Acute effect of caffeine supplementation on neuromuscular performance and repeated-sprint ability in wheelchair rugby players: a case study

Efecto agudo de la suplementación con cafeína en el rendimiento neuromuscular y la capacidad de realizar esprines repetidos en jugadores de rugby en silla de ruedas: estudio de caso

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Abstract

Introduction: Wheelchair sports, such as wheelchair rugby (WR), are intermittent in nature, combining high- and low-intensity actions. Although some data exists on the effects of caffeine intake in WR players, further research using specific physical tests related to the demands of WR gameplay is necessary.
Aims: The aim of this study was to analyze the acute effect of caffeine supplementation on neuromuscular performance and repeated-sprint ability (RSA) in WR players.
Methodology: A total of four WR players participated in this study. Participants ingested 4 mg/kg of anhydrous caffeine dissolved with saccharin in 200 mL of water (CAF) and 200 mL of plain water with saccharin (PLA) 45 minutes before warming up. The following tests were performed: rotator cuff maximum voluntary isometric contraction (MVIC) test, initial maximum push-rim propulsion (IMPRP) test, 10-m sprint test and RSA test (12 x 5 m).
Results: CAF resulted in increased strength and power values in the MVIC and IMPRP tests (≈14.0–18.0%). Also, the CAF group reported a shorter sprint time at 3 (≈5.0%), 5 (≈3.0%), and 10 meters (≈2.0%).
Discussion: Improvements in distance in the IMPRP as well as in a 20m sprint test have previously been reported in WR players after ingesting 4 mg/kg caffeine.
Conclusions: The intake of 4 mg/kg of caffeine 45 minutes before warming up could be slightly enhance performance, especially in neuromuscular actions, in WR players.

Keywords

Cardiorespiratory; ergogenic aid; power; placebo; sprint; strength.

Resumen

Introducción: Los deportes en silla de ruedas, como el rugby en silla de ruedas (RSR), son de naturaleza intermitente, combinando acciones de alta y baja intensidad. Aunque existen algunos datos sobre los efectos de la ingesta de cafeína en jugadores de RSR, son necesarias más investigaciones que utilicen pruebas físicas específicas relacionadas con las exigencias del juego de RSR.
Objetivos: El objetivo de este estudio fue analizar el efecto agudo de la suplementación con cafeína sobre el rendimiento neuromuscular y la capacidad de repetición de sprints (RSA) en jugadores de RSR.
Metodología: Un total de cuatro jugadores de RSR participaron en este estudio. Los participantes ingirieron 4 mg/kg de cafeína anhidra disuelta con sacarina en 200 mL de agua (CAF) y 200 mL de agua simple con sacarina (PLA) 45 minutos antes del calentamiento. Se realizaron las siguientes pruebas: prueba de contracción isométrica voluntaria máxima del manguito de los rotadores (MVIC), prueba de propulsión inicial máxima con aro (IMPRP), prueba de sprint de 10 m y prueba de RSA (12 x 5 m).
Resultados: La CAF produjo un aumento de los valores de fuerza y potencia en las pruebas MVIC e IMPRP (≈14,0-18,0%). Además, el grupo CAF informó de un menor tiempo de sprint a 3 (≈5,0%), 5 (≈3,0%) y 10 metros (≈2,0%).
Discusión: Las mejoras en la distancia en la prueba de IMPRP, así como en una prueba de sprint de 20 metros se han reportado previamente en los jugadores de RSR después de ingerir 4 mg / kg de cafeína.
Conclusiones: La ingesta de 4 mg/kg de cafeína 45 minutos antes del calentamiento podría mejorar ligeramente el rendimiento, especialmente en las acciones neuromusculares en jugadores de RSR.

Palabras clave

Cardiorrespiratorio; ayuda ergogénica; potencia; placebo; esprint; fuerza.

Introduction

Wheelchair rugby (WR) is a Paralympic team sport that originated in Canada during the 1970s (Madden et al., 2018). Initially, WR was developed for athletes with tetraplegia (García-Fresneda et al., 2019). However, individuals with impairments affecting all four limbs (e.g., cerebral palsy, amputations, neuromuscular diseases, and congenital malformations) are also eligible to participate (Goosey-Tolfrey et al., 2021; Mason et al., 2019). WR is classified as an intermittent sport, with matches characterized by prolonged, low-intensity efforts (≤50% of maximum speed) interspersed with short, high-intensity actions (3.48 ± 0.36 m/s) lasting 1.7–1.9 s (Goosey-Tolfrey & Leicht, 2012; Rhodes, Mason, Malone, et al., 2015; Rhodes, Mason, Perrat, et al., 2015). Approximately 75% of active playing time involves low-intensity actions, with players covering distances ranging between 3500 and 4600 m (Goosey-Tolfrey et al., 2021).

The use of sports supplements to optimize physical performance has received significant interest in Paralympic sports over the past decade (Flueck, 2021; Perret & Flueck, 2016). Given the heterogeneity among para-athletes, recommendations on the use of sports supplements are likely to vary considerably (Flueck, 2021; Shaw et al., 2021). Specifically, in WR, caffeine, among other sports supplements, has been reported as one commonly used by athletes (Bauermann et al., 2021; Madden et al., 2018).

The ergogenic effect of caffeine, or 1,3,7-trimethylxanthine, has been extensively studied (Guest et al., 2021; Keisler & Armsey, 2006; Maughan et al., 2018). Caffeine is understood to function through various mechanisms. It appears to block adenosine receptors, resulting in neurotransmitter release, which leads to elevated mood, concentration, and alertness. Additionally, it seems to reduce perceptions of exertion and muscle pain (Graham, 2001; Guest et al., 2021). With regard to musculoskeletal tissue, caffeine appears to benefit muscle contraction through calcium ion (Ca^{2+}) mobilization, facilitating force production per motor unit (Kalmar & Cafarelli, 2004; Rousseau et al., 1988). Furthermore, the fatigue caused by the gradual reduction in Ca^{2+} release could be attenuated following caffeine intake (Ferreira et al., 2022).

Several factors, including dose, timing, habitual use, training level, and genetic predisposition, may influence the effectiveness of caffeine (Martins et al., 2020). General guidelines recommend an intake of 3 to 9 mg/kg of caffeine approximately 60 minutes before exercise, with no additional benefits observed at higher doses (Graham, 2001; Guest et al., 2021; Pickering & Kiely, 2018). However, despite substantial evidence on the effects of caffeine on performance in able-bodied individuals, data on caffeine's effects in athletes with disabilities or Paralympians are limited (Bauermann et al., 2021; Perret & Flueck, 2016; Shaw et al., 2021). Further research is needed, as evidence-based recommendations for able-bodied athletes could be unsuitable for athletes with disabilities due to individual alterations in physiological and metabolic responses (Graham-Paulson et al., 2017).

It is known that in individuals with disabilities, specifically spinal cord injuries (SCI), both metabolic and physiological functions are altered. The level of injury may influence pharmacokinetics (Graham-Paulson et al., 2017; Mestre et al., 2011). Additionally, the upper-body exercise response in individuals with SCI differs from those without disabilities due to differences in muscle mass (Schantz et al., 1997). For these reasons, findings from able-bodied individuals could not be directly applicable to people with SCI. Since current research suggests that the primary mechanism of caffeine at physiological doses is adenosine receptor blockade, which indirectly affects neurotransmitter release, individuals with SCI could represent an interesting study population due to their reduced sympathetic activity and altered catecholamine response (Graham-Paulson et al., 2017; Paulson et al., 2013).

To date, only two studies have reported on the acute effects of caffeine supplementation in WR players. Graham-Paulson et al., (2016) observed in 12 WR players that acute supplementation of 4 mg/kg of caffeine improved both 20 m sprint and push performance. Conversely, Klimešová et al., (2017) reported no significant differences from the placebo group in terms of maximum oxygen consumption (VO_{2max}), maximum power, and heart rate (HR) during an incremental test in 7 elite WR players after ingesting 3 mg/kg of caffeine 60 minutes. It should be noted that participants in the latter study were smokers, and a significant number were habitual coffee consumers.

Wheelchair sports, such as WR, are intermittent in nature, combining high- and low-intensity actions (Goosey-Tolfrey & Leicht, 2012). Although some data exists on the effects of caffeine intake in WR players, further research using specific physical tests related to the demands of WR gameplay is necessary. The ability to accelerate quickly from a stationary position is crucial to WR performance (Vanlandewijck et al., 2001). Additionally, shoulder stabilizing muscles (the rotator cuff, deltoids, and long head of the biceps) play a key role in wheelchair propulsion (García-Fresneda et al., 2019). Despite the importance of the rotator cuff in wheelchair sports, few studies assess the strength of shoulder internal and external rotators (Villacieros et al., 2020). Considering that cardiorespiratory responses have only been measured in continuous incremental tests (Graham-Paulson et al., 2016), it could be valuable to use tests that evaluate repeated maximal intermittent efforts, in line with the physical demands of WR.

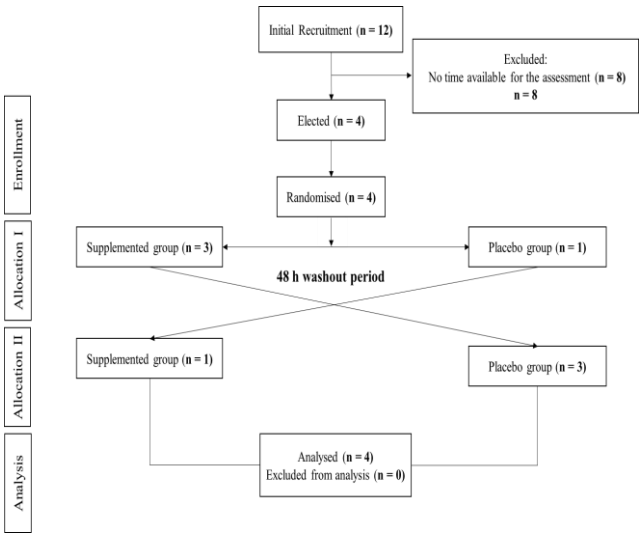
Based on the above, the aim of this study was to analyze the acute effect of caffeine supplementation on neuromuscular performance, as well as the internal and external load during repeat sprint ability (RSA) in WR players. Based on previous studies and scientific literature, we hypothesized that caffeine supplementation could enhance performance in WR players.

Method

Participants

A total of four elite Spanish WR players from the Spanish Federation of Sports for People with Physical Disabilities (FEDDF) participated in this study (Men = 3; Women = 1) (Table 1). Initially, efforts were made to recruit a larger sample of players; however, eight athletes were excluded due to scheduling constraints (Figure 1). All participants were informed verbally and provided written informed consent after receiving detailed information about the study, including its risks and benefits. The study protocol received approval from the Research Ethics Committee of the Catalan Sports Council (015/CEICGC/2023), in compliance with the Declaration of Helsinki.

Figure 1. Flow diagram



The participants were elite players with consistent training routines (3.0 ± 1.22 hours per week; 2.0 ± 0.81 days per week). Additionally, each participant held a classification assigned by the International Wheelchair Rugby Federation (WWR) Classification Committee (World Wheelchair Rugby, 2022). Disabilities among participants included spinal cord injury at levels C6-C7 (n=3) and osteogenesis imperfecta (n=1). Participant characteristics were collected through a questionnaire (Table 1).

To be eligible, participants were required to meet the following criteria: i) be federated athletes; ii) have a minimum of two years of competitive experience in WR; iii) have no medical contraindications for physical exercise and/or caffeine intake; iv) be able to perform the physical test battery independently;

and v) abstain from caffeine consumption throughout the study and one week before the start of the study.

Table 1. Participant characteristics

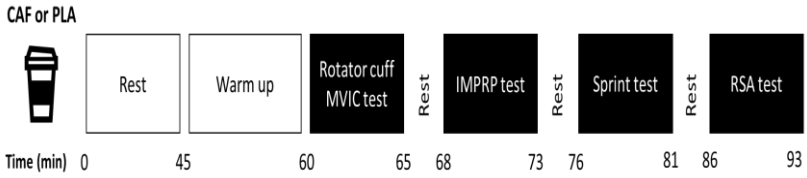
	Sex	Spinal cord injury	WWR classification (Points)*	Age (years)	Height (m)	Body Weight (kg)	Total Weight (BW+WM kg)	Experience (years)
P 1	M	C6-C7	1.5	24	1.92	78.0	95.0	4
P 2	M	C6-C7	2	32	1.70	70.0	90.5	9
P 3	W	OI	3	38	1.35	69.0	77.0	2
P 4	M	C5-C6	0.5	47	1.75	80.0	98.0	5
X ± SD	-	-	-	35.2±9.7	1.68±0.2	74.2±5.5	90.1±9.2	5.0±2.9

P: participant; X ± SD: average ± standard deviation; M: men; W: women; OI: osteogenesis imperfecta; WWR: World Wheelchair Rugby; BW: Body Weight; WM: Wheelchair Weight; * There are seven functional classifications, ranging from 0.5 to 3.5. In general, the 0.5 classification includes athletes with the most severe impairments, while the 3.5 classification includes those with the least severe impairments (World Wheelchair Rugby, 2022).

Procedures

A randomized, controlled, double-blind study design was employed over a total duration of four days, which included two assessment days alternating with two rest days. The study design is defined in Figure 2. Participants attended the laboratory on two separate occasions to perform a series of physical tests: one session followed caffeine supplementation (CAF) and the other followed ingestion of a placebo drink (PLA). The order of physical tests was as follows: i) neuromuscular tests: rotator cuff maximum voluntary isometric contraction (MVIC) test, initial maximum push-rim propulsion test (IMPRP), and 10-m sprint test; ii) repeated sprint ability (RSA) test (12 x 5 m). A rest interval of 3–5 minutes was provided between tests, adjusted according to the physical demands. No familiarization period was implemented, as all participants had previously completed the various physical tests during prior competitive seasons. All tests were conducted in the participants' personal wheelchairs to ensure consistency and relevance to competitive conditions.

Figure 2. Study design



CAF: caffeine; PLA: placebo; MVIC: maximum voluntary isometric contraction; IMPRP: initial maximum push-rim propulsion test; RSA: Repeated Sprint Ability.

After confirming the participation of athletes, group randomization was conducted by a researcher (https://www.randomizer.org/). This researcher, who was not involved in the execution of the physical tests but was involved in the preparation of the CAF or PLA drinks, ensured the blinding and concealment of the allocation. All assessments were conducted in the morning, maintaining consistent conditions across sessions. The laboratory environment was kept stable, with a temperature of 20–25 ºC and 60–65% humidity. Participants were informed to replicate their breakfast and dinner prior to each assessment day to minimize nutritional variability. Additionally, during the rest period, they were advised to avoid any strenuous physical activity.

Caffeine and placebo intake

To control any caffeine-related effects, participants avoided caffeine and caffeine-containing foods or other stimulants for one week before the study began. A researcher, independent of the physical assessments, prepared the doses for the CAF and PLA groups. Both drinks were provided in identical opaque cups with lids to prevent any bias, and each contained five saccharin capsules to standardize taste. The placebo (PLA) group consumed 200 mL of plain water with saccharin, while the caffeine (CAF) group

ingested 4 mg/kg of anhydrous caffeine (226ERS, SPORT THINGS SL, Alicante, Spain) dissolved in 200 mL of water, 45 minutes before warming up (Graham-Paulson et al., 2018; Graham-Paulson et al., 2016). The caffeine was purchased in 100 mg capsules, opened, and dissolved in the drink to ensure precision. A calibrated scale was used to weigh the exact caffeine dose for each participant according to body weight. The caffeine dosage was used in accordance with the recommendations by Graham-Paulson et al., (2016). Furthermore, previous studies have reported that peak caffeine levels in plasma are achieved between 45–60 minutes in athletes with SCI (Graham-Paulson et al., 2017). No gastrointestinal problems were reported.

Rotator cuff maximum voluntary isometric contraction (MVIC) test

The MVIC of the shoulder internal rotators was measured using a calibrated strain gauge (Chronojump v1.7.0.0, Barcelona, Spain). The gauge was positioned perpendicular (0º inclination) to the vertical axis at the participant's elbow height. One end of the gauge was fixed to a railing, while the other end was taped securely to the participant's wrist to ensure a stable grip. Participants were positioned perpendicular to the strain gauge in a fully static position in their wheelchairs, with their glenohumeral joint in a neutral position and the elbow flexed at 90º, disallowing elbow movement from the torso or deviation from 90º flexion. Each participant performed two 5-second repetitions, separated by a 15-second rest interval, maintaining a consistent force throughout each repetition. The highest value sustained between 3–5 seconds from each arm's two attempts was recorded as the best MVIC result. Verbal encouragement was given to maximize exertion (Boettcher et al., 2008).

Initial maximum push-rim propulsion (IMPRP) test

The IMPRP test (García-Fresneda et al., 2019, 2022; Iturricastillo et al., 2023) involved a single, maximum-intensity push from a stationary position, with both arms moving synchronously. Each participant completed two attempts with a 30-second passive recovery period between attempts. Mechanical output was measured using a linear encoder (Chronojump Boscosystem, Barcelona, Spain; precision: ±1 mm, sampling frequency: 1,000 Hz) attached magnetically to a vertical platform. The encoder strap was connected to the wheelchair's horizontal rear axle at a 0º inclination. The associated software (Chronojump v1.7.0.0) calculated the force using instantaneous acceleration values. Each attempt concluded when the instantaneous force dropped to 0, and the repetition with the highest average speed was selected for data analysis.

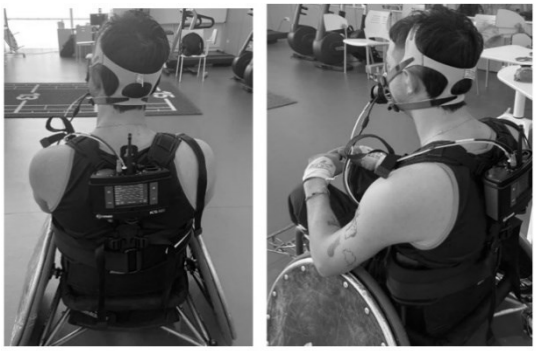
10-m sprint test

Each participant performed two maximum-speed sprints over 10-m, separated by a 2-minute passive rest period. The 10-m course was marked with cones. Participants positioned the front of their wheelchairs at the starting line while keeping their torso behind it. Upon the start signal, participants propelled forward at maximum effort. Race Analyzer (Chronojump Boscosystem 500 Hz, Barcelona, Spain) recorded the time. The device was placed 2 meters behind the starting line. The 10-m sprint test was divided into segments of 3, 5, and 10 meters. The fastest 10-m sprint was selected for evaluation.

Repeated sprint ability (RSA) test

Following the protocol by Romarate et al., (2023), participants completed 12 x 5-m sprints with 10-second active recovery periods between sprints, during which they returned to the starting line. Four photoelectric sensors (Chronojump v1.7.0.0, Barcelona, Spain) monitored sprint time and speed in real time, spaced 5 meters apart with a 3 meters separation. Participants started 0.5 m before the first sensor gate to prevent false starts and continued an additional meter beyond the second gate to avoid deceleration. Cardiorespiratory responses were measured with a portable gas analyzer (K5 COSMED, Rome, Italy) and a heart rate monitor (Polar Electro OY, Kempele, Finland) strapped to the chest. The gas analyzer was securely fastened to the participant's back, as shown in Figure 3.

Figure 3. Portable metabolic analysis equipment K5 Cosmed in the wheelchair.



Data analysis

Dates were processed using IBM SPSS Statistics 25.0 (IBM Corp., Armonk, NY, USA), and figures were generated with GraphPad Software 8 Inc. (Boston, MA, USA). Given the limited sample size, the non-parametric Wilcoxon test for related samples was used (Fagerland, 2012; Kitchen, 2009). However, for parameters involving two factors, such as the sprint test and RSA (number of repetitions, distance covered, and supplementation type), an Analysis of Variance (ANOVA) was employed. In cases where ANOVA was applied, a post hoc Bonferroni test was conducted for multiple comparisons.

For the Wilcoxon test, data were reported as medians and ranges, while ANOVA results were presented as means ± standard deviation. Figure values were shown as individual data points, mean values (displayed as columns), and the mean percentage change. The post hoc statistical power for the Wilcoxon test and ANOVA were calculated as 0.188 and 0.211, respectively, based on an effect size of 0.5 and an alpha level of 0.05. Statistical significance was set at a p-value of <0.05.

Results

The results obtained from the physical tests are presented below. Table 2 shows the results obtained from the rotator cuff MVIC test. The CAF group achieved higher values in maximal force production and average maximal force production over 1 second compared to the PLA group, in both the left and right shoulders. However, the differences were not statistically significant. Figure 4 shows the individual values for each participant and the mean (columns). Improvements were observed in all four participants across all parameters analyzed, with the mean percentage change ranging from approximately ≈14.5% to ≈18.5%.

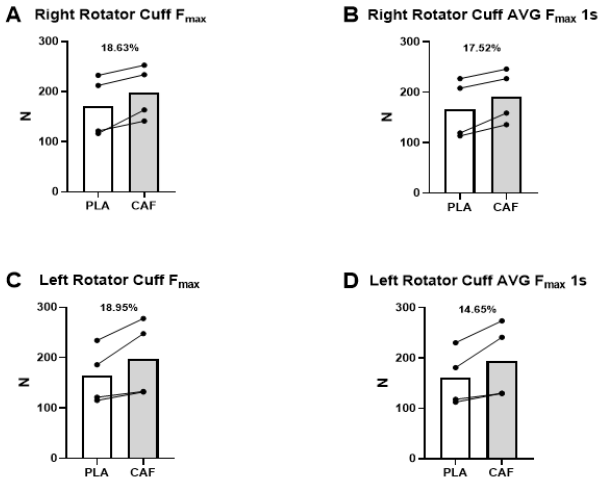
Table 2. Rotator cuff MVIC test.

		Right Rotator Cuff				Left Rotator Cuff			
		PLA	CAF	Z	*p*	PLA	CAF	Z	*p*
Fmax (N)	Median (Ranges)	167.00 (116)	199.00 (112)	-1.82	0.068	154.00 (119)	190.50 (146)	-1.82	0.068
AVG Fmax 1s (N)	Median (Ranges)	163.50 (113)	193.00 (110)	-1.84	0.066	149.50 (119)	185.50 (144)	-1.82	0.068

PLA: placebo; CAF: caffeine; Fmax: maximal force production; AVG: average.

Table 3 presents the results obtained from the IMPRP test. There were no significant differences between the groups. However, a slightly higher performance was observed in the CAF group, particularly in power and force values. On the other hand, Figure 5 displays the individual values for each participant and the meaning (columns). Overall, the CAF group showed improvements in the parameters analyzed, although there were decreases in the values of maximum speed and power.

Figure 4. Individual results obtained in the rotator cuff maximum voluntary isometric contraction test.



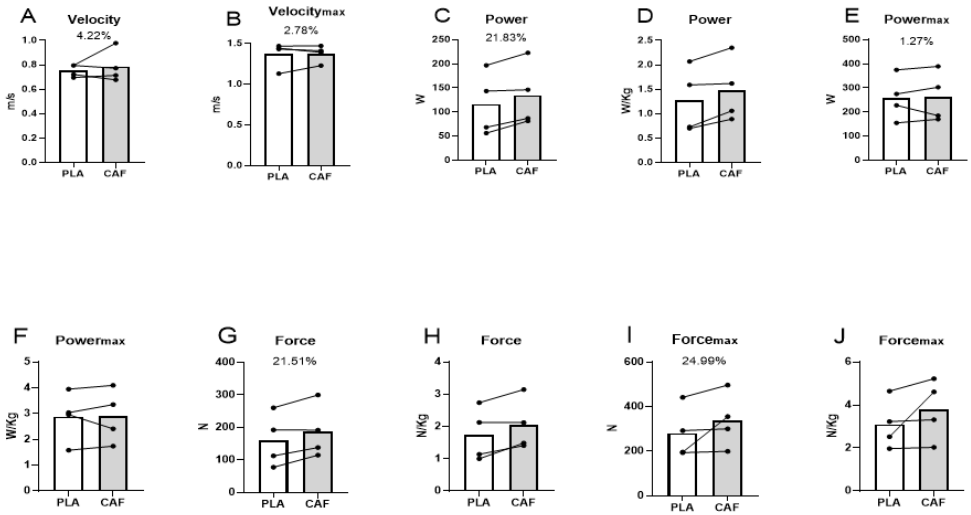
The average values are shown in columns. The percentage shown is the average of the results obtained. **A and B:** Righ Rotator Cuff; **C and D:** Left Rotator Cuff; PLA: placebo; CAF: caffeine; Fmax: maximal force production; AVG: average.

Table 3. IMPRP test.

		PLA	CAF	Z	*p*
Velocity (m/s)	Median (Ranges)	0.758 (0.100)	0.744 (0.300)	0.00	1.000
Velocity$_{max}$ (m/s)	Median (Ranges)	1.43 (0.339)	1.40 (0.250)	0.00	1.000
Power (W)	Median (Ranges)	106.10 (140.70)	116.80 (141.40)	-1.82	0.068
Power (W/kg)	Median (Ranges)	1.159 (1.37)	1.339 (1.45)	-1.82	0.068
Power$_{max}$ (W)	Median (Ranges)	244.30 (219.30)	251.70 (220.40)	-0.365	0.715
Power$_{max}$ (W/kg)	Median (Ranges)	2.879 (2.363)	3.002 (2.370)	-0.365	0.715
Force (N)	Median (Ranges)	152.50 (183.10)	165.05 (185.10)	-1.46	0.144
Force (N/Kg)	Median (Ranges)	1.637 (1.73)	1.805 (1.74)	-1.46	0.144
Force$_{max}$ (N)	Median (Ranges)	249.70 (301.0)	323.75 (248.30)	-0.365	0.715
Force$_{max}$ (N/Kg)	Median (Ranges)	2.929 (3.195)	3.921 (2.670)	-0.365	0.715

PLA: Placebo; CAF: caffeine.

Figure 5. Individual results obtained in the initial maximum push-rim propulsion (IMPRP) test.



The average values are shown in columns. The percentage shown is the average of the results obtained. A: Velocity; B: Velocity maximum; C and D: Power; E and F: Power maximum; G and H: Force; I and J: Force. PLA: placebo; CAF: caffeine.

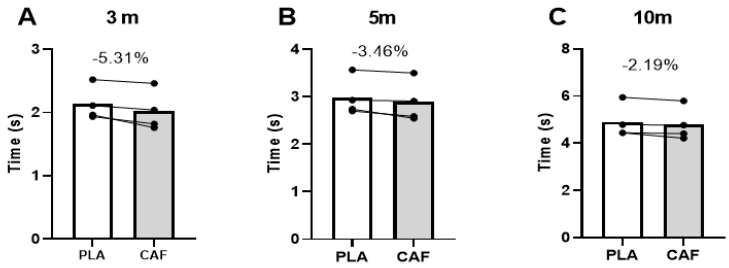
Table 4 and Figure 6 present the results obtained from the 10-metre sprint test. No significant differences were observed between groups. However, the CAF group performed faster sprints compared to the PLA group, with the greatest percentage difference in the first 3 meters (≈5%).

Table 4. 10-m sprint test.

	m	PLA	CAF	Supplement Effect	Distance Effect	Supplement x Repetition
Time (s)	3	2.134±0.270	2.025±0.316	0.617	<0.001	1.000
	5	2.991±0.404*	2.891±0.438*			
	10	4.913±0.714**^^	4.806±0.706**^^			

PLA: Placebo; CAF: caffeine; *p<0.05 and **p<0.01 differences 3 m vs. 5 m and 10 m; ^^p<0.01 differences 5 m vs. 10 m.

Figure 6. Individual results obtained in 10-m sprint test.



The average values are shown in columns. The percentage shown is the average of the results obtained. **A**: 3 meters; **B**: 5 meters; **C**: 10 meters; PLA: placebo; CAF: caffeine.

Finally, Tables 5 and 6, as well as Figures 7 and 8, present the results obtained for internal and external load during the RSA test (12 x 5 m). Table 5 and Figure 7 show the external load data. No statistically significant differences were observed. However, the CAF group completed repetitions 1 to 9 faster. In contrast, the trend reversed in the final repetitions.

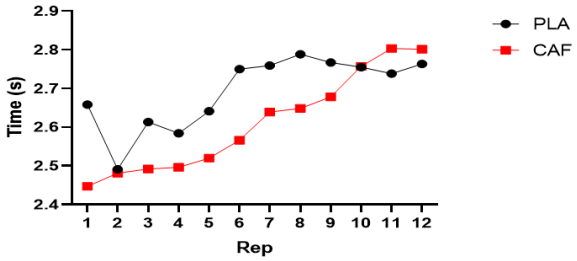
On the other hand, Table 6 and Figure 7 reflect the internal load data (baseline and maximum). The values for oxygen consumption (VO_2), expired volume (VE), and heart rate (HR) were marginally higher in the CAF group, although no statistically significant differences were found.

Table 5. External load in RSA test (12x5 m).

	Repetitions	PLA	CAF	Supplement Effect	Repetition Effect	Supplement x Repetition
Speed (m/s)	1	2.039±0.241	2.066±0.245	0.554	0.996	1.000
	2	2.023±0.226	2.042±0.257			
	3	1.951±0.268	2.042±0.298			
	4	1.971±0.302	2.044±0.313			
	5	1.932±0.330	2.032±0.336			
	6	1.896±0.383	1.989±0.303			
	7	1.908±0.422	1.955±0.368			
	8	1.899±0.446	1.955±0.384			
	9	1.882±0.419	1.936±0.399			
	10	1.901±0.403	1.895±0.414			
	11	1.898±0.376	1.880±0.449			
	12	1.891±0.408	1.875±0.420			
Time (s)	1	2.658±0.392	2.447±0.317	0.507	0.994	1.000
	2	2.490±0.307	2.480±0.343			
	3	2.613±0.345	2.492±0.397			
	4	2.584±0.465	2.495±0.434			
	5	2.640±0.551	2.519±0.482			
	6	2.750±0.682	2.565±0.453			
	7	2.759±0.761	2.639±0.585			
	8	2.788±0.828	2.647±0.617			
	9	2.767±0.812	2.678±0.623			
	10	2.755±0.723	2.756±0.729			
	11	2.738±0.654	2.802±0.822			
	12	2.762±0.744	2.800±0.754			

PLA: Placebo; CAF: caffeine.

Figure 7. Evolution of times in repeated sprint ability test.



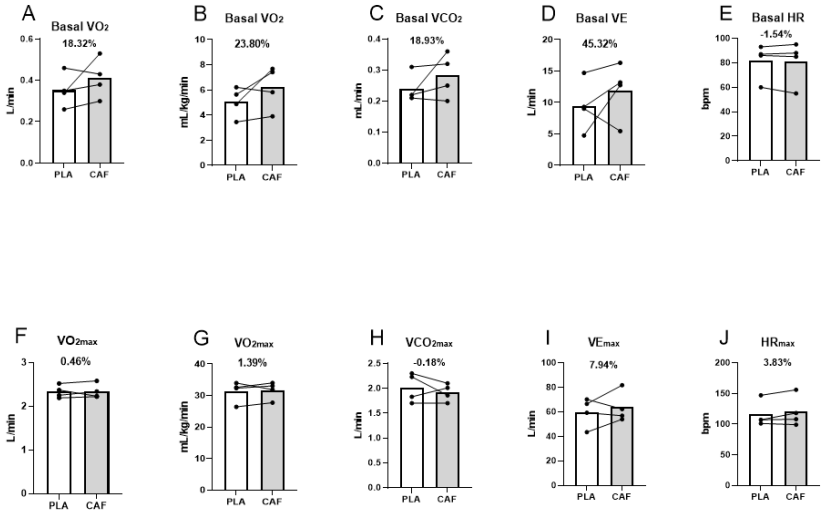
PLA: placebo; CAF: caffeine

Table 6. Internal load in RSA test (12x5 m).

		PLA	CAF	Z	*p*
Basal VO_2 (L/min)	Median (Ranges)	0.360 (0.2009	0.390 (0.230)	-0.736	0.461
Basal VO_2 (mL/kg/min)	Median (Ranges)	5.35 (4.23)	6.81 (3.78)	-1.461	0.144
Basal VCO_2 (L/min)	Median (Ranges)	0.220 (0.100)	0.285 (0.160)	-1.289	0.197
Basal VE (L/min)	Median (Ranges)	9.23 (9.96)	12.56 (10.84)	-1.095	0.274
Basal HR (bpm)	Median (Ranges)	86.50 (33.00)	86.50 (40.00)	-0.184	0.854
VO_{2max} (L/min)	Median (Ranges)	2.28 (0.330)	2.31 (0.360)	-0.365	0.715
VO_{2max} (mL/kg/min)	Median (Ranges)	32.47 (7.56)	33.16 (6.27)	-1.342	0.180
VCO_{2max} (L/min)	Median (Ranges)	2.03 (0.240)	1.98 (0.510)	-0.730	0.465
VE_{max} (L/min)	Median (Ranges)	59.57 (27.85)	62.94 (26.84)	-0.730	0.465
HR_{max} (bpm)	Median (Ranges)	107.50 (46.00)	112.50 (57.00)	-0.730	0.465

VO_2: oxygen uptake; VCO_2: carbon dioxide volume; VE: expired volume; HR: heart rate; PLA: placebo; CAF: caffeine.

Figure 8. Individual results obtained in the repeated sprint ability (RSA) test.



The average values are shown in columns. The percentage shown is the average of the results obtained; A and B: Basal VO2; C: Basal VCO2; D: Basal VE; E: Basal HR; F and G: VO2max; H: VCO2max; I: VEmax; J: HRmax; VO2: oxygen uptake; VCO2: carbon dioxide volume; VE: expired volume; HR: heart rate; PLA: placebo; CAF: caffeine.

Discussion

The aim of this study was to analyze the acute effect of caffeine supplementation on neuromuscular performance, specifically in rotator cuff MVIC, IMPRP and 10-meters sprint test, as well as on both the internal and external loads of RSA in WR players. Small but consistent improvements were observed in neuromuscular and RSA test performance, which could positively influence WR performance. However, given the limited number of participants, results should be interpreted cautiously. To our knowledge,

this is one of the first studies to evaluate the acute effects of caffeine on cardiorespiratory capacity in a WR-specific test. This research aims to expand the evidence on the effect of caffeine in WR players.

The literature on the ergogenic effects of caffeine in athletes with spinal cord injury (SCI) diverges from findings in able-bodied populations (Shaw et al., 2021). While some studies indicate no discernible benefits (Klimešová et al., 2017; Flueck et al., 2014), others have reported beneficial effects similar to those observed in healthy participants (Graham-Paulson et al., 2016). As in the present work, the study by Graham-Paulson et al., (2016) involved WR players with diverse characteristics: SCI (n = 7), cerebral palsy (n = 2), osteogenesis imperfecta (n = 1), distal limb weakness (n = 1), and vanishing-white-matter disease (n = 1). Similarly, the study by Klimešová et al., (2017) included players with injuries ranging from C4 to Th1. Additionally, in the research by Flueck et al., (2014), 9 male and female athletes with injuries from Th4 to L2 participated, including one athlete with spina bifida. As shown in this study's figures, despite the limited number of participants, individual responses to caffeine dosage varied. This aligns with previous findings by Graham-Paulson et al., (2017) who concluded that further research is necessary to stablish specific doses recommendations.

According to previous literature, in athletes with SCI, the optimal caffeine intake time is around 60 to 90 minutes before exercise, with ideal doses ranging between 4–6 mg/kg (Shaw et al., 2021). Prior studies conducted in WR used 3 and 4 mg/kg of caffeine ingested 60–70 minutes before evaluations (Graham-Paulson et al., 2016; Klimešová et al., 2017). In the present study, we administered a dose of 4 mg/kg, consumed 45 minutes before warming up, with physical tests conducted 60 minutes post-ingestion. Among athletes with SCI, it has been reported that caffeine reaches peak plasma concentration 80 minutes after ingestion of a 3 mg/kg dose (Graham-Paulson et al., 2017). Notably, individuals with tetraplegia exhibit higher caffeine concentrations compared to those with lower-level SCI and able-bodied individuals (Graham-Paulson et al., 2017). Additionally, data highlight significant variability within each group. The pronounced increase in caffeine concentrations among athletes with tetraplegia could be attributed to a reduced blood volume due to muscle and vascular atrophy in the lower limbs (Graham-Paulson et al., 2017).

Caffeine is widely used by athletes with physical disabilities (Graham-Paulson et al., 2015), yet few studies have been conducted with this group. Evidence of caffeine's ergogenic effects suggests it could be more beneficial for short-duration, explosive events rather than endurance exercise (Flueck et al., 2015; Graham-Paulson et al., 2018; Graham-Paulson et al., 2016). Notably, results obtained in the different tests used are similar to those reported in previous studies (García-Fresneda et al., 2019; Goosey-Tolfrey & Leicht, 2012). Furthermore, the internal load parameters reported in this study are consistent with those previously observed in WR players (Baumgart et al., 2018; Klimešová et al., 2017).

This study observed slight performance improvements in various tests following caffeine supplementation. Graham-Paulson et al., (2016) previously reported distance improvements in the push test, as well as a 20-meters sprint test in WR players after ingesting 4 mg/kg of caffeine. Similarly, Flueck et al., (2014) reported a higher peak power output in a 3-minute all-out test following the ingestion of 6 mg/kg of caffeine. Graham-Paulson et al., (2018) also used multiple doses (2, 4, and 6 mg/kg) prior to a 20-km handcycling time trial and found that 6 mg/kg yielded greater benefits than 2 mg/kg. However, no benefits in time were observed in a 1500-meters test following caffeine ingestion (Flueck et al., 2014). Generally, scientific literature indicates that caffeine tends to improve strength, time, and power metrics compared to placebo. Concerning RSA external load, higher performance was observed at the beginning and end of the test in terms of speed and time, although performance declined at the end. This may be related to the higher performance observed in brief, intense actions obtained in rotator cuff MVIC, IMPRP and sprint tests. Additionally, the greater intensity used in the initial repetitions may have fatigued participants, reducing performance in the final RSA test phase (Greer et al., 1998). Participants were able to push faster during the initial repetitions of the RSA test, which may have led to the development of fatigue. Consequently, no further improvements were observed, and performance even declined towards the end of the test. Regarding cardiorespiratory capacity, only one study was found that evaluated the effect of caffeine on cardiorespiratory parameters in WR. Klimešová et al., (2017) reported a slight increase in HR and VO2max after ingesting 3 mg/kg of caffeine in an incremental test. However, the nature of the test differed from that in the present study, and the VO2max values were considerably lower in comparison.

The changes observed in the present study following caffeine supplementation could be attributed to various factors (Warren et al., 2010). Caffeine enables the performance of physical exercise at higher intensities for prolonged periods due to a reduction in perceived effort and pain (Maridakis et al., 2007; Motl et al., 2003). It is widely known that caffeine stimulates the central nervous system, specifically through adenosine receptor antagonism (Davis & Green, 2009). Physical exercise can increase adenosine concentration in skeletal muscle. Adenosine, a molecule structurally similar to caffeine, appears to be related to increased pain perception, sleep induction, and inhibition of motor activity (Davis & Green, 2009; Fredholm, 1995). Caffeine exerts an inhibitory effect on adenosine, leading to a modified perception of pain while maintaining motor unit firing frequency and neuroexcitability (Davis & Green, 2009; Guest et al., 2021). Additionally, caffeine increases motor unit recruitment as well as Ca2+ release from the sarcoplasmic reticulum, facilitating force production per motor unit (Kalmar & Cafarelli, 2004; Rousseau et al., 1988). Studies examining catecholamine response to high-intensity exercise have shown increased adrenaline secretion with caffeine administration compared to a placebo (Davis & Green, 2009; Shearer & Graham, 2014; Warren et al., 2010). Higher adrenaline levels could enhance performance by increasing glycolytic flux (Davis & Green, 2009).

The research presents the following limitations: i) sample size was small. However, research on this topic often involves sample sizes of 1 (Graham-Paulson et al., 2018), 7 (Klimešová et al., 2017) o 9 (Flueck et al., 2014) subjects; ii) Nutritional intake in the days prior to assessments was not controlled, although participants were encouraged to consume similar meals beforehand; iii) Absence of caffeine measurement in plasma or saliva; iv) Lack of subjective effort and muscle pain assessment, which could complement the results obtained. Future studies should increase the sample size and provide complementary data (e.g., plasma caffeine levels) to strengthen the findings.

Conclusions

Ingesting 4 mg/kg of caffeine, 60 minutes prior, results in small but consistent improvements in neuromuscular and RSA test performance in WR players. These enhancements appear more pronounced in neuromuscular test, specifically rotator cuff MVIC, IMPRP and 10-meters sprint.

Given the sample size, results should be interpreted cautiously, and there appears to be some interindividual performance variability.

Due to the specific characteristics of the WR tests and their execution (using personal wheelchairs), WR athletes may benefit from 4 mg/kg of caffeine supplementation at least 45 minutes before pre-competition warm-up. However, caffeine supplementation strategies should be individualized. It is recommended that athletes trial caffeine intake during training before implementing it in competition and avoid developing caffeine tolerance to maximize its ergogenic potential.

Since the sample predominantly involved SCI players, this study may help increase understanding regarding caffeine supplementation in this group.

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