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Effects of a circuit training program in improving cardiorespiratory fitness, upper extremity strength, and agility in paraplegic subjects

Efectos de un programa de entrenamiento en circuito en la mejora de la aptitud cardiorrespiratoria, la fuerza de las extremidades superiores y la agilidad en sujetos parapléjicos

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Abstract. Exercise and sports may play a crucial role for individuals with disabilities due to their restricted levels of physical activity. Among people with disabilities, engaging in sports and exercise has the potential to notably enhance their physical and physiological functioning. Consequently, the aim of this research was to investigate the effects of a circuit training program on the cardiorespiratory fitness, musculoskeletal strength, and agility of wheelchair users. The study involved 28 participants with paraplegia as a result of spinal cord injury, aged between 19 and 40 years, who were divided into two groups: an experimental group (EG, n = 14) participating in circuit training, and a control group (CG, n = 14) undergoing aerobic upper-body exercise exclusively. All subjects took part in the wheelchair yo-yo test and hand grip test, both conducted at the commencement and conclusion of the training period. The results displayed a significant Time x Group interaction for both variables, indicating a substantial improvement in the intervention group ($p < 0.001$), while no significant changes were observed in the control group. Therefore, the findings suggest that incorporating circuit training into the daily routine of wheelchair users has a positive impact on their overall well-being, ultimately enhancing their quality of life.
Key words: physiology; exercise; sport; spinal cord injuries; cardiorespiratory fitness.

Resumen. El ejercicio y los deportes pueden desempeñar un papel crucial para las personas con discapacidades debido a sus niveles restringidos de actividad física. Entre las personas con discapacidad, la práctica de deportes y ejercicio tiene el potencial de mejorar notablemente su funcionamiento físico y fisiológico. En consecuencia, el objetivo de esta investigación fue investigar los efectos de un programa de entrenamiento en circuito sobre la aptitud cardiorrespiratoria, la fuerza musculoesquelética y la agilidad de los usuarios de sillas de ruedas. En el estudio participaron 28 participantes con paraplejia como consecuencia de una lesión medular, con edades comprendidas entre los 19 y los 40 años, que se dividieron en dos grupos: un grupo experimental (GE, n = 14) que participaba en entrenamiento en circuito, y un grupo control (GC, n = 14) que realizaba ejercicio aeróbico de la parte superior del cuerpo exclusivamente.Todos los sujetos participaron en la prueba de yo-yo en silla de ruedas y en la prueba de prensión manual, ambas realizadas al inicio y al final del período de formación. Los resultados mostraron una interacción significativa Tiempo x Grupo para ambas variables, lo que indica una mejoría sustancial en el grupo de intervención ($p < 0,001$), mientras que no se observaron cambios significativos en el grupo control. Por lo tanto, los hallazgos sugieren que la incorporación del entrenamiento en circuito en la rutina diaria de los usuarios de sillas de ruedas tiene un impacto positivo en su bienestar general, mejorando en última instancia su calidad de vida.
Palabras clave: fisiología; ejercicio; deporte; lesiones medulares; aptitud cardiorrespiratoria.

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Introduction

Increasing levels of physical activity have been found to be correlated with a decreased likelihood of developing cardiovascular conditions (Cataldi et al., 2019; Latino, Saraiello, Tafuri, 2023; Latino & Tafuri, 2023, 2024 a-b). Manual wheelchair users, in comparison to individuals with full physical capabilities, exhibit lower levels of physical activity and fitness. This circumstance significantly influences their daily routines, social engagement, and overall well-being (Mazzeo et al., 2016; Morsanuto et al., 2023; Muscogiuri et al., 2016; Latino et al., 2023; La Torre et al., 2023). The exertion involved in propelling a wheelchair throughout the day may not be adequate to stimulate beneficial cardiovascular responses (Guerra et al., 2014; Rocca et al., 2016). Thus, overcoming the detrimental cycle of reduced physical condition in manual wheelchair users may necessitate engaging in exercise regimens, defined as a form of physical activity characterized by organized, planned, systematic, and repetitive body movements aimed at enhancing or preserving various aspects of physical fitness (Morgan, Tucker, Klaesner, & Engsberg, 2017). Enhancing physical fitness could also lead to a decrease in the relative effort required for daily tasks. Given that manual wheelchair users primarily rely on hand rim wheelchair propulsion for mobility, exercise programs should target improvements in their physical fitness to optimize the impact of hand rim wheelchair propulsion in daily living. The term wheelchair propulsion capacity refers to the ability to perform hand rim wheelchair propulsion. The concept of wheelchair propulsion capacity encompasses both endurance and sprint capacity for various daily activities (Schottler, Graf, Kelly, & Vogel, 2019). Achieving optimal wheelchair propulsion capacity necessitates factors such as cardiorespiratory fitness (aerobic capacity), upper-body muscular strength, and agility skills. Moreover, it is crucial to translate these physiological aspects into functional wheelchair propulsion. Mechanical efficiency, alongside physical fitness, plays a significant role in wheelchair propulsion capacity (Keeler, Kirby, Parker, McLean, & Hayden, 2018). The power output generated during hand rim wheelchair propulsion is considered the primary outcome measure closely associated with wheelchair propulsion capacity and the ability to maneuver the wheelchair effectively. Additional comprehensive outcome measures for wheelchair propulsion capacity are derived from practical field tests assessing wheelchair propulsion outcomes. Valent et al. (2007) conducted a review on upper-body exercise effects, specifically focusing on individuals with spinal cord injuries; however, due to the overall poor quality of studies, no definitive conclusions could be drawn. It is suggested that training wheelchair propulsion capacity could benefit a broader range of diagnostic groups, and exploring the training effects in able-bodied individuals may offer valuable insights into potential effects for persons with disabilities. Furthermore, the impact of exercise training on daily life wheelchair propulsion should be a key consideration (Leving, Vegter, De Groot, & Van der Woude, 2016). Recent studies have indicated the beneficial impact of moderate- to high-intensity physical activity on enhancing exercise capacity among individuals with spinal cord impairments (Latino, Cataldi, & Fischetti, 2021; Peters et al., 2021; Verbrugghe et al., 2021; Wouda, Lundgaard, Becker, & Strøm, 2018). One particular approach known as circuit training has been highlighted for its ability to yield notable advancements in cardiovascular and respiratory health. Circuit training, a widely utilized method in fitness and sports settings, is recognized for its capacity to elicit physiological enhancements like muscular strength, power, and cardiovascular and respiratory adaptations. Typically comprising a range of exercises performed successively within a specified timeframe, circuits are designed to facilitate adaptation to the various movements involved (Latino et al., 2021). These exercises may target the entire body or specific muscle groups, catering to individual needs and goals. Notably, circuit resistance training, which involves performing a series of resistance exercises without breaks, has been shown to enhance both cardiorespiratory endurance and muscular strength in able-bodied individuals. By setting exercise durations and progressively enhancing the intensity, circuit training contributes to improvements in muscle strength, breathing efficiency, and blood circulation. The absence of rest intervals between exercises is intended to boost cardiopulmonary enhancements, resulting in higher metabolic rates compared to traditional resistance training programs. As such, circuit training stands out as a promising option for individuals with spinal cord injuries characterized by reduced muscle strength and respiratory function. However, in reality, there are no standardized circuit training programs specifically for people with spinal cord injury, and relevant previous studies are also lacking. Indeed, to the best of our knowledge, only four other previous studies have examined upper extremity strength training for persons with paraplegia (Melo et al., 2019; Nash, van de Ven, van Elk, & Johnson, 2007; Willig, Garcia, da Silva, Corredeira, & Carvalho, 2022; Yildirim et al., 2016).

Therefore, the present study aims to explore the effectiveness of circuit training program in improving hand rim wheelchair propulsion capacity and the agility in manage the wheelchair in individual with spinal-cord injury.

Method

Study design

The research regarded a randomized controlled study to analyze the role of a circuit training program on cardiorespiratory performance, musculoskeletal strength, and agility skills among wheelchair users with spinal-cord injury. The intervention program involved 12-week and participants were randomized for parallel-group into experimental and control groups. Baseline homogeneity between the groups was examined after randomization, and double blinding was applied such that the participants and assessors were blinded to the group assignment. The experimental group received a circuit training program, while the control group received solely a regular aerobic upper-body exercise training. Both groups participated in the respective exercise programs for 12 weeks, twice per week, and evaluations were performed pre- and post-training. We have chosen to follow this protocol since a recent systematic review suggest that performing resistance exercises 2-3 times per week for 8-12 weeks can produce suboptimal, yet significant increases in both cardiorespiratory endurance and muscular strength in able-body men (Androulakis-Korakakis, Fisher, & Steele, 2020).

Participants

Between March and May 2024, individuals with paraplegia due to spinal cord injury volunteered to participate in the study. Inclusion criteria encompassed: (i) being between 19 and 40 years old at enrollment; (ii) absence of cardiovascular, neuromuscular, orthopedic, or neurologic conditions; (iv) capability to adhere to measurement instructions; (v) being a paraplegic wheelchair basketball player with spinal cord injury (SCI) disabilities at the T5 to T12 levels. Exclusion criteria included: (i) presence of artificial prostheses; (ii) manifestation of symptoms warranting exclusion as determined by a medical professional; (iii) interference of any (medical) event with testing outcomes leading to participant exclusion. The subjects were enrolled from an Italian Wheelchair Association.

Engagement in the study was voluntary, and all wheelchair users with SCI disabilities were encouraged to partake. Out of the 37 individuals recruited, 9 were eliminated (4 due to incomplete tests, 0 due to missing all assessments, and 5 for not meeting inclusion criteria). Consequently, the final sample comprised 28 athletes, with 14 males and 14 females (Fig.1). All participants provided written informed consent before inclusion in the study in accordance with the Helsinki Declaration and subsequent amendments. Reserchers have ensured the anonymity of the participants assigning unique identifiers instead of names, and lim-

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iting the collection of personal data to only what's necessary. Moreover, data were stored using encrypted formats and restrict access to authorized personnel only. Sample size was calculated using G*Power 3.1 (Heinrich-Heine-Universität Düsseldorf, Germany), a priori power analysis was completed and showed that a sample size of 26 would provide statistical power (α=0.05, 1-β= 0.80) to identify a medium effect size (f= 0.25 or 0.4) given a coefficient of correlation p=0.80 with 95% power and α=0.05, using a within-between mixed design. To prevent the experimental mortality, due to participants leave of participants, 28 subjects were enrolled.

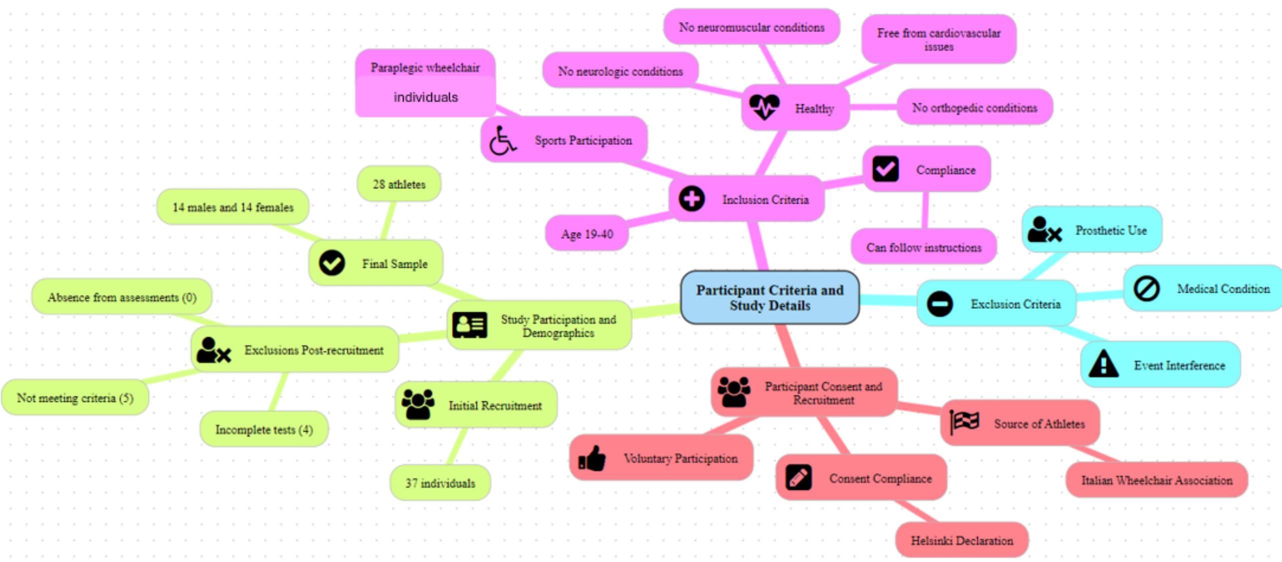

Figure 1. Study flow chart.

Measures

The data were obtained first by pre-test of the following variables: (1) cardiorespiratory fitness (VO_2max), (2) upper-body muscle strength, (3) agility skills. The pre-test was done to establish the strengths and weaknesses of the participants at baseline. After the training lasting 12 weeks, the post-test of the previous variables has been conducted because the fitness testing is a great way to monitor and assess subject' ability as it relates to aerobic fitness, agility, and strength. To evaluate cardiorespiratory fitness and agility, it was chosen a Field test since field tests are easier, faster, and cheaper to administer than laboratory evaluation, making them ideal during the season.

Anthropometric measures

A standard protocol was followed and standardized instruments were used to carried out the anthropometric evaluations (Weiner, & Lourie, 1981). Height and weight measurements were performed in a room where the participants' privacy was ensured. The subjects were asked to leave any personal belongings (wallet, watch, coat, etc.). The measurements were getting out three times each and the verification were performed always by the same experienced researcher, in order to avoid incurring errors. Participants were weighed using a chair medical scale with a precision of 0.1 kg (Detecto 6868-C-AC-W - Bariatric Flip Seat Scale). A digital stadiometer was used to measures height to the nearest 0.1 cm (Charder's HM200D, Charder Electronic Co., Taiwan) (Okosun, Bhatt, Boltri, & Ndirangu, 2008). The height and weight measurements were used to calculate Body Mass Index (BMI) (kg/m2) (Rothman, 2008).

Wheelchair Yo-Yo Test

This version of the yo-yo test is the modified version (Goosey-Tolfrey, & Leicht, 2013) of the official yo-yo test version as created by Jens Bangsbo. It is design for wheelchair users where participants with a disability perform the yo-yo test in a wheelchair over a distance less than the original 20m. The standard distance for the yo-yo test is over a 20m course, however for wheelchair athletes this distance may be challenging, making the test conclude much quicker than usual and with greater stress on the anaerobic energy system. Therefore, this modified yo-yo test has been proposed by Yanci et al. (2015) where the distance covered in each shuttle is reduced to 10 m (20m out and back).

Yanci et al. (2015) found that a 10m yo-yo test with wheelchair basketballers was reliable, and an appropriate tool for measuring the aerobic fitness in wheelchair users. In addition, the 10m yo-yo test is particularly suitable for evaluate agility and turning ability, which is also an important aspect of the management of the wheelchair. The diagram of the yo-yo 10m test requires that cones were placed 10 meters apart, requiring the wheelchairs to go around the turning cone.

Hand grip strength test

Handgrip strength test (Cronin, Lawton, Harris, Kilding, and McMaster, 2017) measures the maximum isometric strength of the hand and forearm muscles. Handgrip strength is important for any sport in which the hands are used for catching, throwing, or lifting. It was measured in the dominant hand, with the arm in extension and in the vertical axis. The participants performed the test seated in their wheelchairs with the arm fully extended and not touching the wheelchairs. The testing protocol consisted of three maximal isometric contractions for 5 s, with a rest period of at least 60 s.

Training intervention

The circuit training program applied to the experimental group comprised warm-up, main exercise, and cool-down. The following 6 full range bilateral exercise were performed as main exercise:

1. Upper back seated row
2. Medicine ball criss-cross
3. Reverse Butterfly (using resistance bands)
4. Biceps Curls (using resistance bands)
5. Shoulder Press (using resistance bands)
6. Chest Press (using resistance bands)

Each session consisted of a conditioning phase where typically 3 sets of 12 repetitions were performed.

While the control group performed a regular aerobic upper-body exercise training as follow:

1. Reach across
2. Swim
3. Scissors cross
4. Lateral raises
5. Side to side
6. Bicep kickback

Both groups followed, beyond the intervention program under study, rehabilitation programs aimed at improving joint mobility, strengthening of the upper limbs, respiratory gymnastics, posture and changes of position.

Statistical analysis

All statistical analyses were conducted using SPSS software (21.0 version; IBM Corp., Armonk, NY, USA), and the means and standard deviations of all variables were calculated. Validation for normality assumptions was performed via the Shapiro-Wilk test, and homogeneity of variances was assessed using the Levene test. An independent sample t-test was employed to assess group differences at baseline. All outcome measures were examined across time using a one-way ANOVA for repeated measures and paired-sample t-tests were performed to assess within-group differences (pre-and post-intervention). The magnitude of the significant 'Time x Group' interaction was analyzed using the partial eta squared (η2p) value, with interpretations of small ($\eta^2 p < 0.06$), medium ($0.06 \leq \eta 2p < 0.14$), and large ($\eta 2p \geq 0.14$). Additionally, Cohen's d was employed to determine effect sizes for pairwise comparisons, with classifications of small ($0.20 \leq d < 0.50$), moderate ($0.50 \leq d < 0.79$), and large ($d \geq 0.80$) [47]. Statistical significance was defined as $p < 0.05$.

In all cases a *P*-value less than 0.05 was used as the criterion for statistical significance.

Results

All participants were administered the treatment conditions as assigned, and there were no reported injuries throughout the duration of the trial. The subjects engaged in the research exhibited no variations in age, sex, or anthropometric attributes. ($p > 0.05$) (Tabel 1). Data results for all dependent measures are show in Table 2.

Table 1.
Characteristic of participants.

Variable	EG (n = 14) Mean ± SD	CG (n = 14) Mean ± SD
Age (y)	26 ± 7.28	29.33 ± 4.71
Height (cm)	166.33 ± 4.22	167.26 ± 3.88
Weight (kg)	60.60 ± 2.66	60.13 ± 1.40
Body mass index ($kg.m^{-2}$)	22.60 ± 0.26	21.65 ± 1.05
Sex, n (%)		
Male	6 (21.43)	8 (28.57)
Female	9 (32.14)	5 (17.86)

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

	Experimental Group (n = 14)			Control Group (n = 14)		
	Baseline	Post-test	Δ	Baseline	Post-test	Δ
Wheelchair Yo-Yo Test	1013.80 (2.30)	1020.23 (3.08)†*	7.13 (3.92)	1012.40 (4.68)	1010.00 (3.81)	-2.40 (3.79)
Hand Grip test	41.80 (1.14)	51.46 (2.74)†*	9.66 (1.67)	41.46 (1.68)	40.53 (4.22)	-0.93 (3.84)

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 ($p < 0.001$).

Wheelchair Yo-Yo Test

A two-factor repeated measures ANOVA found a significant 'Time x Group' interaction for the 12 minutes wheelchair propulsion distance test ($F_{1,26} = 46.66$, $p < 0.001$, $\eta^2_p = 0.74$, large effect size). The post-hoc analysis revealed a significant improvement in the score for this variable ($t = 8.21$, $p < 0.001$, $d = 2.19$, 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 ($F_{1,26} = 83.78$, $p < 0.001$, $\eta^2_p = 0.76$, large effect size). The post-hoc analysis revealed a significant improvement in the score for this variable ($t = 22.14$, $p < 0.001$, $d = 5.91$, large effect size) in the intervention group. No significant changes were found for the control group ($p > 0.05$).

Discussion

The aim of this study was to explore the effects of a 12-week of a circuit training intervention program on cardiorespiratory fitness, musculoskeletal strength, and agility skill among wheelchair users with paraplegia secondary to SCI.

In this study, the circuit training was selected as an exercise modality for programming training pathway of wheelchair users specifically to improve their cardiorespiratory fitness, musculoskeletal strength, and agility. The findings resulting from this paper suggest that a circuit training program can significantly improve physiological performance during the daily routine of wheelchair users with SCI, improving their quality of life.

The wheelchair persons daily routine requires a high degree of skill and technical expertise in the management of the wheelchair (Aidar et al. 2022; Corvino et al., 2020; Silva et al., 2022; Farì et al., 2023). Acceleration, speed, and agility are of particular importance in order to maintain mobility through hand rim wheelchair propulsion. Upper-extremity muscle strength is important for wheelchair users since they serve both wheelchair mobilization and propulsion. Strength development may increase performance of the individuals in their daily life; however, we can only speculate whether the speed and agility performance would improve. Circuit training in wheelchair individuals may have led to specific neural adaptations, such as an increased rate of activation of motor units (Leving et al., 2021; Messina et al., 2015). The neural adaptations such as an increased motor unit synchronization and firing rate may have contributed to the improvement of speed. It is very likely that the development of strength was the result of neural adaptations because the training period was short. The role of these adaptions is well recognized during the early phase of strength training (Jones et al., 2022; Farì et al., 2021). Other studies have shown the importance of upper extremity strength in wheelchair users. Janssen et al. demonstrated that there is a strong positive association between upper-body isometric strength and sprint power. Tupling et al. (2022) showed that the initiation of wheelchair movement depends on upper-extremity strength. Van Der Woude et al. (2001) reported that sprint performance is related to disability level and wheelchair propulsion technique. Turbanski and Schmidtbleicher (2010) trained 8 wheelchair athletes with SCI and 8 healthy physical education students at high intensity.

Although there is a correlation between muscle strength and the force imparted to the hand rim, increased force does not necessarily lead to more effective hand rim force or propulsion cadence. This suggests that improving not only muscle strength, but also propulsion technique is important. Future research should use exercise programs incorporating both muscle strength exercises specifically designed to improve hand-rim propulsion and functional, effective propulsion technique training (Ozmen, Yuktasir, Yildirim, Yalcin, & Willems, 2014).

Therefore, this type of training seems to have the highest potential to improve cardiorespiratory fitness, endurance wheelchair propulsion capacity and individuals' agility in the management of wheelchair. These results seem to be in line with previous research which have reported significant improvement in terms of endurance capacity and peak oxygen uptake. This cautious conclusion supports the findings of Helgerud et al. (2022) and Gibala et al. (2009) who found that circuit training is significantly more effective in improving peak oxygen uptake than performing the same (or more) total work during continuous aerobic exercise training. However, more research is needed to find out whether this also holds for wheelchair exercise.

The limiting factor for improving peak oxygen uptake in individuals with a disability is generally a lack of active muscle mass. Circuit training can increase muscle mass 52,53 and might have a positive effect on peak oxygen uptake (Iturricastillo et al., 2022).

In wheelchair users with a spinal-cord injury, aerobic capacity accounts for 69% of maximal tolerated power during wheelchair propulsion. This makes peak oxygen uptake an important physical fitness parameter. All studies in which peak oxygen uptake improved significantly also found improved endurance capacity. The same pattern holds for mechanical efficiency; when mechanical efficiency improved significantly, endurance capacity improved as well. A highly significant relation between mechanical efficiency and maximal tolerated power supports this finding. Both peak oxygen uptake and mechanical efficiency are good predictive physical fitness parameters for wheelchair propulsion capacity.

However, this research exhibits specific limitations. Primarily, the study's limited sample size of 28 participants stemmed from challenges in participant recruitment. Additionally, the lack of control over participants' dietary and sleep patterns poses a significant restriction. Moreover, the uneven distribution of genders among participants within the research groups may hinder the study's generalizability. The study failed to investigate socio-emotional aspects linked to physical activity, highlighting another constraint. Hence, forthcoming studies should examine similar variables across a wider and more diverse sample. Academics suggest employing a more comprehensive research instrument to analyze the effects of this training program on athletes' mental health. Subsequent research endeavors could entail using gender and age as selection criteria for participants to enhance the range of data supporting the development of training protocols for physical endurance in paraplegic individuals.

Conclusion

In conclusion, a circuit training program of the upper extremity resulted in significant improvements in cardiorespiratory fitness, musculoskeletal strength, and agility performance in wheelchair individual with SCI. In this population, upper-extremity conditioning, as well as cardiorespiratory responses is very important for the management of the daily life routines. For this reason, the circuit training program as used in this study may be advised to improve wheelchair user performance.

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.

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Conflicts of Interest

The authors declare no conflicts of interest.

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