2024, Retos, 57, 800-808

Physiological Responses of Wheelchair Basketball Athletes to a Combined Aerobic and Anaerobic Training Program

Respuestas Fisiológicas de los Atletas de Baloncesto en silla de Ruedas al Programa Combinado de Entrenamiento Aeróbico y Anaeróbico

*Francesca Latino, **Rosabel Martinez-Roig, ***Hendra Setyawan, ****Nugroho Susanto, *****Khoiril Anam, ******Emma Saraiello, *******Francesco Tafuri

*Pegaso University (Italy), **University of Alicante (Spain), ***Universitas Negeri Yogyakarta (Indonesia),****Padang State University (Indonesia), *****Universitas Negeri Semarang (Indonesia), ******University of Naples "Parthenope" (Italy), *******Niccolò Cusano University (Italy)

Abstract. Among the multifarious adapted sports, wheelchair basketball stands out as a highly recommended group activity among individuals with paraplegia, including those with Spinal Cord Injury (SCI). Athletes facing this particular impairment exhibit distinct alterations in their metabolic, cardiorespiratory, neuromuscular, and thermoregulatory systems, ultimately leading to a diminished physiological respiratory capacity in comparison to able-bodied individuals or those with other forms of impairments. The primary objective of the present research endeavor is therefore to explore the impact of a comprehensive exercise regime, encompassing both aerobic and anaerobic components, upon the enhancement of the aerobic capacity of wheelchair basketball athletes. A total of 32 wheelchair basketball players, ranging in age from 34 to 42, were enlisted in the study, with half allocated to an experimental group engaging in combined aerobic and anaerobic training [EG, n = 16], while the remaining participants were assigned to a control group undertaking solely aerobic exercise training [CG, n = 16]. The 12-minute wheelchair propulsion distance was utilized to evaluate the V̇O2peak in individuals with paraplegia, both before and after the intervention. The findings revealed a significant Time x Group interaction for the 12-minute wheelchair propulsion distance variable, highlighting a notable enhancement in the treatment group ($p < 0.001$). In contrast, no substantial changes were detected in the control group. Thus, the outcomes suggest that the integration of aerobic and anaerobic exercise yields a highly positive impact on the aerobic performance of wheelchair basketball players.
Key words: physiology; exercise; sport; spinal cord injuries; cardiorespiratory fitness.

Resumen. Entre los diversos deportes adaptados, el baloncesto en silla de ruedas se destaca como una actividad grupal muy favorecida entre las personas con paraplejia, incluidas las personas con lesión medular (LME). Los atletas que se enfrentan a esta discapacidad en particular exhiben alteraciones distintivas en sus sistemas metabólico, cardiorrespiratorio, neuromuscular y termorregulador, lo que en última instancia conduce a una disminución de la capacidad fisiológica respiratoria en comparación con las personas sanas o aquellas con diferentes formas de discapacidades. En consecuencia, el objetivo principal del presente esfuerzo de investigación es explorar el impacto de un régimen de ejercicio integral que abarque componentes aeróbicos y anaeróbicos en la mejora de la capacidad aeróbica de los atletas de baloncesto en silla de ruedas. Un total de 32 jugadores de baloncesto en silla de ruedas, con edades comprendidas entre los 34 y los 42 años, se inscribieron en el estudio, y la mitad se asignó a un grupo experimental que realizaba un entrenamiento aeróbico y anaeróbico combinado [GE, n = 16], mientras que los participantes restantes fueron asignados a un grupo de control que realizaba únicamente entrenamiento con ejercicios aeróbicos [GC, n = 16]. La distancia de propulsión de la silla de ruedas de 12 minutos se utilizó para evaluar el $\dot{V}O_2$máx en individuos con paraplejia, tanto antes como después de la intervención. Los resultados revelaron una interacción significativa Tiempo x Grupo para la variable distancia de propulsión en silla de ruedas de 12 minutos, destacando una mejora notable en el grupo de tratamiento ($p < 0,001$). Por el contrario, no se detectaron cambios sustanciales en el grupo control. Por lo tanto, los resultados sugieren que la integración de ejercicios aeróbicos y anaeróbicos produce un impacto positivo considerable en el rendimiento aeróbico 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: 12-06-24
Francesco Tafuri
francesco.tafuri@unicusano.it

Introduction

The adverse implications of spinal cord injuries (SCI) often result in limitations in performing daily tasks and restrict mobility and community engagement (Bofosa, Miangindula, & Nkiama, 2019; Cataldi et al., 2019; Farì et al., 2023). A decreased level of cardiorespiratory fitness (CRF), defined as peak oxygen uptake (VO_2 peak) or peak power output (PPO), is a well-documented outcome of SCI and a significant risk factor linked to chronic illnesses. In clinical settings, CRF is generally characterized by an individual's peak oxygen uptake (VO_2 peak) or peak power output (PPO), both assessed through graded cardiopulmonary exercise testing (CPET) until voluntary exhaustion, reflecting the coordinated operation of various body systems (respiratory, cardiovascular, and skeletal) in oxygen uptake, transport, and utilization for metabolic activities (De Lira et al., 2010). Several prospective studies have highlighted the crucial role of CRF, sometimes surpassing traditional cardiovascular disease risk factors (e.g., obesity, hypertension, and smoking), in mortality risk (Latino et al., 2021; Pereira et al., 2016).

Engaging in adapted sports, however, can enhance the functionality of individuals with SCI, complementing the rehabilitation process for wheelchair users (Latino, & Tafuri, 2023a; Latino, Tafuri, Saraiello, & Tafuri, 2023). Wheelchair basketball stands out as a popular team sport among paraplegics, including those with SCI. Among adapted sports, basketball stands out for its high-speed requirements for wheelchair athletes, involving rapid changes in direction, agility, and substantial upper body strength, particularly in the muscles utilized for wheelchair propulsion. Athletes with SCI exhibit distinct alterations in metabolic, cardiorespiratory, neuromuscular, and thermoregulatory systems, leading to reduced physiological capacity compared to able-bodied individuals or those with different impairments (Iturricastillo, Yanci, Los Arcos, & Granados, 2016).

Enhancing aerobic fitness among athletes facing physical disabilities such as spinal cord injuries is presently a crucial element of physical training due to the anticipated correlations between fitness levels and overall health (Latino, Saraiello, Tafuri, 2023; Morsanuto, Peluso Cassese, Tafuri, & Tafuri, 2023). The aerobic fitness levels of young individuals with spinal cord injuries are notably lower in comparison to their peers with typical development, as well as in contrast to youths with other chronic conditions. Within the cohort of wheelchair users affected by spinal cord injuries, approximately 69% of the maximal tolerated power during wheelchair propulsion is determined by aerobic capacity (Conners, Elliott, Kyle, Solomon, & Whitehead, 2020). This underscores the significance of peak oxygen uptake as a key parameter of physical fitness. Notably, studies revealing a significant enhancement in peak oxygen uptake have consistently shown improvements in endurance capacity. A similar trend is observed in mechanical efficiency, where notable enhancements are also linked to improved endurance capacity. Given that manual wheelchair users predominantly rely on hand rim wheelchair propulsion for mobility, exercise regimens should target the enhancement of their physical fitness levels to optimize the impact on sport performance (Iturricastillo, Yanci, & Granados, 2018). The ability for hand rim wheelchair propulsion is denoted as wheelchair propulsion capacity, which is further categorized into endurance and sprint capacities, crucial for wheelchair basketball activities. Achieving an optimal wheelchair propulsion capacity necessitates the development of cardio-respiratory fitness (aerobic capacity), anaerobic capacity, and muscular fitness. Moreover, these physiological parameters must be effectively translated into functional wheelchair propulsion. Apart from physical fitness, mechanical efficiency plays a vital role in wheelchair propulsion capacity, with power output during hand rim wheelchair propulsion being a pivotal outcome measure closely associated with wheelchair propulsion capacity (Latino, & Tafuri, 2024a). Other comprehensive outcome measures for evaluating wheelchair propulsion capacity include the outcomes of wheelchair propulsion tests conducted in practical field settings (Croft, Dybrus, Lenton, & Goosey-Tolfrey, 2010).

Research findings have suggested that the combination of aerobic and anaerobic training could potentially lead to a greater enhancement in aerobic performance compared to engaging in aerobic training alone (Gillen, Wyatt, Winchester, Smith, & Ghetia, 2016). The simultaneous implementation of aerobic and strength training is a crucial component of physical training designed to enhance both athletic performance and overall health. The recommendation to incorporate both aerobic and strength training into workout routines is significant due to the distinct adaptations and health advantages that each activity can offer (Vanlandewijck, Daly, & Theisen, 1999). To illustrate, aerobic training facilitates an increase in aerobic capacity (e.g., central adaptations) and metabolic alterations in skeletal muscle, such as heightened mitochondrial density and capillarization. Conversely, consistent strength training leads to muscle hypertrophy, enhanced strength, and power, while also potentially contributing to the improvement of bone mineral density. Furthermore, recent emphasis has been placed on the significance of both muscle mass and muscle function as key indicators of physical well-being and autonomy in daily activities (Soylu, Yıldırım, Akalan, Akınoğlu, & Kocahan, 2021).

During the recent decades, the insights acquired through research in the realm of exercise physiology have significantly contributed to the enhancement of training methodologies for able-bodied athletes (La Torre et al., 2023). A robust research repository exists, delineating the correlation between athletic performance and the fundamental constituents of physical fitness, including anaerobic power and capacity, aerobic power, muscular strength and endurance, body composition, and flexibility. Consequently, numerous advancements and enhancements in the evaluation, conditioning, and supervision of athletes have ensued (Muller et al., 2000). Nonetheless, a parallel scenario is not observed in the sphere of disability sports. A study (Liow, & Hopkins, 1996) concerning the training regimes of elite athletes with disabilities (comprising 41 wheelchair racers, 20 swimmers, and 14 throwers) revealed that one-third of wheelchair racers did not benefit from any coaching. This deficiency may be attributed to insufficient knowledge regarding training principles in wheelchair sports and the scarcity of proficient personnel in this domain. To optimize training methodologies, prevent detrimental training practices, and mitigate the risks of overtraining, the cultivation of scientific expertise in the realm of disability sports is imperative (Gavel, Macrae, Goosey-Tolfrey, & Logan-Sprenger, 2023).

Although extensive descriptive information exists regarding the physiological characteristics of wheelchair athletes, particularly in the realms of road racing and basketball, there is a scarcity of research pinpointing the optimal type of exercise for enhancing aerobic capacity in wheelchair basketball players. Existing evidence indicates that certain physiological parameters mentioned earlier have the potential to forecast performance outcomes in sprinting and long-distance events. Valent et al. (2007) conducted a comprehensive analysis of studies focusing on the impact of upper-body workouts, noting the inability to draw definitive conclusions due to the generally substandard quality of research. Zwinkels et al. (2014) delved into the exploration

2024, Retos, 57, 800-808

of diverse exercise training regimens to gauge their efficacy in enhancing wheelchair propulsion capabilities. Their findings revealed a modest yet notable enhancement in aerobic performance following a regimen of mixed training exercises. Consequently, the current body of knowledge lacks substantial data on the potential correlation between advancements in aerobic responses through the integration of physical activities (Moreno, Saldarriaga, Castro, & Valencia, 2024).

The focus of the present study will therefore be on analyzed the role of a combined aerobic and anaerobic exercise training in improving the aerobic performance of wheelchair basketball athletes.

Materials and Methods

Study design

The research regarded a randomized controlled study to analyze the role of a combined aerobic and anaerobic exercise program on aerobic capacity among wheelchair basketball players. The intervention program involved 12-week of combined aerobic and anaerobic training for the intervention group, and aerobic training program for the control group.

Participants

A total of 32 individuals in middle adulthood (mean age = 40.12 ± 3.04 years) were randomly allocated in a 1:1 ratio. They were assigned to either the experimental group, which engaged in combined aerobic and anaerobic training [EG, n = 16], or the control group, which underwent aerobic exercise training [CG, n = 16].

The flowchart of the study can be observed in Figure 1. Inclusion criteria encompassed: (i) being between 35 and 45 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. 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. Upon meeting the inclusion criteria, participants provided consent in compliance with the Helsinki Declaration and its subsequent revisions.

Athletes were recruited from the Italian Wheelchair Basketball Federation. Engagement in the study was voluntary, and all wheelchair basketball players with SCI disabilities were encouraged to partake. Out of the 46 individuals recruited, 11 were eliminated—6 due to incomplete tests, 3 due to missing all assessments, and 2 for not meeting inclusion criteria. Consequently, the final sample comprised 32 athletes, with 21 males and 11 females.

Participants received an email providing guidance prior to their involvement in the study. Subsequently, a second electronic correspondence was dispatched to instruct them to attend a briefing session during which the objectives of the trial were emphasized, and written consent for research participation was obtained. Following the satisfaction of inclusion criteria, participants were required to complete consent forms before commencing the study. These forms delineated the study's aims, selection criteria, procedures, potential benefits and risks, available alternatives, confidentiality measures, withdrawal process, and a disclaimer regarding injuries.

By utilizing G*Power (version 3.1.9.6), a priori power analysis was conducted, revealing that a sample size of 24 would yield sufficient statistical power (α=0.05, 1-β= 0.80) for detecting a moderate effect size (f= 0.25 or 0.4) with a correlation coefficient of p=0.80, a 95% power level, and α=0.05, employing a within-between mixed design. To mitigate experimental attrition resulting from participant dropout, 32 individuals were recruited.

The confidentiality of all participants was safeguarded by the investigators. The study took place between January 2024 and March 2024, adhering to the principles of the Helsinki Declaration and its subsequent revisions.

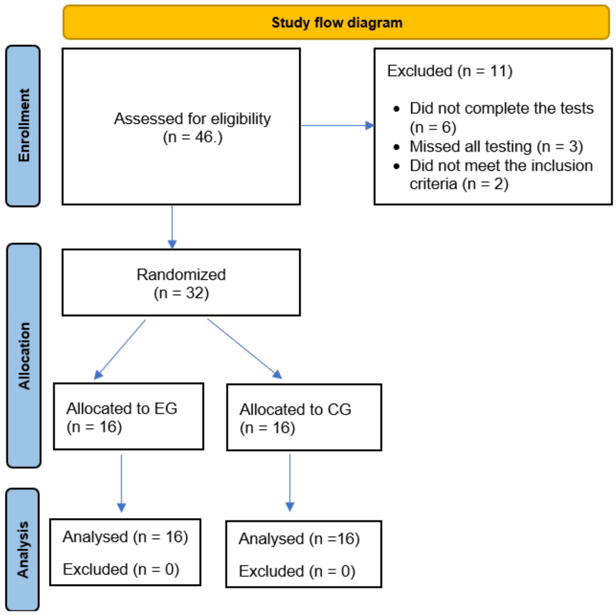

Figure 1. Study flow diagram.

Procedures

All measurements were conducted during two sessions. The testing sessions occurred with a 72-hour gap between the commencement of the program and the baseline evaluation. Within the initial session, respondents completed a survey in which they disclosed demographic information such as age, gender, medical background, smoking routines, and other attributes. Subsequently, athletes engaged in the 12-minute wheelchair propulsion distance test (modeled after the Cooper 12-minute run-walk) to analyze aerobic capacity both at baseline and post-intervention.

The students underwent individual assessments and performed each examination in a consistent sequence, at the same time of day, and under comparable experimental conditions. All assessments and physical activity regimens were delineated, monitored, and executed by two proficient fitness instructors.

Measures

A standard protocol was followed and standardized instruments were used to carried out the anthropometric evaluations (Weiner, & Lourie, J.A., 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). BMI evaluation was performed before to and after the intervention programs (Rothman, 2008).

To evaluate the percentage of Fat Mass (FM) as a sensitive indicator for changes in body composition of athlete subjects was used anthropometric field methods, such as Jackson and Pollock (1978) equation, and Jackson, Pollock, and Ward (1980) equation. Jackson-Pollock: Body Fat % = (1.61 x BMI) + (0.13 x Age) - (12.1 x Gender) - 13.9.

They are classical equations that are considered still valid to estimate total body fat mass or body fat percentage in adult population. They can provide a simple, quick, and easy informative indicators of adiposity in adults (Marin-Jimenez et al., 2022).

The 12-minute wheelchair propulsion distance, which was developed based on the Cooper 12-minute run-walk test (Franklin et al., 1990), was employed for assessing the aerobic capacity before and after the intervention. This test, known for its strong validation and reliability, has been found to have a significant association with $\dot{V}O_2$peak among individuals with paraplegia (Franklin et al., 1990). Conversely, the test does not show a similar relationship with individuals having quadriplegia (Franklin et al., 1990). Previous research studies have indicated that the correlation coefficient becomes more robust when $\dot{V}O_2$peak is normalized to body weight (0.84 compared to 0.54). This finding implies that body mass is a crucial factor influencing wheelchair propulsion distance. Therefore, the researchers deemed this test most suitable for addressing the specific requirements of the study.

Training program

Following the initial assessment at baseline (T_0), individuals engaged in a 12-week exercise regimen utilizing simulated resisted propulsion as a means of integrated aerobic/anaerobic training. A thorough orientation session was conducted for all participants, encompassing guidance on the simulated-resisted propulsion exercise regime, warm-up procedures, muscle endurance and aerobic exercise engagement, practical application of all facets of the exercise protocol, and cooldown activities. To ensure participant safety, detailed instructions were provided regarding the key clinical indicators and symptoms necessitating attention. The exercise routine comprised upper-limb stretching, succeeded by 8-12 repetitions of maximally resisted simulated propulsion, and culminated with a 20-minute aerobic exercise session.

The approach to aerobic exercise involved affixing a sequence of therapeutic elastic bands to a stationary structure. These bands were arranged to allow the individual to remain seated in their wheelchair, with the wheels immobilized, and imitate the propulsion movement as the bands were continually stretched and relaxed. Handles were affixed to the elastic bands to offer a gripping mechanism. Researchers were able to adjust the intensity of the muscle endurance segment by opting for various elastic bands with differing stretch resistances ranging from low to medium to high (Theraband), thereby inducing fatigue within 8 to 12 repetitions. Furthermore, the resistance level for the aerobic exercise component was determined by selecting elastic bands of varying resistances (low, medium, high) to achieve the desired intensity when the band was repetitively stretched and relaxed at a pace of 1 cycle per second. In both muscle endurance and aerobic training, resistance was applied across the complete range of motion utilized during manual wheelchair propulsion.

The resistance of the elastic bands for aerobic conditioning was augmented to sustain the target heart rate at a stretching rate of 1 cycle per second. Adherence to the program was monitored through meticulous examination of the daily exercise logs.

Statistical Analysis

The statistical analyses were conducted using IBM SPSS version 25.0 (IBM, Armonk, NY, USA). Data were presented in the form of group mean (M) values and standard deviations (SD). 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. To investigate the impact of the exercise program on dependent variables, a two-way ANOVA (group (experimental/control) × time (pre/post-intervention)) with repeated measures on the time dimension was utilized. In cases where 'Group x Time' interactions were significant, paired t-tests were conducted to identify significant differences. The magnitude of the significant 'Time x Group' interaction was analyzed using the partial eta squared ($\eta 2p$) value, with interpretations of small ($\eta 2p < 0.06$), 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 ($d \geq 0.80$) (Cohen, 1992). Statistical significance was defined as $p < 0.05$.

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 = 16) Mean ± SD	CG (n = 16) Mean ± SD
Age (y)	37.56 ± 61.67	42.68 ± 1.53
Height (cm)	165.37 ± 2.21	166.37 ± 4.28
Weight (kg)	60.06 ± 1.38	60.05 ± 1.75
Body mass index ($kg.m^{-2}$)	22.01 ± 0.27	21.91 ± 1.16
Sex, n (%)		
Male	11 (34.38)	10 (31.25)
Female	5 (15.63)	6 (18.75)

Table 2.
Changes in cardiorespiratory fitness, BMI and FM after a 12-week combined exercise program.

	Experimental Group (n = 16)			Control Group (n = 16)		
	Baseline	Post-test	Δ	Baseline	Post-test	Δ
12 minutes wheelchair propulsion distance test – VO_{2peak}	23.09 (2.82)	27.16 (5.06)†*	4.07 (3.59)	23.09 (1.82)	22.65 (1.89)	-0.44 (1.16)
BMI	22.01 (0.27)	20.88 (0.18)†*	-1.12 (0.26)	21.91 (1.16)	21.42 (0.90)	-0.48 (0.64)
FM	18.03 (6.07)	16.33 (5.96)†*	-1.70 (0.77)	19.12 (5.57)	18.43 (5.95)	-0.69 (0.67)

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).

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 ($F_{1,30} = 22.85$, $p < 0.001$, $\eta^2_p = 0.83$, large effect size). The post-hoc analysis revealed a significant improvement in the score for this variable ($t = 4.53$, $p < 0.001$, $d = 1.13$, large effect size) in the intervention group. No significant changes were found for the control group ($p > 0.05$). In this study Cronbach's alpha reliability for the 12 minutes wheelchair propulsion distance test was α=0.69.

Body Mass Index (BMI)

A two-factor repeated measures ANOVA found a significant 'Time x Group' interaction for the BMI ($F_{1,30} = 74.28$, $p < 0.001$, $\eta^2_p = 0.71$, large effect size). The post-hoc analysis revealed a significant improvement in the score for this variable ($t = -17.25$, $p < 0.001$, $d = -4.31$, large effect size) in the intervention group. No significant changes were found for the control group ($p > 0.05$).

Fat Mass (FM)

A two-factor repeated measures ANOVA found a significant 'Time x Group' interaction for the FM ($F_{1,30} = 15.35$, $p < 0.001$, $\eta^2_p = 0.79$, large effect size). The post-hoc analysis revealed a significant improvement in the score for this variable ($t = -7.72$, $p < 0.001$, $d = -1.36$, large effect size) in the intervention group. No significant changes were found for the control group ($p > 0.05$).

Discussion

The aim of this investigation was to assess whether the respiratory physiological responses of wheelchair basketball athletes are linked to a combined aerobic/anaerobic exercise regimen. The findings suggest that implementing a blend of aerobic and anaerobic exercise can significantly enhance the long-term aerobic performance of wheelchair basketball players utilizing a manual wheelchair.

These outcomes are consistent with prior studies that suggest that the combination of aerobic and anaerobic training (known as concurrent training) may lead to greater improvements in aerobic performance compared to solely engaging in aerobic training. Several investigations exploring the impact of both aerobic and anaerobic workouts on dynamic respiratory parameters have concluded that each type of exercise positively influences various respiratory variables (FVC, FEV1, and PEF) (Cho, Choi, & Seo, 2024; de Jesus, Nascimento, & de Jesus, 2024; Gamonales, Ibáñez, Muñoz-Jiménez, Espada, & Hernández-Beltrán, 2024; Rocca et al., 2016). Aerobic exercise primarily concentrates on bolstering cardiovascular fitness, increasing lung capacity, and optimizing oxygen consumption. Throughout aerobic exercises, individuals partake in continuous rhythmic movements that necessitate steady and controlled breathing, consequently promoting greater lung expansion and strengthening respiratory muscles over time, ultimately benefiting PEF (Gottlieb, Levi, Shalom, Gonzalez, & Meckel, 2024). Conversely, resistance exercises such as weightlifting, or resistance band training are primarily focused on enhancing muscle strength and endurance. Although resistance exercises may not have as direct an impact on PEF as aerobic exercises, they play a crucial role in overall pulmonary function. Strengthening the respiratory muscles can enhance respiratory function and coordination, indirectly contributing to an improved PEF (Rietveld, Vegter, der Woude, & de Groot, 2024). The physiological response to exercise in individuals with disabilities exhibits distinct characteristics in comparison to able-bodied individuals (Mazzeo et al., 2016; Muscogiuri et al., 2016; Latino, & Tafuri, 2024b). Wheelchair athletes demonstrate unique physiological responses during upper limb exercise due to vascular insufficiency in the lower limbs and adrenergic dysfunction. Factors such as cardiorespiratory fitness, anaerobic fitness, and upper limb coordination significantly influence the performance of wheelchair athletes. A correlation has been observed where a more severe sequel leads to a tendency for a more limited VO_2 peak (Farì et al., 2024; Guerra et al., 2014). Autonomic nervous system dysfunction in athletes with high thoracic-level spinal cord injuries, as indicated by Booth and Grogono (1998), hampers the cardiovascular system's capacity to respond to the demands of exercise, primarily due to the loss of reflex redistribution of blood to working muscles and reduced sympathetic control of heart rate and myocardial contractility. Consequently, exercising muscles rely more on anaerobic metabolism to fulfill energy requirements. Therefore, active wheelchair athletes often seek to compensate for muscle loss in lower limbs by developing hypertrophy in their arms and shoulders (Shephard, 1988).

Gass and Camp (1979) reported that elite Australian paraplegic athletes with low-level spinal cord lesions exhibited cardiorespiratory fitness levels comparable to sedentary able-bodied individuals of similar age. Conversely, individuals using wheelchairs often display low fitness levels, particularly in terms of maximum oxygen intake, often due to limitations in physical activity resulting from inadequate opportunities or awareness." Individuals with lower-limb disabilities may face physiological impediments like a reduced maximum heart rate and diminished stroke volume in cases of high-level lesions. A contributing factor to the latter issue is the loss of vasomotor regulation below the level of the lesion, leading to restricted venous return, reduced central blood volume, and consequently, impaired cardiac performance". Furthermore, lower-limb disabled individuals commonly exhibit a notably large arteriovenous oxygen difference at submaximum work rates, reflecting inadequate regional blood flow to active muscles, an excessive amount of active muscle relative to available blood flow, or a combination of both factors (Wang, 2024).

Although the act of wheelchair ambulation may not elicit a cardiorespiratory training response, it can subject a disabled individual to significant physical strain. In individuals new to this activity, the energy expenditure, measured in oxygen consumption, during wheelchair propulsion is comparable to that of walking at a similar pace (Silveira, de Groot, & Cowan, 2024). Nonetheless, the muscle mass utilized in walking is substantially larger than what is engaged in propelling a wheelchair. Even with the potential hypertrophy of arm muscles in certain paraplegic patients, the energy expenditure associated with wheelchair propulsion is mainly sustained by a relatively limited muscle mass. Moreover, a significant portion of the energy demand is placed on muscles that are not well-suited for prolonged exertion (Ammann, Knuchel, Hertig-Godeschalk, & Perret, 2024). The typical daily routine offers minimal stimuli for muscle hypertrophy in lower-limb disabled individuals who possess reasonable mobility; those with a sedentary lifestyle engage few muscles except when transferring from a wheelchair to a stationary seat or bed. Hjeltnes (1997) and Vokac et al. (1995) highlighted that, apart from occasional bursts of high energy output, wheelchair users seldom reach the heart rate threshold necessary for stimulating aerobic fitness. This observation appears to support previous findings indicating that routine activities are insufficient to preserve the cardiorespiratory health of rehabilitated paraplegic patients. Skilled individuals can propel wheelchairs with lower oxygen expenditure compared to beginners, and over time, they consume less energy than what is needed for walking due to reduced vertical body movement in a wheelchair. Nevertheless, since smaller muscles bear the load, the heart rate tends to be higher in wheelchair users than in individuals walking (Hertig-Godeschalk, & Perret, 2024; Aidar et al., 2022; Silva et al., 2022).

Paraplegic athletes may exhibit a higher heart rate compared to able-bodied individuals engaging in similar exercise while using a wheelchair. Conversely, disabled individuals experiencing a handicap in arm and shoulder muscles do not demonstrate an increase in oxygen consumption for a given task. This suggests that the elevated heart rate observed in paraplegic individuals might be attributed not to the absence of stabilizing muscles but rather to localized muscle fatigue, potentially stemming from an inadequate overall fitness level. Evidently, enhancing muscle strength could greatly benefit such individuals. Knutsson and colleagues highlighted the challenges that may arise from the lack of regular physical activity among paraplegic patients, emphasizing that many struggled to endure efforts, making it challenging for them to commence the extended and repetitive training sessions essential for effective rehabilitation (Antonelli, Hartz, da Silva Santos, & Moreno, 2020).

Numerous studies have indicated the significant role of local muscular strength in the physical performance of wheelchair users. In a study by Wicks and colleagues (1977), five able-bodied men and two paraplegic men were compared, revealing a similar relationship between oxygen consumption and power output during arm-cranking exercises across all participants. Additionally, research has explored how individuals maneuver a wheelchair on various surfaces, including hard low-resistance surfaces and high-resistance surfaces like carpet and gravel. It was found that disabled men exhibited a lower "strike" frequency, which refers to the rate at which the wheel's rim is gripped, compared to able-bodied men when propelling the chair against the same submaximum resistance (Iturricastillo et al., 2018; Farì et al. 2021).

Evidently, the able-bodied subjects could execute a comparable amount of work with fewer interruptions by mastering the skill of exerting force with increased torque during the striking phase. The acquisition of such a technique could significantly impact an individual's mechanical efficiency in both wheelchair propulsion and wheelchair ergometry exercises (Latino & Tafuri, 2023a,b). It is posited that the effectiveness of wheelchair operation might also be influenced by trunk stability. Some individuals can effectively harness trunk momentum to drive their wheelchair, especially in competitive scenarios or when undergoing maximal-effort assessments. Nevertheless, a comprehensive evaluation of these factors' practical significance would entail testing a substantial number of individuals with lower-limb disabilities (Iturricastillo, Yanci, Granados, & Goosey-Tolfrey, 2016).

The current investigation provides evidence supporting a positive association between concurrent resistance and strength training and respiratory physiological performance in wheelchair basketball athletes; nonetheless, certain limitations in the study necessitate further scrutiny. Primarily, the study's small sample size of 32 participants was due to challenges in participant recruitment. Moreover, the inability to regulate participants' dietary and sleep habits constitutes a notable constraint. Furthermore, the unequal gender distribution among participants in the research teams could impede the study's generalizability. The study also overlooked examining socio-emotional factors related to physical activity, indicating another area of constraint. Therefore, future studies should explore similar variables across a broader and more varied sample. Despite these limitations, the outcomes obtained could provide valuable insights for future research initiatives. Consequently, the study's efficacy was enhanced by a methodical approach that yielded immediately applicable positive outcomes for everyday training routines.

Conclusions

Aerobic exercise and strength training play pivotal roles in enhancing physiological responses. Particularly, the combined aerobic anaerobic exercise regimen proposed in this investigation led to noteworthy enhancements in the cardiorespiratory capacity of the subjects. These results underscore the significance of carefully considering the concurrent training to maximize physiological outcomes. The research illustrates that implementing a concurrent training regime is a viable choice for grown-ups, enhancing their physical well-being and involvement. These outcomes carry practical implications for both individuals and elite athletes, indicating the importance of adaptability in crafting workout schedules tailored to personal preferences, time limitations, or specific training goals. Therefore, an exercise regimen incorporating resistance and strength training appears to be the optimal approach for enhancing physiological performance in wheelchair basketball players.

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.; b-ibliographical 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.

References

Aidar, F.J., Cataldi, S., Badicu, G., Silva, A.F., Clemente, F.M., Latino, F., Greco, G., & Fischetti, F. (2022) Paralympic Powerlifting as a Sustainable Way to Improve Strength in Athletes with Spinal Cord Injury and Other Disabilities. *Sustainability*; 14(4):2017. https://doi.org/10.3390/su14042017

Ammann, F., Knuchel, A., Hertig-Godeschalk, A., & Perret, C. (2024). The effects of eccentric arm crank training on upper body performance in elite athletes with a spinal cord injury. *Current Issues in Sport Science (CISS)*, *9*(2), 025-025.

Antonelli, C. B., Hartz, C. S., da Silva Santos, S., & Moreno, M. A. (2020). Effects of inspiratory muscle training with progressive loading on respiratory muscle function and sports performance in high-performance wheelchair basketball athletes: A randomized clinical trial. *International journal of sports physiology and performance*, *15*(2), 238-242.

Bofosa, T., Miangindula, B., & Nkiama, C. (2019). Effectiveness of aerobic exercise and strengthening on the cardiorespiratory endurance of Paralympic basketball players. *Turkish Journal of Kinesiology*, *5*(2), 57-62.

Booth DW, Grogono JS. Athletes with disabilities. In: Harries M, Willams C, Stanish WD, Mcheli LJ, eds. Oxford textbook of sports medicine, 2nd edn. Oxford University Press, New York, 1998: 815–834

Cataldi S, Latino F., Greco, G., Fischetti F. (2019). Multilateral training improves physical fitness and fatigue perception in cancer patients. *Journal of Human Sport and Exercise*, vol. 14, p. 910-920, ISSN: 1988-5202, doi: https://doi.org/10.14198/jhse.2019.14.Proc4.54

Cho, E. H., Choi, B. A., & Seo, Y. (2024). Development of Field Tests for Cardiovascular Fitness Assessment in Wheelchair. In *Healthcare* (Vol. 12, No. 5, p. 580). MDPI.

Cohen, J. (1992). A Power Primer. *Psychological Bulletin, 112*(1), 155-159.https://doi.org/10.1037/0033-2909.112.1.155.

Conners, R. T., Elliott, J. M., Kyle, D. L., Solomon, S., & Whitehead, P. N. (2020). Physiological Responses of Youth Players During Wheelchair Basketball Games. *European Journal of Adapted Physical Activity*, *13*(2).

Croft, L., Dybrus, S., Lenton, J., & Goosey-Tolfrey, V. (2010). A comparison of the physiological demands of wheelchair basketball and wheelchair tennis. *International Journal of Sports Physiology and Performance*, *5*(3), 301-315.

de Jesus, K., Nascimento, L. S., & de Jesus, K. (2024). Symmetric analysis in a wheelchair basketball player during an incremental intermittent test: a case study. *Brazilian Journal of Motor Behavior*, *18*.

De Lira, C. A. B., Vancini, R. L., Minozzo, F. C., Sousa, B. S., Dubas, J. P., Andrade, M. S., ... & Da Silva, A. C. (2010). Relationship between aerobic and anaerobic parameters and functional classification in wheelchair basketball players. *Scandinavian journal of medicine & science in sports*, *20*(4), 638-643.

Farì, G., Di Paolo, S., Ungaro, D., Luperto, G., Farì, E., & Latino F. (2021). The Impact of COVID-19 on Sport and Daily Activities in an Italian Cohort of Football School Children. *International Journal of Athletic Therapy and Training*, *26(5):274-278*. https://doi.org/10.1123/ijatt.2020-0066

Farì, G., Latino, F., Tafuri, F., Dell'Anna, L., Raele, M.V., Fai, A., De Serio, C., Intonti, G., De Salvo, A.L., Ricci, V., et al. (2023). Shoulder Pain Biomechanics, Rehabilitation and Prevention in Wheelchair Basketball Players: A Narrative Review. Biomechanics, 3, 362–376. https://doi.org/10.3390/biomechanics3030030

Farì, G., Quarta, F., Longo, S. C., Masiero, L., Ricci, V., Coraci, D., ... & Bernetti, A. (2024). How does classification score affect falls in wheelchair basketball? A video-based cross-sectional study on the Italian national team during the European Para Championships 2023. *Physical therapy in sport*, *67*, 77-82.

Franklin BA, Swantek KI, Grais SL, Johnstone KS, Gordon S, Timmis GC. (1990). Field test estimation of maximal oxygen consumption in wheelchair users. *Arch Phys Med Rehabil.*;71:574-578.

Gamonales, J. M., Ibáñez, S. J., Muñoz-Jiménez, J., Espada, M. C., & Hernández-Beltrán, V. (2024). External and internal load of wheelchair basketball players. *Journal of Human Sport & Exercise*, *19*(1).

Gass, G.C., Camp, E.M. (1979) Physiological characteristics of trained Australian paraplegic and tetraplegic subjects. *Med Sci Sports Ex* 11: 256–259.

Gavel, E. H., Macrae, H. Z., Goosey-Tolfrey, V. L., & Logan-Sprenger, H. M. (2023). Reliability of anaerobic and aerobic mobility performance tests used in wheelchair rugby, wheelchair basketball and wheelchair tennis: A systematic review. *Journal of Sports Sciences*, *41*(12), 1146-1170.

Gillen, Z. M., Wyatt, F. B., Winchester, J. B., Smith, D. A., & Ghetia, V. (2016). The Relationship Between Aerobic and Anaerobic Performance in Recreational Runners. *International journal of exercise science*, *9*(5), 625–634.

Gottlieb, R., Levi, A., Shalom, A., Gonzalez, J. C., & Meckel, Y. (2024). The Use of Sleds as a Unique Training Technique for Anaerobic Performance Development among Young Basketball Players. *Applied Sciences*, *14*(7), 2696.

Guerra, G., Testa, D., Montagnani, S., Tafuri, D., Salzano, F. A., Rocca, A., ... & Motta, G. (2014). Surgical management of pleomorphic adenoma of parotid gland in elderly patients: role of morphological features. *International Journal of surgery*, *12*, S12-S16.

Hertig-Godeschalk, A., & Perret, C. (2024). How Elite Athletes with a Spinal Cord Injury Sweat during Exercise—An Exploratory Study. *Sports*, *12*(3), 81.

Hjeltnes N. (1977). Oxygen uptake and cardiac output in graded arm exercise in paraplegics with low level spinal lesions. Scand J Rehabil Med.;9(3):107–113.

Iturricastillo, A., Granados, C., Cámara, J., Reina, R., Castillo, D., Barrenetxea, I., ... & Yanci, J. (2018). Differences in physiological responses during wheelchair basketball matches according to playing time and competition. *Research Quarterly for Exercise and Sport*, *89*(4), 474-481.

Iturricastillo, A., Yanci, J., & Granados, C. (2018). Neuromuscular responses and physiological changes during small-sided games in wheelchair basketball. *Adapted Physical Activity Quarterly*, *35*(1), 20-35.

Iturricastillo, A., Yanci, J., Granados, C., & Goosey-Tolfrey, V. (2016). Quantifying wheelchair basketball match load: a comparison of heart-rate and perceived-exertion methods. *International Journal of Sports Physiology and Performance*, *11*(4), 508-514.

Iturricastillo, A., Yanci, J., Los Arcos, A., & Granados, C. (2016). Physiological responses between players with and without spinal cord injury in wheelchair basketball small-sided games. *Spinal Cord*, *54*(12), 1152-1157.

Jackson, A.S., Pollock, M.L., Ward, A. (1980). Generalized equations for predicting body density of women. Med Sci Sports Exerc.;12(3):175–81.

Jackson, A.S., Pollock, M.L. (1978). Generalized equations for predicting body density of men. Br J Nutr. 1978;40(3):497–504.

La Torre, M.E., Monda, A., Messina, A., De Stefano, M.I., Monda, V., Moscatelli, F., Tafuri, F., Saraiello, E., Latino, F., Monda, M., Messina, G., Polito, R., Tafuri, D. (2023). The potential role of nutrition in Overtraining syndrome. Nutrients, 15, 4916. https://doi.org/10.3390/nu15234916.

Latino F., Saraiello, E., Tafuri, F. (2023). Outdoor Physical Activity: A Training Method for Learning in an Experiential and Innovative Way. Journal of Physical Education and Sport (JPES), 23 (7): 1852 – 1860. DOI:10.7752/jpes.2023.07225

Latino F., Tafuri F. (2024a). Physical Activity and Cognitive Functioning. Medicina, 60(2):216. https://doi.org/10.3390/medicina60020216.

Latino, F., & Tafuri, F. (2024b). Wearable Sensors and the Evaluation of Physiological Performance in Elite Field Hockey Players. *Sports*, 12(5), 124.

Latino, F., Cataldi, S., Carvutto, R., De Candia, M., D'Elia, F., Patti, A., ... & Fischetti, F. (2021). The importance of lipidomic approach for mapping and exploring the molecular networks underlying physical exercise: A systematic review. *International Journal of Molecular Sciences*, *22*(16), 8734.

Latino, F., Tafuri, F. (2023). Physical Activity and Academic Performance in School-Age Children: A Systematic Review. Sustainability, 15(8):6616. https://doi.org/10.3390/su15086616

Latino, F., Tafuri, F., Saraiello, E., & Tafuri, D. (2023). Classroom-based Physical Activity as a Means to Improve Self-efficacy and Academic Achievement among Normal-weight and Overweight Youth. Nutrients, 15, 2061. https://doi.org/10.3390/nu15092061.

Liow, D.K., Hopkins, W.G. (1996). Training practices of athletes with disabilities. Adapt Phys Activity Q; 13: 372–81.

Marin-Jimenez, N., Cruz-Leon, C., Sanchez-Oliva, D. et al. (2022). Criterion-Related Validity of Field-Based Methods and Equations for Body Composition Estimation in Adults: A Systematic Review. Curr Obes Rep 11, 336–349. https://doi.org/10.1007/s13679-022-00488-8

Mazzeo, F., Monda, M., Messina, G., Santamaria, S., Messina, A., Montesano, M., ... & Tafuri, D. (2016). Doping in Italy: An analysis of its spread in ten years. *Biology and Medicine*, *8*(1), 1.

Moreno, M. C. T., Saldarriaga, V. C. T., Castro, P. G. G., & Valencia, M. C. M. Z. (2024). Scoping Review on Adapted

Physical Activity and Wheelchair Sports Interventions for Adults with Disabilities.

Morsanuto, S., Peluso Cassese, F., Tafuri, F., & Tafuri, D. (2023). Outdoor Education, Integrated Soccer Activities, and Learning in Children with Autism Spectrum Disorder: A Project Aimed at Achieving the Sustainable Development Goals of the 2030 Agenda. Sustainability, 15(18), 13456.

Muller, E., Benko, U., Raschner, C., et al. (2000). Specific fitness training and testing in competitive sports. Med Sci Sports Exerc; 32: 216–20.

Muscogiuri, G., Palomba, S., Caggiano, M., Tafuri, D., Colao, A., & Orio, F. (2016). Low 25 (OH) vitamin D levels are associated with autoimmune thyroid disease in polycystic ovary syndrome. *Endocrine*, *53*, 538-542.

Okosun, I. S., Bhatt, D. V., Boltri, J. M., & Ndirangu, M. (2008). Self-reported and Measured Height and Weight. *Ethnicity & Disease*, *18*(4), 415-420.

Pereira, R. N., Abreu, M. F. R., Gonçalves, C. B., Corrêa, W. F. S., Mizuhira, D. R., & Moreno, M. A. (2016). Respiratory muscle strength and aerobic performance of wheelchair basketball players. *Motriz: Revista de Educação Física*, *22*, 124-132.

Rietveld, T., Vegter, R. J., der Woude, L. H., & de Groot, S. (2024). The interaction between wheelchair configuration and wheeling performance in wheelchair tennis: a narrative review. *Sports biomechanics*, *23*(3), 370-391.

Rocca, A., Aprea, G., Surfaro, G., Amato, M., Giuliani, A., Paccone, M., ... & Amato, B. (2016). Prevention and treatment of peritoneal adhesions in patients affected by vascular diseases following surgery: a review of the literature. Open Medicine, 11(1), 106-114.

Rothman, K. J. (2008). BMI-related errors in the measurement of obesity. *International journal of obesity*, *32*(3), S56-S59.

Shephard RJ. Sports medicine and the wheelchair athlete. Sports Med 1988: 5: 226–247.

Silva, A.F., Oliveira, R., Cataldi, S., Clemente, F.M., Latino, F., Badicu, G., Greco, G., Leão, C., Bonavolontà, V., & Fischetti, F., (2022). Weekly Variations of Well-Being and Interactions with Training and Match Intensities: A Descriptive Case Study in Youth Male Soccer Players. *International Journal of Environmental Research and Public Health*; 19(5):2935. https://doi.org/10.3390/ijerph19052935

Silveira, S. L., de Groot, S., & Cowan, R. E. (2024). Association between individual wheelchair skills and fitness in community-dwelling manual wheelchair users with spinal cord injuries. *Disability and Rehabilitation: Assistive Technology*, *19*(1), 60-65.

Soylu, Ç., Yıldırım, N. Ü., Akalan, C., Akınoğlu, B., & Kocahan, T. (2021). The relationship between athletic performance and physiological characteristics in wheelchair basketball athletes. *Research Quarterly for Exercise and Sport*, *92*(4), 639-650.

Tafuri F., Latino F. (2024b). School Medical Service: Strategies to Promote Psycho-Physiological Well-Being. Pediatric Reports, 16, 214–231. https://doi.org/10.3390/pediatric16010019

Valent, L. J. M., Dallmeijer, A. J., Houdijk, H., Slootman, J., Janssen, T. W. J., & Hollander, A. P. (2007). The individual relationship between heart rate and oxygen uptake in people with a tetraplegia during exercise. *Spinal cord*, *45*(1), 104-111.

Vanlandewijck, Y. C., Daly, D. J., & Theisen, D. M. (1999). Field test evaluation of aerobic, anaerobic, and wheelchair basketball skill performances. *International journal of sports medicine*, *20*(08), 548-554.

Vokac Z, Bell H, Bautz-Holter E, Rodahl K. (1995). Oxygen uptake/heart rate relationship in leg and arm exercise, sitting and standing. J Appl Physiol. 1975 Jul;39(1):54–59.

Wang, T. (2024). The Impact of Varied Training Approaches on Physical Fitness and Performance. *training (CT)*, *6*(2), 40-44.

Weiner, J.S. and Lourie, J.A., Eds., (1981) Practical human biology. Academic Press, London.

Wicks, J.R., Lumburner, L., Dinsdale, S.M. & Jones, N.L. (1977). The use of multistage exercise testing with wheelchair ergometry and arm cranking in subjects with spinal cord lesions. Paraplegia, 15, 252-26r.

Zwinkels, M., Verschuren, O., Janssen, T. W., Ketelaar, M., Takken, T., Sport-2-Stay-Fit study group, & Sport-2-Stay-Fit study group (2014). Exercise training programs to improve hand rim wheelchair propulsion capacity: a systematic review. *Clinical rehabilitation*, *28*(9), 847–861. https://doi.org/10.1177/0269215514525181

Datos de los/as autores/as y traductor/a:

Francesca Latino	francesca.latino@unipegaso.it	Autor/a
Rosabel Martinez-Roig	rosabel.martinez@ua.es	Autor/a
Hendra Setyawan	hendra7777setyawan@uny.ac.id	Autor/a
Nugroho Susanto	nugrohosusanto@fik.unp.ac.id	Autor/a
Khoiril Anam	khoiril.ikor@mail.unnes.ac.id	Autor/a
Emma Saraiello	esaraiello@uniparthenope.it	Autor/a
Francesco Tafuri	francesco.tafuri@unicusano.it	Autor/a
Bronwen Hughes	*bronwen.hughes@uniparthenope.it*	Traductor/a