundo impacto en las funciones musculoesqueléticas, metabólicas y cardiorrespiratorias de un individuo. Varios programas centrados en la intervención de la actividad física han demostrado mejorar eficazmente estas respuestas fisiológicas en los usuarios de sillas de ruedas. Sin embargo, ha habido un número limitado de estudios que investigan el impacto de un programa adaptativo de actividad física de entrenamiento en circuito en la mejora de estos parámetros en los participantes de baloncesto en silla de ruedas. Por lo tanto, el objetivo principal de esta investigación fue evaluar e identificar alteraciones en la aptitud cardiorrespiratoria y la fuerza musculoesquelética entre jugadores de baloncesto en silla de ruedas después de una intervención de entrenamiento en circuito. En el estudio participaron 36 atletas masculinos de baloncesto en silla de ruedas con lesiones medulares de entre 19 y 26 años. Se dividieron en un grupo experimental que participaba en un programa de entrenamiento en circuito [EG, n = 18] y un grupo de control que se sometía exclusivamente a un entrenamiento aeróbico de ejercicios para la parte superior del cuerpo [CG, n = 18]. Se realizaron mediciones antropométricas y la prueba de distancia de propulsión en silla de ruedas de 12 minutos, que evalúa el consumo máximo de oxígeno (VO_2max), para todos los participantes al comienzo y al final del período de entrenamiento. Los resultados demostraron una interacción significativa entre el tiempo y el grupo para la variable distancia de propulsión en silla de ruedas de 12 minutos, lo que indica una mejora notable en el grupo de intervención ($p < 0,001$). Por el contrario, no se observaron cambios significativos en el grupo control. Por lo tanto, los hallazgos sugieren que la incorporación de ejercicios de entrenamiento en circuito en el régimen de entrenamiento diario puede tener una influencia positiva sustancial en la aptitud cardiorrespiratoria y la fuerza musculoesquelética de los jugadores de baloncesto en silla de ruedas.
Palabras clave: fisiología; ejercicio; deporte; lesiones medulares; aptitud cardiorrespiratoria.

Fecha recepción: 03-06-24. Fecha de aceptación: 18-06-24
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Introduction

Physical activity represents a crucial lifestyle behavior among individuals with physical disabilities. Specifically tailored for this demographic, consistent physical activity helps lower the risk of secondary diseases related to disability, enhances lipid profiles, and boosts functional capacity (Cataldi et al., 2019; Farì et al., 2021; Latino et al., 2021). Nevertheless, numerous individuals with physical disabilities fail to engage in regular physical activity due to diverse exercise barriers. Those with ambulation limitations, particularly individuals reliant on wheelchairs, face the highest likelihood of leading a sedentary lifestyle and having limited opportunities for participation in physical activity (Latino, Saraiello, Tafuri, 2023).

Sports tailored for individuals with disabilities encompass a broad array of activities crafted to accommodate various impairments and offer avenues for physical activity, competition, and leisure (Aidar et al., 2022; Silva et al., 2022; Latino, & Tafuri, 2023). These sports can be modified or specially developed to address different disabilities, such as spinal cord injury. Consequently, physical activity programs are customized as needed for individuals with SCI to enhance their cardiorespiratory fitness, endurance, and strength (Tsimaras, Giamouridou, Kokaridas, Sidiropoulou, & Patsiaouras, 2012).

Cardiorespiratory capacity (VO_2 max) constitutes a fundamental element of an individual's comprehensive fitness,

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as it encompasses the functionality of the cardiovascular system, respiratory system, and the capacity of blood vessels and capillaries to deliver oxygen throughout the body for energy production (De Lira et al., 2010; Rocca et al., 2016). The equilibrium of various fitness elements is crucial for sustaining postural stability against gravitational and external forces, as well as for preserving the body's center of mass aligned with the pivot plane. Tailored physical activity regimens aimed at enhancing cardiorespiratory fitness in individuals with Spinal Cord Injury (SCI) are imperative for their overall well-being (Bofosa, Miangindula, & Nkiama, 2019; Mazzeo et al., 2016). Hence, consistent engagement in physical conditioning routines enhances the physical fitness of individuals with SCI, even though their selection of exercise modalities is more constrained compared to those available to individuals without disabilities.

One of the frequently utilized training modalities among individuals with paraplegia is Wheelchair Basketball (WB). In the realm of team sports, basketball is categorized as an intermittent sport that necessitates a diverse range of physical attributes, including strength, power, endurance, balance, as well as various coordinative and technical-tactical proficiencies (Farì et al., 2023; Guerra et al., 2014; Muscogiuri et al., 2016).

WB is distinguished by the presence of high-intensity activities interspersed with extended recovery periods. Within the high-intensity phase, WB athletes engage in brief, vigorous exercise sessions involving rapid accelerations, decelerations, dynamic positional changes, and the maintenance or acquisition of a specific position on the playing field. These sports encompass both aerobic and anaerobic energy production pathways (Petrigna, Pajaujiene, & Musumeci, 2022). While the primary movements in each sport are typified by high intensity, enhanced aerobic capacity can enhance the capacity to repeat sprints and expedite recovery intervals between them, thereby contributing to the preservation of performance levels throughout a match. Furthermore, athletes with superior aerobic capacity experience prompt restoration of phosphocreatine reserves, crucial for swift movements (Conners, Elliott, Kyle, Solomon, & Whitehead, 2020).

Recent studies have indicated the beneficial impacts of moderate- to high-intensity physical activity on enhancing exercise tolerance in individuals with spinal cord injuries (Alrashidi et al., 2021). Among these training modalities, circuit training has emerged as particularly effective in yielding notable enhancements in cardiorespiratory fitness levels (Peters et al., 2021). Circuit training, a widely embraced approach in fitness regimens, wellness initiatives, and athletic training programs, is favored for its ability to elicit various physiological advantages, encompassing enhancements in strength, power, and cardiovascular-respiratory adaptations (Jacobs, Nash, & Rusinowski, 2001). WB is distinguished by the presence of high-intensity activities interspersed with extended recovery periods. Within the high-intensity phase, WB athletes engage in brief, vigorous exercise sessions involving rapid accelerations, decelerations, dynamic positional changes, and the maintenance or acquisition of a specific position on the playing field. These sports encompass both aerobic and anaerobic energy production pathways. While the primary movements in each sport are typified by high intensity, enhanced aerobic capacity can enhance the capacity to repeat sprints and expedite recovery intervals between them, thereby contributing to the preservation of performance levels throughout a match. Furthermore, athletes with superior aerobic capacity experience prompt restoration of phosphocreatine reserves, crucial for swift movements (Sol et al., 2022).

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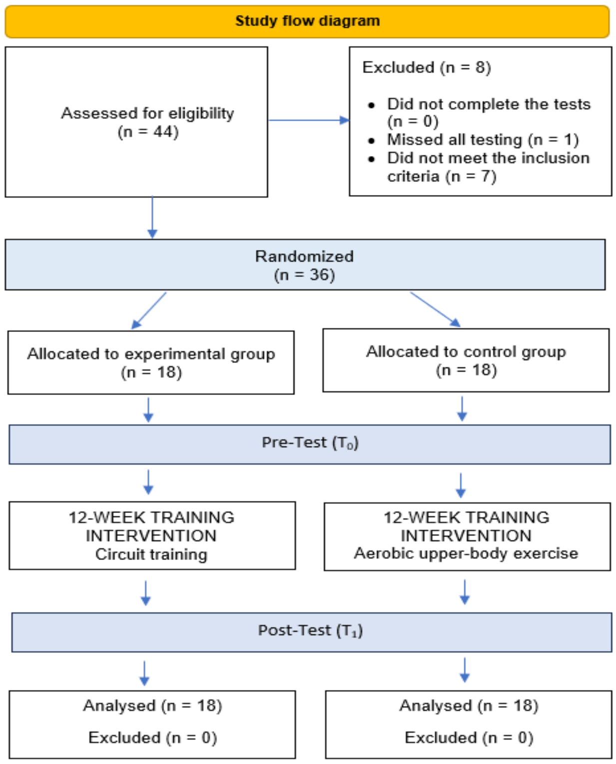

Figure 1. Study flow diagram.

Method

Study design

The investigation entailed a randomized controlled trial aimed at examining the impact of a circuit training regimen on cardiorespiratory function in wheelchair basketball athletes. Allocation of participants involved a 12-week intervention with random assignment to experimental and control cohorts. Following randomization, baseline comparability between the groups was assessed, and a double-blind approach was implemented to ensure both participants and evaluators remained unaware of group allocation. The experimental group undertook the resistance circuit training regimen, while the control group engaged in exclusively aerobic upper-body exercises. Over a period of 12 weeks, both groups adhered to their respective exercise protocols twice weekly, with evaluations conducted both pre- and post-training sessions (Fig. 1).

Participants

From February to April 2023, a cohort of individuals afflicted with paraplegia stemming from spinal cord injury willingly enlisted in the investigation. The specified inclusion criteria encompassed adults exceeding 19 years of age, proficient in maneuvering a manual wheelchair both indoors and outdoors autonomously, capable of comprehending the directives issued by the researchers, possessing an understanding of the study, and offering their consent voluntarily. Conversely, the exclusion criteria pertained to individuals afflicted with cardiovascular ailments or neurological disorders. The determination of the sample size was facilitated through the utilization of G*Power 3.1 (Heinrich-Heine-Universität Düsseldorf, Germany), wherein a priori power analysis was conducted, manifesting that a sample size of 34 would yield the requisite statistical power (α=0.05, 1-β= 0.80) to detect a moderate effect size (f= 0.25 or 0.4) at a correlation coefficient of p=0.80 with 95% power and α=0.05, employing a within-between mixed design. In anticipation of potential experimental attrition due to participant dropout, 36 subjects were recruited. The cohort of athletes was sourced from the Italian Wheelchair Basket Federation. Each participant underwent a comprehensive process of providing written informed consent prior to their involvement in the study, adhering to the principles outlined in the Helsinki Declaration and its subsequent revisions.

Measures

The data was initially acquired through the pre-testing of two key variables: (1) cardiorespiratory fitness (VO_2 max) and (2) upper-body muscle strength. This preliminary assessment aimed to ascertain the athlete's strengths and limitations at the beginning of the study. After a 12-week training program, the post-assessment of the aforementioned variables was carried out. Fitness testing serves as an effective method to monitor and evaluate an athlete's capabilities in terms of aerobic fitness and strength. In order to assess cardiorespiratory fitness, a Field test was selected due to its advantages over laboratory evaluations in terms of ease, speed, and cost-effectiveness, particularly during the competitive season.

Anthropometric measures

A conventional procedure and standardized tools were utilized to conduct the anthropometric assessments (Weiner, & Lourie, 1981). The determination of height and weight was carried out in a designated space that ensured the participants' confidentiality. Personal items such as wallets, watches, and coats were required to be removed by the subjects. Each measurement was repeated three times, with consistency ensured through verification by the same proficient researcher to mitigate the risk of inaccuracies. The individuals' weight was measured using a medical scale with a precision of 0.1 kg (Detecto 6868-C-AC-W - Bariatric Flip Seat Scale). A digital stadiometer, accurate to 0.1 cm, was employed for height measurements (Charder's HM200D, Charder Electronic Co., Taiwan) (Okosun, Bhatt, Boltri, & Ndirangu, 2008). Subsequently, the data from the height and weight assessments were utilized in the computation of the Body Mass Index (BMI) (kg/m2) (Rothman, 2008).

12-minute wheelchair propulsion distance

The 12-minute wheelchair propulsion distance, developed based on the Cooper 12-minute run-walk test (Franklin et al., 1990), was employed for assessing aerobic capacity both before and after the intervention. This test has been thoroughly validated and proven reliable, showing a significant association with $\dot{V}O_2$peak in individuals with paraplegia, although not in those with quadriplegia. Numerous research studies have illustrated that the strength of the correlation coefficient increases when $\dot{V}O_2$peak is normalized by body weight (0.84 compared to 0.54), indicating the crucial role of body mass in determining wheelchair propulsion distance. Consequently, the researchers deemed it the most suitable test considering the specific requirements of the study.

Handgrip strength test

The assessment of handgrip strength (Innes, 1999) evaluates the peak isometric force generated by the muscles of the hand and forearm. This metric holds significance across various athletic disciplines where manual dexterity is involved in activities such as grasping, throwing, and lifting. The evaluation specifically focused on the dominant hand, maintaining the arm in an extended position along the vertical axis. During the assessment, participants were situated in their wheelchairs, ensuring the arm was fully stretched without contact with the wheelchair. The standardized procedure encompassed three instances of maximal isometric contractions lasting 5 seconds each, interspersed with a minimum rest interval of 60 seconds.

Training intervention

The resistance circuit training program administered to the experimental group consisted of warm-up, main exercise, and cool-down. The primary exercise involved six full range bilateral resistance maneuvers conducted on a Younix back-to-back multi-station exercise system (Fig. 2).

The first maneuver is the overhead press, which entails shoulder abduction combined with scapular elevation and upward rotation, commencing from a position of full adduction and depression. Next is the inverted rows, involving shoulder horizontal abduction with scapular adduction, starting from the maximum forward reach position. Following that is the pec dec fly, which requires shoulder horizontal adduction while externally rotating towards the midline, from the furthest point of horizontal abduction in external rotation that can be tolerated. Then, the preacher curls exercise focuses on elbow flexion supported on an inclined pad starting from the fully extended position. Additionally, the wide grip latissimus pull-down involves shoulder adduction with scapular downward rotation and depression, beginning from the highest point of upward reaching. Lastly, the seated dips (or "Rickshaw") exercise includes shoulder flexion, scapular depression, and elbow extension while keeping the arms as close to the body as possible, starting from the maximum allowed point of shoulder joint extension, scapular elevation, and elbow flexion.

Each training session commenced with a 2-minute warm-up phase utilizing an Arm Cycle Upper Body Ergometer. Following this, participants executed a single set of 10 repetitions involving resistive maneuver 1, succeeded by 10 repetitions of resistive maneuver 2. A complete repetition was characterized by a 6-second movement sequence, encompassing roughly 3 seconds each of concentric and eccentric contraction stages. Subsequently, subjects transitioned between stations seamlessly, engaging in 2 minutes of vigorous arm ergometer propulsion with minimal resistance. Following the aforementioned, maneuvers 3 and 4 were conducted, succeeded by an additional 2 minutes of arm propulsion. Participants then proceeded to execute maneuvers 5 and 6, followed by another 2 minutes of arm propulsion. This sequence constituted a singular "circuit," with each training session comprising three such cycles executed continuously. The intervals between exercise stations were confined to the duration needed for subjects to move to the subsequent exercise station, resulting in an incomplete recovery period between exercise sets typically lasting less than 15 seconds. Resistance levels were adjusted to be equal to or greater than 50% of the one repetition maximum (RM) and were gauged for each exercise apparatus. The exercise intensity was determined based on the heart rate recorded during exercise and the rate of perceived exertion (RPE). The target heart rate was computed utilizing the Karvonen formula, with the target being established at 10%–20% of the maximum heart rate during warm-up and cool-down phases, and at a minimum of 50% of the maximum heart rate during the primary exercises. An RPE range of 11–13 was designated as the upper threshold for all exercises.

While the Control Group performed exclusively aerobic upper-body exercises. An example of exercise routine was the following: (1) Medicine ball bouncing; (2) Aeroplane arms; (3) Handcycle machine; (4) Wheelchair sprinting (Fig. 3); (5) Pec fly with resistance band; (6) Rowing.

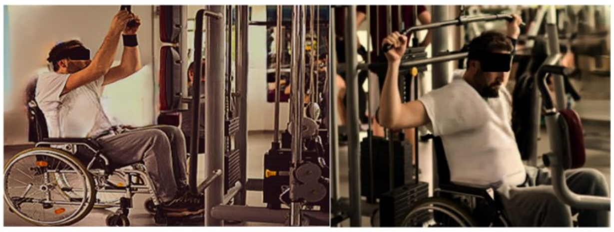

Figure 2. Example of exercise performed by EG.

Figure 3. Example of exercise performed by CG.

Statistical analysis

All statistical analyses were conducted utilizing the SPSS software (version 21.0; IBM Corp., Armonk, NY, USA), with the computation of means and standard deviations for all variables. The validation of normality assumptions was executed through the Shapiro-Wilk test, and the assessment of homogeneity of variances was carried out using the Levene test. An independent sample t-test was utilized to evaluate group variances at the baseline. The examination of all outcome measures over time was performed utilizing a one-way ANOVA for repeated measures, while paired-sample t-tests were implemented to assess within-group distinctions (pre- and post-intervention). The assessment of the significant 'Time x Group' interaction effect size was conducted employing the partial eta squared ($\eta2p$) value, where the magnitude was interpreted as small ($\eta2p < 0.06$), medium ($0.06 \leq \eta2p < 0.14$), and large ($\eta2p \geq 0.14$). Moreover, Cohen’s d was employed to ascertain effect sizes for pairwise comparisons, with categorizations of small ($0.20 \leq d < 0.50$), moderate ($0.50 \leq d < 0.79$), and large ($d \geq 0.80$). Statistical significance was defined as $p < 0.05$.

In all instances, a P-value below 0.05 was utilized as the threshold for determining statistical significance.

Results

All participants received the designated treatment conditions as allocated, and no incidents of injury were documented during the trial period. The individuals involved in the study displayed consistent characteristics in terms of age, gender, and anthropometric features. Statistical analysis indicated no significant differences in the variables of interest ($p > 0.05$) (Table 1). The outcomes of all outcome measures are presented in Table 2.

Table 1.
Characteristic of participants.

Variable	EG (n = 18) Mean ± SD	CG (n = 18) Mean ± SD
Age (y)	21.77 ± 2.64	22.05 ± 2.68
Height (cm)	165.33 ± 2.08	166.77 ± 4.53
Weight (kg)	60.05 ± 1.30	60.38 ± 1.50
Body mass index ($kg.m^{-2}$)	22.01 ± 0.26	21.65 ± 1.05
Sex, n (%)		
Male	18 (50.00)	18 (50.00)

Table 2.
Changes in cardiorespiratory fitness, musculoskeletal strength, and BMI after a 12-week circuit training program

	Experimental Group (n = 18)			Control Group (n = 18)		
	Baseline	Post-test	Δ	Baseline	Post-test	Δ
12 minutes wheelchair propulsion distance test (VO_2max)	24.61 (1.71)	37.69 (1.40)†*	13.08 (0.49)	26.63 (1.76)	25.37 (2.34)	-1.26 (1.67)
Hand Grip test	49.16 (1.24)	57.16 (2.25)†*	8.00 (1.02)	48.33 (1.28)	47.50 (2.06)	-0.83 (1.58)
BMI	22.01 (0.26)	20.89 (0.17)†*	-1.12 (0.24)	21.65 (1.05)	21.32 (1.05)	-0.32 (0.25)

Note: values are presented as mean (± SD); Δ: pre- to post-training changes; †Significant 'Group x Time' interaction: significant effect of the intervention ($p< 0.001$). *Significantly different from pre-test ($p< 0.001$); $^{\Omega}$ BMI percentile indicates the relative position of the child's BMI number among children of the same sex and age.

12 minutes wheelchair propulsion distance test

A two-factor repeated measures ANOVA found a significant 'Time x Group' interaction for the 12 minutes wheelchair propulsion distance test ($F_{1,34} = 1.217.28$, $p < 0.001$, $\eta^2_p = 0.97$, large effect size). The post-hoc analysis revealed a significant improvement in the score for this variable ($t = 111.49$, $p < 0.001$, $d = 26.27$, large effect size) in the intervention group. No significant changes were found for the control group ($p > 0.05$).

Hand grip test

A two-factor repeated measures ANOVA found a significant 'Time x Group' interaction for the Hand grip test ($F_{1,34} = 394.65$, $p < 0.001$, $\eta^2_p = 0.92$, large effect size). The post-hoc analysis revealed a significant improvement in the score for this variable ($t = 32.98$, $p < 0.001$, $d = 7.77$, large effect size) in the intervention group. No significant changes were found for the control group ($p > 0.05$).

Body Mass Index (BMI)

A two-factor repeated measures ANOVA found a significant 'Time x Group' interaction BMI ($F_{1,34} = 93.23$, $p < 0.001$, $\eta^2_p = 0.73$, large effect size). The post-hoc analysis revealed a significant improvement in the score for this variable ($t = -19.41$, $p < 0.001$, $d = -4.57$, large effect size) in the intervention group. No significant changes were found for the control group ($p > 0.05$).

Discussion

Resistance circuit training was chosen as the modality for physical exercise in this research endeavor due to its potential to elicit both aerobic and anaerobic adaptations in individuals with paraplegia. The intricate sequence of movements involved in circuit training is not only engaging but also addresses issues related to lack of interest commonly encountered during exercise programs. The brief intervals between exercises characteristic of circuit training contribute to its high efficiency in terms of time utilization. Individuals with spinal cord injury who contend with a reduction in the number of active muscles, muscle contraction strength, and cardiopulmonary endurance can benefit significantly from a circuit training regimen featuring resistance exercises, thereby enhancing their overall physical well-being.

The results of this investigation align with existing literature, indicating that circuit training has the potential to yield superior enhancements in cardiorespiratory fitness when compared to alternative resistance training modalities.

In the 6-minute propulsion test evaluating cardiopulmonary endurance, a noteworthy discrepancy was observed between both groups before and after the intervention. Prior research studies (Ferreira et al., 2017; Latino, Tafuri, 2024 a-b; Molik et al., 2017; Weber et al., 2021) have implemented resistance circuit training in individuals with paraplegia, leading to enhancements in cardiopulmonary endurance (10.4%–29.7% in peak oxygen uptake).

A total of six to eight exercise stations are utilized, with inter-station rest periods limited to 10–15 seconds. Enhanced cardiorespiratory adaptations have been documented when endurance activities like cycling or treadmill running were incorporated as individual exercise stations or modes of active recovery periods rather than actual rest intervals. In the present investigation, these recommendations were utilized to formulate a protocol involving six resistance exercises on a multi-station isoinertial exercise machine tailored for wheelchair users (Iturricastillo, Yanci, & Granados, 2018). Alternating pairs of isoinertial exercises with low-resistance, high-frequency aerobic exercises were performed to sustain an elevated heart rate above baseline. Regular heart rate monitoring during exercise sessions revealed average values ranging from 120 to 160 beats per minute throughout the circuit (Latino, Tafuri, Saraiello, & Tafuri, 2023; Seron, de Carvalho, & Greguol, 2019).

The mean elevation in VO_2peak observed in the participants exceeded the improvements in aerobic capacity documented in previous extensive endurance exercise programs. It is plausible that the rise in VO_2peak seen in individuals partaking in this regimen stemmed partly from advancements in trunk stability acquired through training. This enhanced stability in the trunk region would be advantageous for individuals necessitating better body support during wheelchair movement in competitive settings and everyday tasks. While there was a notable increase of 12–30% in isoinertial strength across all training exercises, enhancements in isokinetic strength were primarily noted in movements resembling those practiced in the training regimen. These findings imply a necessity for heightened focus on strengthening muscles involved in shoulder external rotation, as weakness and imbalance in these muscles have been linked to shoulder instability and pain that hinders physical activity in individuals with paraplegia (Snyder et al., 2022). Nilsson et al. (2006) were the pioneers in outlining a program that combined interval aerobic exercise with progressive resistance training. Participants in their study engaged in a 7-week regimen involving thrice-weekly arm exercises, consisting of three 4-minute sessions on a Monark ergometer followed by triceps muscle training while sitting and lying down. Their outcomes displayed enhancements in peak VO_2 (10.6%) and muscle strength (18.8%), results that are notably inferior to those reported in the present investigation.

With respect to musculoskeletal strength, EG exhibited noteworthy enhancements in the handgrip assessments. The outcomes demonstrated a substantial rise in muscle strength following an eight-week circuit training regimen specifically tailored for this research. This surge in strength surpassed significantly the metrics observed in the control cohort. The escalation in strength was to be anticipated, given that numerous stations in the exercise routine entailed resistance elements such as barbells and dumbbells. The findings of this investigation align closely with those of Schmidt et al. (2001), where a combination of low-intensity circuit training and high-resistance exercises over a span of 12 weeks led to a marked improvement in bench press performance, knee extension strength, and muscle endurance among female participants. Likewise, the recent research conducted by Stavrinou, Bogdanis, Giannaki, Terzis, & Hadjicharalambous, (2018) revealed that adolescent males, engaging in interval circuit training twice weekly as part of their physical education curriculum, experienced notable enhancements in muscle strength and vertical jump capability.

This notion is supported by previous researchers who conducted resistance training programs for individuals who use wheelchairs. Davis and Shephard posit that a structured regimen of circuit training involving physical activities can enhance muscle strength, thereby improving the ability to carry out daily tasks. By enhancing their residual motor functions, individuals with paraplegia can potentially prolong their lifespan in a healthy and independent manner. Duran, Lugo, Ramírez, & Lic, (2001) noted a significant increase of approximately 46% in the weight lifted during bench press exercises among spinal cord injury (SCI) patients. Through a combination of various exercises over 16 weeks and circuit training over 12 weeks using a multi-station gym system and arm ergometer, strength levels notably improved by 12 to 30% in SCI patients. Similarly, Hicks et al. (2011) employed arm ergometer and circuit training over a 9-month period with participants aged between 19 and 65 years. The diverse range of exercises, mostly of moderate intensity, resulted in strength gains ranging from 19 to 34% in different muscle groups. In a recent study focused on a 4-month circuit training program, strength enhancements varied from 38.6 to 59.7% across all maneuvers tested. However, limitations of this study include the small sample size of only 7 middle-aged men (aged 39 to 58 years) with SCI and the absence of a control group. In essence, longitudinal studies have demonstrated that individuals with SCI exhibit improved strength levels as a consequence of engaging in circuit training routines.

The research uncovered changes observed in Body Mass Index (BMI), with the experimental group displaying notable reductions following the exercise intervention. Corresponding with prior research, these BMI reductions suggest that resistance circuit training serves as an effective strategy to increase lean body mass and decrease fat mass (La Torre et al., 2023; Morsanuto et al., 2023)). This holds significant implications given the high BMI, body fat percentage, and levels of serum lipids, cholesterol, and blood glucose among wheelchair users. The predominant engagement of smaller upper limb muscles during manual wheelchair propulsion results in rapid muscle fatigue and lower energy expenditure compared to larger lower limb muscles (Katch, Katch, & McArdle, 1996). Consequently, maintaining normative levels of body fat and BMI poses a challenge for wheelchair users (Seo, Noh, & Kim, 2019). Elevated levels of body fat and BMI contribute to an unfavorable cardiometabolic profile, heightening the risk for obesity, diabetes mellitus, hypertension, various cardiovascular diseases, as well as osteoporosis and osteoarthritis (Kim, Ko, Seo, & Kim, 2018, Messina et al., 2015). Grogery et al. (2014) highlighted a negative relationship between extended periods of wheelchair sitting and adverse cardiometabolic risk factors.

Recent studies have indicated the beneficial impacts of moderate- to high-intensity physical activity on enhancing exercise endurance in individuals with spinal cord injuries. One group of researchers administered a regimen of moderate- to high-intensity exercise for a duration of at least 6 weeks, conducted three times weekly, with each session lasting 50 to 60 minutes, to patients with spinal cord injuries ranging from C4 to L2. Their findings demonstrated a decrease in body weight and body mass index (BMI), as well as enhancements in physical fitness parameters such as oxygen consumption. Similarly, a different group of researchers implemented a 12-week comprehensive exercise program, conducted thrice a week for a minimum of 30 minutes per session, among patients with spinal cord injuries spanning from T5 to T12. Their results showcased enhancements in the cardiorespiratory system and the strength of upper extremity muscles (Ballesta-García, Martínez-González-Moro, Rubio-Arias, & Carrasco-Poyatos, 2019).

A prior investigation categorized 66 individuals over the age of 65 without spinal cord injury into two distinct cohorts, subjecting one group to 12 weeks of resistance circuit training (conducted thrice weekly) and leaving the other group without any form of exercise regimen. The results indicated a notable enhancement in lean body mass and a considerable reduction in fat mass within the experimental group compared to the control group (Wouda, Lundgaard, Becker, & Strøm, 2018). In a separate research endeavor, 35 participants lacking spinal cord injury were allocated into experimental and control clusters, with the experimental group undergoing 12 weeks of combined aerobic and resistance circuit exercise training (performed thrice weekly) while the control group remained devoid of any exercise protocol. Upon analysis, the experimental cohort exhibited a marked decline in body fat (16%, $p<0.01$) when juxtaposed with the control group (Peters et al., 2021).

The ongoing investigation presents findings that support a positive correlation between circuit training and respiratory physiological performance in wheelchair basketball players; however, this research encountered certain constraints. Initially, the significance of the results should be reinforced through studies involving larger participant numbers. Secondly, the duration and frequency of sessions were inadequate to fully assess the long-term impacts. Thirdly, the assessment of cardiopulmonary endurance relied solely on the 12-minute propulsion test, neglecting to measure the VO2 peak value. Subsequent research should also consider the measurement of oxygen consumption. Additionally, it is recommended that upcoming studies integrate dietary plans with exercise regimens to facilitate weight loss. These concerns need to be resolved in order to establish standardized exercise protocols and home training regimens for individuals living in the community with paraplegia due to spinal cord injuries. Hence, future investigations should explore similar parameters across a wider and more diverse population. Despite these limitations, the findings obtained have the potential to offer valuable insights for future research endeavors. As a result, the effectiveness of the study was augmented by a systematic approach that generated immediately applicable positive outcomes for day-to-day training regimes.

Conclusions

Upon analysis of the research findings and the preceding discourse, one can infer that the modified circuit training regimen has the potential to enhance cardiorespiratory capacity, upper-body muscular strength, and Body Mass Index (BMI) in wheelchair basketball athletes, as well as in the broader population of individuals reliant on wheelchairs in their daily routines. Evidently, this regimen holds promise for utilization by coaches and healthcare professionals aiming to enhance cardiorespiratory fitness, upper-body strength, and BMI levels in individuals with paraplegia.

Author Contributions

Conceptualization, F.L. and F.T.; methodology, F.L. and F.T.; software, R.M.R.; validation, F.L.; formal analysis, F.L.; investigation, F.L.; resources, F.T.; data curation, F.L. and F.T.; Bibliographical research, S.H., S.N. and A.K.; writing—original draft preparation, F.L.; writing—review and editing, F.L.; supervision, F.L. and F.T.; project administration, F.T.; funding acquisition, E.S. All authors have read and agreed to the published version of the manuscript.

Funding

This research received no external funding.

Conflicts of Interest

The authors declare no conflicts of interest.

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