

Sanz-Quinto, S.; Moya-Ramón, M.; Brizuela, G.; Rice, I.; López-Grueso, R (2023) ESTRATEGIAS DE HIDRATACIÓN DE UN MARATONIANO CONCENTRADO A 4000 M DE ALTITUD. Revista Internacional de Medicina y Ciencias de la Actividad Física y el Deporte vol. 23(91) pp451-468. <https://doi.org/10.15366/rimcafd2023.91.028>

ORIGINAL

HYDRATION STRATEGIES AT 4000 M ALTITUDE SOJOURN IN A MARATHONER

ESTRATEGIAS DE HIDRATACIÓN DE UN MARATONIANO CONCENTRADO A 4000 M DE ALTITUD

Sanz-Quinto, S.^{1,2}; Moya-Ramón, M.²; Brizuela, G.³; Rice, I.⁴; López-Grueso, R.^{1,5}

¹ Comité Paralímpico Español, España, ² Universidad Miguel Hernández, Elche (Spain) fisiologia@paralimpicos.es

² Universidad Miguel Hernández, Elche (Spain). mmoya@umh.es

³ Universidad de Valencia, Valencia (Spain). gabriel.brizuela@uv.es

⁴ Universidad de Illinois, Urbana-Champaign (USA). ianrice@illinois.edu

⁵ Universidad Isabel I, Burgos (Spain). raul.lopez.grueso@ui1.es

Spanish-English translator: Sanz-Quinto, S.; Rice, I. fisiologia@paralimpicos.es, ianrice@illinois.edu

Código UNESCO / UNESCO code: 241106 Fisiología del Ejercicio

Clasificación Consejo de Europa / Council of Europe classification: 6 Fisiología del Ejercicio

Recibido 11 de abril de 2022 **Received** April 11, 2022

Aceptado 22 de junio de 2023 **Accepted** June 22, 2023

ABSTRACT

The purpose of this study was to evaluate an individualized hydration intervention, and its effects on an elite wheelchair marathon racer's body mass, diuresis, and hydration status at ~4000 m altitude. Total daily fluid intake, urine excretion, fluid intake during training sessions (Fluid), and urine specific gravity upon waking (SG AM) and before bedtime (SG PM) were assessed before, during the course, and after a 5-wk training camp at 3860-4090 m altitude. Body mass and total sodium daily intake (Na⁺) were recorded. Increased fluid requirements (Cohen's d = 1.21) and diuresis (Cohen's d ≥ 2.85) were observed in a wheelchair athlete at altitude. Interestingly, hydric balance (HB) was not ideal ($\pm 2\%$) when following hydration rates suggested for able-bodied athletes.

KEY WORDS: Hypoxia, hydric balance, hyponatremia, marathon, fluid replacement

RESUMEN

El objetivo de este estudio fue evaluar una intervención de hidratación individualizada y sus efectos sobre la masa corporal, diuresis y el estatus de hidratación de un maratoniano de élite en silla de ruedas a ~4000 m de altitud. La ingesta total de líquido diaria, excreción de orina (orina), ingesta de líquido (Fluido) durante los entrenamientos, y la gravedad específica de orina al levantarse (SG AM) y antes de acostarse (SG PM) fueron medidos antes, durante y después de una concentración de 5 semanas a 3860-4090 m de altitud. La masa corporal y la ingesta de sodio (Na^+) se registraron diariamente. Se observó un incremento de los requerimientos de la ingesta de líquido en altitud comparado a nivel del mar (d de Cohen = 1,21), al igual que un aumento de la diuresis (d de Cohen \geq 2,85). Resulta interesante destacar que, siguiendo las recomendaciones de hidratación para atletas a pie, el equilibrio hídrico (HB) no fue el ideal (\pm 2 %).

PALABRAS CLAVES: Hipoxia, equilibrio hídrico, hiponatremia, maratón, intercambio de fluidos.

1. INTRODUCTION

Altitude training among elite endurance athletes has become a popular strategy for performance improvement. However, athletes must contend with a host of physiological challenges in order to derive benefits from these conditions. For example, body mass maintenance is often compromised when athletes train at altitude. Initial body mass loss typically occurs due to water loss, followed by a loss of fat and muscle mass due to malnutrition (Kayser, 1994). Moreover, during altitude acclimatization, there is a reduction of intra and extra cellular water, which combined with a decrease in plasma volume (CONSOLAZIO, Matoush, JOHNSON, & DAWS, 1968); Krzywicki *et al.*, 1971; Jain *et al.*, 1980; Hoyt *et al.*, 1992; (Milledge, 1992) results in a mass loss of up to 2 kg (CONSOLAZIO *et al.*, 1968), Matoush, Johnson & Daws, 1968; (Milledge, 1992). Up to 4000 m altitude, increased ventilation contributes to respiratory water loss (Carlson & Marriott, 1996) along with urinary water loss which may reach 500 mL per day (Butterfield *et al.*, 1992). Consequently, rapid fluid rehydration, may be utilized during altitude training to compensate for water loss, greater diuresis, and increased ventilation (Burke, 1995). Specifically, consumption of 100 mL of fluid every ten minutes during and after training can reduce the effects of dehydration at a comfortable rate (C. Dennis, Noakes, & Hawley, 1997), in order to prevent dehydration and overdrinking (\pm 2 % body mass after training session), which could lead to hyperthermia and hyponatremia, respectively (Kenefick, 2018). In this regard, (Urdampilleta & Gómez-Zorita, 2015) suggest the intake of 500 to 1000 mL \cdot h⁻¹ of a carbohydrate solution with a 4-8 % concentration, a sodium (Na^+) content of 0.5 to 1 g \cdot L⁻¹, and a frequency of intake ranging from 15 to 30 minutes (Abremski & Roben, 2021).

Although assorted studies have examined hydration strategies among long-endurance athletes, there is a dearth of literature focused on hydration strategies for special populations (Rosety et al., 2016; Taneva, Karaolanis, Pipitone, Torsello, & Donas, 2019b). Currently, there are no clinical recommendations for hydration strategies among endurance athletes training at altitude. Importantly, (Na^+) excretion has been reported when acute mountain symptoms (AMS) occurs which may jeopardize both health and performance (Milleedge, 1992).

Therefore, a minimum quantity of Na^+ has been recommended for endurance athletes during long training session ($0.5 - 0.7 \text{ g} \cdot \text{L}^{-1}$) (Cheuvront, Montain, & Sawka, 2007; Von Duvillard, Braun, Markofski, Beneke, & Leithäuser, 2004), occurring at high temperatures ($\geq 22.3^\circ \text{C}$) (Kakamu, Wada, Smith, Endo, & Fukushima, 2017), where carbohydrate solutions should be consumed at a concentration of near 4 % (Urdampilleta & Gómez-Zorita, 2015). In order to reach the optimum daily range of Na^+ , the intake should occur in a range of 1500 to 2300 $\text{mg} \cdot \text{d}^{-1}$ (Cook, Appel, & Whelton, 2014), Appel & Whelton, 2014).

Moreover, the inclusion of Na^+ in drinks for use during exercise and recovery has previously been recommended for several reasons (i.e., stimulate thirst, increased voluntary fluid intake, enhanced glucose and water intestinal absorption, optimized extracellular and intracellular fluid balance, and hyponatremia prevention (plasma sodium $< 135 \text{ mmol} \cdot \text{L}^{-1}$) (Maughan, 2013; Shirreffs, Casa, & Carter III, 2007; Speedy et al., 1999; Vrijens & Rehrer, 1999). Importantly, a study completed with seven trained males at 5050 m altitude demonstrated the urinary Na^+ concentration was only significantly greater compared to sea level ($166 \pm 34 \text{ mEq} \cdot \text{d}^{-1}$) in the acute exposure phase ($427 \pm 46 \text{ mEq} \cdot \text{d}^{-1}$). Furthermore, four weeks after arrival at altitude, values did not differ significantly from sea level ($257 \pm 34 \text{ mEq} \cdot \text{d}^{-1}$) (Zaccaria, Rocco, Noventa, Varnier, & Opocher, 1998), which suggests excess of Na^+ excretion tends to normalize during acclimation phase (Abreu, Duarte, Grande, Lima Neto, & Ottoni, 2020). The purpose of this case study was to administer and evaluate an individualized hydration intervention and its effects on body mass, diuresis, and hydration status of an elite wheelchair marathon racer before, during a five-week altitude training camp in the Peruvian Andes at 3860 m, and immediately after returning to sea level. We hypothesized that utilization of hydration recommendations for able-bodied athletes, would both minimize the impact of high-altitude on body mass and optimize markers of hydration status (i.e., hydric balance).

2. MATERIAL AND METHODS

2.1 Participant

A professional wheelchair athlete took part in this case study. His main features were: (Age = 36 years old; height = 1.76 m; Body Mass = $52.6 \pm 0.4 \text{ kg}$; class T52 (upper limb affection); 107 victories in international road events, including 5 victories at the Boston Marathon, 7 victories at the Oita Wheelchair

Marathon, 1 victory at the London Marathon, and 5 victories at Los Angeles Marathon). The participant was diagnosed at the age of eighteen months with Charcot Marie Tooth disease (CMT) (Banchs, 2009).

Importantly, neuropathy, common to CMT has no effect on the athlete's thermoregulation which is not the case for many athletes with spinal cord injury (SCI) who may display limited sudomotor capacity, and physiological perturbation depending on level of injury (e.g., tetraplegics and quadriplegics). This population is limited in their ability to perform endurance activities, especially at high temperature (Griggs, Stephenson, Price, & Goosey-Tolfrey, 2020). The racing wheelchair used in this study was (Eaglesportschairs-Racing, Snellville, Georgia, USA).

Based on the participants extensive high-altitude training experience at altitudes ranging from 1600 m to 2900 m, the athlete and his coach decided to conduct the base general training period to enhance red blood cell volume (Hopkins, Marshall, Batterham, & Hanin, 2009), three months before racing at the Boston and London Marathons, where he finished first and second respectively. Through several conversations with authors, the athlete received assistance with the implementation of an individualized hydration program, which was designed according to training loads and altitude requirements (Taha & Dizaye, 2022).

2.2 Study design

A multidimensional case study was carried out in combination with a high-altitude sojourn at 3860-4090 m terrestrial elevation in Puno (Peruvian Altiplano) as part of the preparation for the Boston Marathon which would be celebrated ten weeks after finishing the altitude training camp. Moreover, during the sojourn the athlete was training and residing at altitude (Live High – Train High) (Rusko, Tikkanen, & Peltonen, 2004). It should be noted, to date, only one study has exposed a low land resident (lowlanders) to an elevation greater than 3500 m altitude, in this case, 4000 m altitude (Buskirk, Kollias, Akers, Prokop, & Reategui, 1967), in which, Buskirk et al. included collegiate athletes without previous experience in hypoxic conditions.

The current study targeted analysis of the physiological perturbation of different biological systems occurring with the change from training/residing at sea level to training/residing at 4000 m terrestrial altitude, Pre-altitude (W_{-1}) acclimatization (W_1), and post-altitude (W_{+1}) under equivalent training loads. Both W_{-1} and W_{+1} were carried out at 16 m of terrestrial elevation (almost sea level) (Taneva, Karaolanis, Pipitone, Torsello, & Donas, 2019a).

In addition, the high physiologically demanding sessions were set from the 2nd to the 5th weeks at altitude (W_{2-5}). In these weeks the athlete performed one of this training sessions, if he reached a reference value of heart rate variability (Vesterinen et al., 2016): i) Session A, 20 x 400 m repetitions at the second

ventilatory threshold (VT2) with 75 s recovery in a plateau located at 4090 m altitude; ii) Session B, 2 hours at the first ventilatory threshold (VT1) in an altitude elevation ranging from 3860 to 4090 m; iii) Session C, 6 x 2000 m repetitions at the second ventilatory threshold (VT2) with 120 s recovery in a plateau located at 4090 m altitude (AKYOL, CEYHAN, & CAPAPÉ, 2020). Additionally, if the reference value of the heart rate variability was not reached, two workouts below the first ventilatory threshold (<VT1) were accomplished (20 km in the morning and 16 km in the afternoon). Furthermore, maximal strength sessions at the gymnasium were administered Mondays and Thursdays afternoons while Sundays were rest days. Training details are explained deeply in the publication of (Sanz-Quinto, López-Grueso, Brizuela, Flatt, & Moya-Ramón, 2019).

The experiments reported in this study respect the ethical standards and are in accordance with the Declaration of Helsinki. The participant provided written permission for publication of the case study having read the manuscript before the original submission date, which conforms to the principle approved by the Ethics Research Committee of the Miguel Hernandez University (project #DPS.MMR.02.15 with date of approval on December 17th, 2015). Moreover, the participant and researched conformed with the norms from Belmont report, as he was taking part in this study with a double role researcher and participant because this research was part of his doctoral thesis.

2.3 Outcome variables

Ambient temperature and relative humidity were recorded with a portable device (Tenmars TM-183[®], Taipei, Taiwan) attached to the racing wheelchair. Average temperature and humidity were recorded daily 2 minutes prior to training sessions. Body mass was recorded upon wakening in a fasting condition with a scale (Tanita BC-601[®], TANITA Corporation, Tokyo, Japan).

Urine was collected throughout the day (resting and training hours) with a 2000 mL recipient with 100 mL reference marks. For daily recording, urine volume was weighed (Tanita kd-321[®], TANITA Corporation, Tokyo, Japan), while liquid intake was recorded by weighing bottles with liquid on same scale during training and resting hours. Urine specific gravity (SG) was measured upon waking (AM SG) (Mission[®] U500, ACON Laboratories, San Diego, California) and two hours after dinner (PM SG), in order to know the hydration status throughout the day. To estimate Hydric Balance (HB) after each session, we used the formula; $HB = (\text{ingested fluid volume}) - (\text{sweat loss})$ (Armstrong, Johnson, McKenzie, Ellis, & Williamson, 2015) where ingested fluid volume correspond to the liquid intake during a session. If volume suggested (VS) for training was not consumed completely, leftover liquid (LL) was weighed and formula (fluid volume = VS – LL) was applied.

Sweat loss was quantified as the difference between pre and post training body mass, following same body mass recording procedures, as the upon wakening state. In the current study, Na⁺ from solid intake was estimated according to the nutritional composition from database (BEDCA) supported by

Spanish Ministry of Science and Innovation (BEDCA, 2016). In addition, to estimate the Na⁺ intake during training, we consider the nutritional properties of the sport drinks to be explained next.

2.4 Hydration program

The sport drink used for workout routines was Isolin Isotonic (AMIX). It was recommended that the athlete drink ~700 mL solution for workouts at <VT1 and a solution of 1250 mL plus a 70 mL gel in demanding physiological sessions (A, B, C). Recommended drinking rate was 100 mL every 10 min (C. Dennis et al., 1997; Urdampilleta & Gómez-Zorita, 2015).

Alternatively, during resistance training sessions, the athlete was encouraged to drink water *ad libitum*. However, immediately after each gym session a minimum of 400 mL was consumed as a rehydration strategy. Overall, the goal for daily consumption of liquid (Fluid), targeted at 4 to 5 L (Table 1), also SG was inside normal range (≤ 1.20), except AM SG after altitude (W_{+1}), where liquid intake was below 4 L per day (Table 1).

2.5 Statistical analysis

All data are presented as mean (\pm SD). Data were screened for normality of distribution with a Kolmogorov-Smirnov test. A repeated measures ANOVA was carried out for all the variables including factor TIME with levels W_{-1} , W_1 , W_2 , W_3 , W_4 , W_5 , and W_{+1} . A post hoc LSD multiple range test was performed to examine differences between the levels of the factor. Effect size (d) associated with change in body mass, Fluid and urine were calculated using Cohen's d (difference in mean scores over time divided by pooled SD) and were interpreted as trivial ($d \leq 0.19$), small (0.20-0.49), medium (0.50-0.79), and large ($d \geq 0.80$) (Hopkins et al., 2009).

Pearson correlation coefficients were estimated for analyzed variables. Alpha level of 0.05 was stated for the level of statistical significance. Statistical analyses were performed using the SPSS version 22.0 (SPSS, Inc., Chicago, IL, USA) software and Statgraphics version 16.1.17 software (STSC, Inc., Rockville, MD, USA).

3. RESULTS

Results from the hydration intervention are displayed in Tables 1 and 2 below. There was an increase in the fluid intake (Fluid) at the first altitude week (4280.8 ± 723.0 mL in W_{-1} vs 5552.2 ± 1302.6 mL in W_1 ; $p < 0.05$; $d = -1.21$) which decreased after returning to sea level in W_{+1} (3763.6 ± 1321.9 mL; $p < 0.05$; $d = 0.49$). Moreover, a significant decrease throughout the altitude sojourn from W_2 (4628.8 ± 839.6 mL) to W_{+1} (3763.6 ± 1321.9 mL) ($p < 0.05$; $d = 0.78$) was observed.

Table 1. Nutritional parameters, body composition parameters, and hydration status at sea level and altitude.

Phase	Body Mass (kg)	SG AM	SG PM	Fluid (mL)	Na ⁺ (mg)	Urine (mL)
W ₋₁	52.6 ± 0.4 ^{b*** c*** d***}	1.020 ± 0.003	1.014 ± 0.004	4280.8 ± 723.0	2249 ± 845	3504.3 ± 652.4
W ₁	50.7 ± 0.5 ^{f***}	1.014 ± 0.006 ^{a*} c*	1.012 ± 0.006	5552.2 ± 1302.6 ^{a*}	1980 ± 681	4448.0 ± 444.3 ^{a*** c*** d*** e***}
W ₂	50.5 ± 0.2	1.019 ± 0.002	1.008 ± 0.003 ^{a*}	4834.7 ± 850.7	1601 ± 244	3815.0 ± 382.9 ^{b***}
W ₃	50.8 ± 0.4	1.018 ± 0.004	1.012 ± 0.004	4628.8 ± 839.6	1921 ± 568	3610.7 ± 476.1 ^{b***}
W ₄	50.9 ± 0.3 ^{a***}	1.018 ± 0.003	1.016 ± 0.003 ^{c***}	4257.1 ± 499.9 ^{b*}	2033 ± 656	3141.4 ± 471.0 ^{c***}
W ₅	51.2 ± 0.3 ^{a*** c***}	1.018 ± 0.004	1.015 ± 0.004 ^{c***}	4213.1 ± 460.4 ^{b*}	1838 ± 656	3206.4 ± 518.1 ^{c***}
W ₊₁	52.1 ± 0.5 ^{a*** b*** c*** d*** e*** f***}	1.023 ± 0.006 ^{b*}	1.017 ± 0.006 ^{c***}	3763.6 ± 1321.9 ^{b*} c*	2379 ± 750	2526.0 ± 517.3 ^{a*** b*** c*** d*** e*** f***}

W₋₁, pre-altitude week; W₁₋₅ weeks at altitude; W₊₁, post-altitude week.

a, Differences from W₋₁., b, Differences from W₁.

c, Differences from W₂., d, Differences from W₃.

e, Differences from W₄., f, Differences from W₅.

*p < 0.05; ***p < 0.001.

Table 2. Session's fluid intake at sea level and altitude.

Phase	Fluid Vol. 1 (mL)	Fluid Vol. 2 (mL)
W ₋₁	700.0	700.0
W ₁	678.8 ± 219.4 ^{e*}	707.3 ± 12.7
W ₂	1089.2 ± 340.5 ^{b*}	730.0 ± 157.1
W ₃	1199.0 ± 324.8 ^{a*b*}	321.0 ± 29.7 ^{a*b*c*e*f*}
W ₄	1146.7 ± 294.3 ^{a*}	620.0 ± 282.8
W ₅	780.0 ± 270.7 ^{d*e*}	561.3 ± 134.2
W ₊₁	700.0 ^{d*e*}	500.0 ^{a*b*c*d*}

Fluid Vol. 1 & 2 son are the fluid volumes for AM and PM respectively training sessions.

W₋₁, pre-altitude week; W₁₋₅ weeks at altitude; W₊₁, post-altitude week.

a, Differences from W₋₁., b, Differences from W₁.

c, Differences from W₂., d, Differences from W₃.

e, Differences from W₄., f, Differences from W₅.

*p < 0.05.

A significant decrease in body mass was observed upon arrival to altitude (50.7 ± 0.5 kg in W_1 vs 52.6 ± 0.4 kg in W_{-1} ; $p < 0.001$; $d = 4.19$), which normalized, to pre-altitude values after returning to sea level in W_{+1} (52.6 ± 0.5 kg). However, body mass increased throughout the sojourn from W_2 (50.8 ± 0.4 kg in W_2 vs 51.2 ± 0.3 kg in W_5 ; $p < 0.001$; $d = -1.13$). Diuresis increased at altitude (4448.0 ± 444.3 mL in W_1 vs 3504.3 ± 652.4 mL in W_{-1} ; $p < 0.001$; $d = -1.69$), W_2 (3815.0 ± 382.9 mL; $d = 1.53$), W_3 (3610.7 ± 476.1 mL; $d = 1.82$), W_4 (3141.4 ± 471.0 mL; $d = 2.85$) and W_5 (3206.4 ± 518.1 mL; $d = 2.57$) and decreased after returning to sea level in W_{+1} (2526.0 ± 517.3 mL; $p < 0.001$) compared to the rest of periods ($d \geq 1.24$). The observed changes in body mass and diuresis patterns highlight the significant physiological adaptations that occur when individuals are exposed to high altitudes. Upon arrival at altitude (W_1), there was a notable reduction in body mass, with individuals weighing 50.7 ± 0.5 kg, compared to their pre-altitude weight of 52.6 ± 0.4 kg (W_{-1}). This decrease was statistically significant ($p < 0.001$) and indicated an immediate response to the altitude environment. The effect size, as indicated by Cohen's d , was substantial at 4.19, underlining the magnitude of this change. However, it is noteworthy that upon returning to sea level in W_{+1} , body mass fully normalized, reaching the pre-altitude values of 52.6 ± 0.5 kg. This recovery suggests that the initial decrease in body mass was a transient response to altitude exposure, and the body was able to regain lost weight upon returning to lower elevations.

Fluid changes in normoxia and hypoxia conditions as function of urine volume excretion can be observed in Figure 1. AM SG was lower in the first week of altitude exposure (1.010 ± 0.006 in W_1 ; $p < 0.05$; $d = 2.23$), compared to pre-altitude in W_{-1} (1.020 ± 0.002), second week at altitude W_2 (1.019 ± 0.002 ; $d = -2.01$), and after returning to sea level in W_{+1} (1.023 ± 0.006 ; $d = -2.17$). Data concerning training sessions is shown in Table 3. Regarding hydric balance (HB), we observed positive HB in every training session, with the exception of one strength session performed at the gym, where temperature was higher than usual (21° C). Interestingly, we observe an HB $> 2\%$ of the body mass in 9 sessions, all of them specific sessions (#3A; #3B; #3C). Moreover, HB was $\geq 2.5\%$ of body mass in two training sessions, where ambient temperature was $\leq 5^\circ$ C and relative humidity was $\leq 46\%$. In those sessions the Fluid rate was (820.4 mL \cdot h $^{-1}$ and 597.2 mL \cdot h $^{-1}$). Another interesting result was observed after returning to sea level in W_{+1} , where Fluid intake during training sessions was in the range of 503.1 to 599.4 mL \cdot h $^{-1}$. According to each type of session, average fluid intake per hour was: 586.8 ± 102.7 mL \cdot h $^{-1}$ for 20 km $<VT_1$ sessions; 749 ± 86.5 mL \cdot h $^{-1}$ for 16 km $<VT_1$ sessions; 495.4 ± 175.6 mL \cdot h $^{-1}$ for strength sessions; 834.4 ± 17.9 mL \cdot h $^{-1}$ for A session; 704.9 ± 130 mL \cdot h $^{-1}$ for B sessions; 642.2 ± 34.7 mL \cdot h $^{-1}$ for C sessions. We found a negative moderate correlation between ambient temperature and HB ($r = -0.37$; $p = 0.006$), also a moderate correlation was found between HB and Fluid ($r = 0.53$; $p = 0.001$). As expected, Fluid showed a strong correlation with urine production ($r = 0.67$; $p = 0.001$). A negative moderate correlation was found between sweat loss and HB ($r = -0.59$; $p = 0.001$).

Table 3. Hydric balance (HB), fluid intake, and water loss at sea level and altitude.

Date	Day	Phase	Altitude (m)	AM Session (km)	PM Session (km)	Duration (h-min-s)	Temp. (C)	Hum. (%)	Fluid Vol. (mL)	Intake Rate (mL · h ⁻¹)	Water Loss (mL)	HB (mL)
6/01/16	3	W ₋₁	16	19.9 <VT1		1:06:30	13	56	700	631.6	500	200
6/01/16	3	W ₋₁	16		16.8 <VT1	0:59:38	16	61	700	704.3	300	400
7/01/16	4	W ₋₁	16	20.3 <VT1		1:06:17	22	52	700	633.6	200	500
7/01/16	4	W ₋₁	16		16.8 <VT1	0:52:45	23	56	700	796.2	100	600
8/01/16	5	W ₋₁	16	20.2 <VT1		1:04:22	19	53	700	652.5	300	400
8/01/16	5	W ₋₁	16		16.2 <VT1	0:50:24	23	58	700	833.3	100	600
9/01/16	6	W ₋₁	16	17.8 <VT1		0:56:53	15	63	700	738.4	150	550
9/01/16	FLIGHT ALICANTE-MADRID-LIMA-JULIACA-CAR DRIVE TO PUNO											
10/01/16												
10/01/16												
13/01/16	10	W ₁	3860	20.1 <VT1		1:15:40	9	44	350	277.5	0	350
13/01/16	10	W ₁	3860		15.7 <VT1	1:06:55	15	48	700	627.6	200	500
14/01/16	11	W ₁	3860	20.2 <VT1		1:12:49	5	41	800	659.2	100	700
14/01/16	11	W ₁	3860		16.2 <VT1	0:59:12	17	51	722	731.8	300	400
15/01/16	12	W ₁	3860	20.2 <VT1		1:11:10	10	40	790	666.1	100	690
15/01/16	12	W ₁	3860		16.2 <VT1	0:58:58	17	44	700	712.3	200	500
16/01/16	13	W ₁	3860	20.2 <VT1		1:09:46	5	49	775	666.5	100	675
18/01/16	15	W ₂	3860	16.2		1:03:06	11	51	775	736.9	300	475

				<VT1		Rain						
18/01/16	15	W ₂	3860		Strength	1:10:00	17	47	590	505.7	300	290
19/01/16	16	W ₂	4090	20 x 400 m		1:42:23	4	46	1400	820.4	100	1300
20/01/16	17	W ₂	3860	20.2 <VT1		1:13:58 Rain	11	45	775	628.7	100	675
20/01/16	17	W ₂	3860		16.2 <VT1	0:55:25	17	49	700	757.9	500	200
21/01/16	18	W ₂	3860	16.3 <VT1		0:54:20	10	46	785	866.9	200	585
21/01/16	18	W ₂	3860		Strength	1:10:00	17	48	900	771.4	300	600
22/01/16	19	W ₂	3860- 4090	29.7 VT1		2:20:40	2	44	1400	597.2	100	1300
23/01/16	20	W ₂	4090	6 x 2000 m		2:03:34	4	45	1400	679.8	300	1100
25/01/16	22	W ₃	3860	16.3 <VT1		0:54:45	11	52	785	860.3	400	385
25/01/16	22	W ₃	3860		Strength	1:10:00	21	51	300	257.1	1300	-1000
26/01/16	23	W ₃	4090	20 x 400 m		1:39:00	5	51	1400	848.5	200	1200
27/01/16	24	W ₃	3860	30.4 VT1		1:36:54	18	53	1434	887.9	800	634
28/01/16	25	W ₃	3860	16.2 <VT1		0:55:41	9	54	775	831.1	300	475
28/01/16	25	W ₃	3860		Strength	1:10:00	16	44	342	293.1	0	342
29/01/16	26	W ₃	4090	6 x 2000 m		2:06:08	7	51	1400	665.9	300	1100
30/01/16	27	W ₃	4090	20 x 400 m		1:38:11	5	43	1400	855.5	0	1400
1/02/16	29	W ₄	3860	16.3 <VT1		0:57:31	7	52	775	808.5	0	775
1/02/16	29	W ₄	3860		Strength	1:10:00	16	50	820	702.9	300	520
2/02/16	30	W ₄	3860- 4090	29.7 VT1		2:06:20	10	48	1400	664.9	300	1100
3/02/16	31	W ₄	4090	6 x 2000 m		2:01:12	9	46	1280	633.7	300	980

4/02/16	32	W ₄	3860	16.3 <VT1	0:54:42	6	44	775	850.1	100	675
4/02/16	32	W ₄	3860	Strength	1:10:00	14	49	420	360	0	420
5/02/16	33	W ₄	4090	20 x 400 m	1:43:17	10	51	1400	813.3	600	800
6/02/16	34	W ₄	3860- 4090	28.7 VT1	1:59:05	8	44	1250	629.8	0	1250
9/02/16	37	W ₅	3860	16.3 <VT1	0:53:52	11	51	700	779.7	100	600
9/02/16	37	W ₅	3860	Strength	1:10:00	14	48	552	473.1	0	552
10/02/16	38	W ₅	3860	20.3 <VT1	1:03:31	9	49	550	519.5	100	450
10/02/16	38	W ₅	3860	16.3 <VT1	0:54:28	16	53	700	771.1	400	300
11/02/16	39	W ₅	3860	16.3 <VT1	0:53:32	7	44	700	784.5	0	700
11/02/16	39	W ₅	3860	Strength	1:10:00	16	51	700	600	200	500
12/02/16	40	W ₅	4090	6 x 2000 m	2:07:13	7	49	1250	589.5	200	1050
13/02/16	41	W ₅	3860	20.3 <VT1	1:07:24	14	48	700	623.1	200	500
15/02/16	CAR DRIVE PUNO-JULIACA FLIGHT JULIACA-LIMA-MADRID-ALICANTE										
16/02/16											
17/02/16	45	W ₊₁	16	20.3 <VT1	1:10:24	16	61	700	596.6	1200	-500
17/02/16	45	W ₊₁	16	16.2 <VT1	0:53:23	12	44	500	561.9	300	200
18/02/16	46	W ₊₁	16	20.3 <VT1	1:03:05	12	41	700	570.7	100	600
18/02/16	46	W ₊₁	16	16.2 <VT1	0:47:47	17	57	500	627.8	400	100
19/02/16	47	W ₊₁	16	20.3 <VT1	1:02:38	11	53	700	503.1	0	700
19/02/16	47	W ₊₁	16	16.5 <VT1	0:50:03	13	61	500	599.4	100	400

Temp., Ambient temperature; Hum., Ambient humidity; Water loss, body mass difference between pre- and post-session.

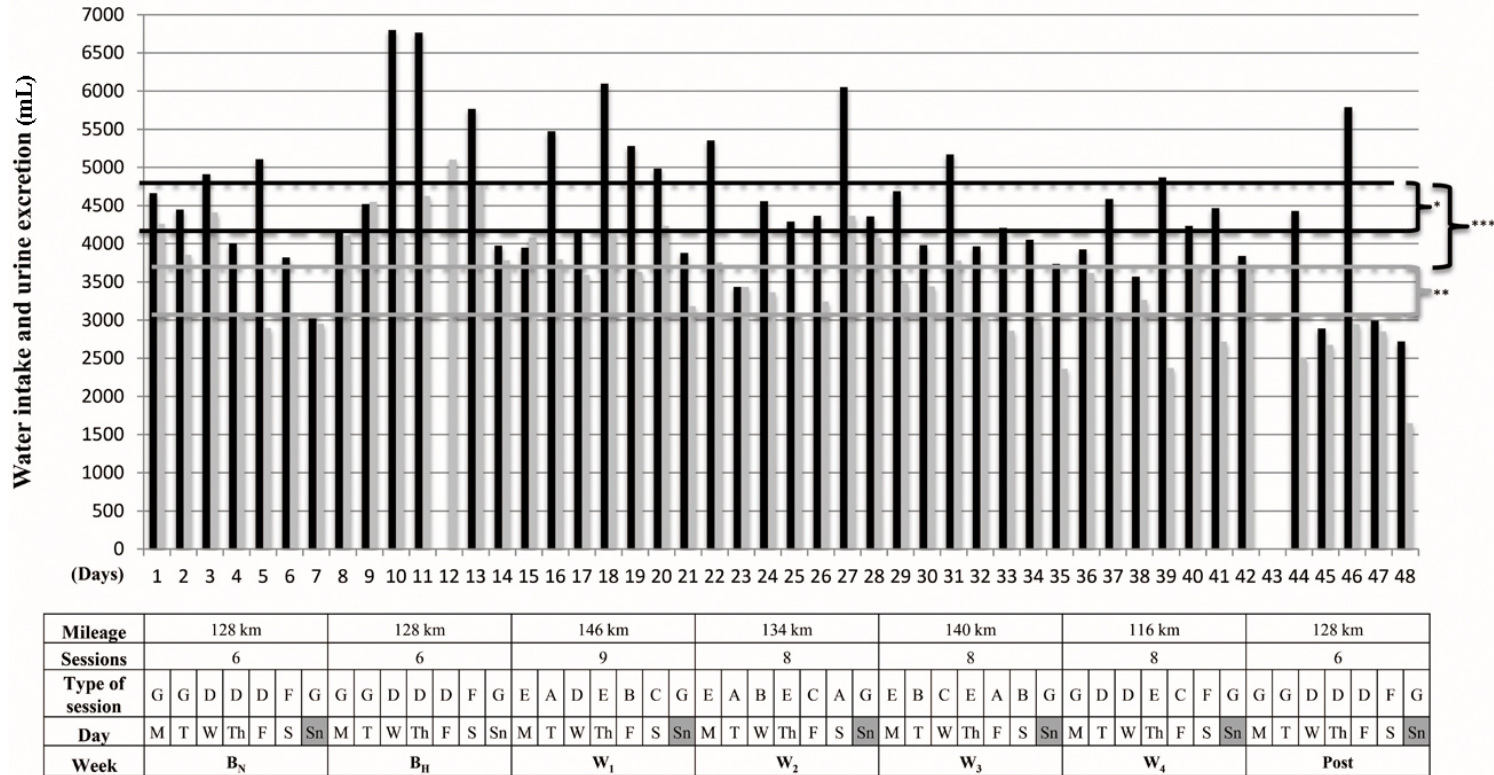


Figure 3. Training program and daily water intake plus urine excretion during W₋₁, W_{1,2,3,4,5} and W₊₁

Session A: 20 x 400 m VT2. Session B: 2 hours VT1. Session C: 6 x 2000 m VT2. Session D: 20 km < VT1 in the morning + 16 km < VT1 in the afternoon. Session E: 16 km < VT1 in the morning + resistance session in the afternoon. Session F: 20 km < VT1 in the morning + resting afternoon. Session G: Rest day. Black columns: Represent daily water intake. Grey columns: Represent daily urine excretion.

Dashed black line: Represents mean water intake (4065 mL) under normoxic conditions at 16 m altitude. Round dotted black line: Represents mean water intake (4634 mL) under hypoxic conditions at 3860 m altitude. Dashed grey line: Represents mean urine excretion (3097 mL) under normoxic conditions at 16 m altitude. Round dotted grey line: Represents mean urine excretion (3644 mL) under hypoxic conditions at 3860 m altitude. Differences from water intake under normoxic conditions: * p < 0.1. Differences from urine excretion under normoxic conditions: ** p < 0.01. Differences between water intake and urine excretion under altitude conditions: *** p < 0.001.

4. DISCUSSION

The present case report suggests differences in the hydration needs between wheelchair racing and able-bodied marathoners, however results should be interpreted cautiously, because high altitude training scenarios are not well described well in the literature, particularly above 4000 m elevation (Buskirk et al., 1967). Indeed, there are only a few studies reporting the biological response of athletes (sprinters and middle-distance collegiate athletes) to elevations close to 3000 m altitude, however with little focus on hydration status or training programs (we highly recommend the Lexington – Leadville studies led by professors Reeves and Grover). Ultimately, use of the hydration strategies for able-bodied endurance athletes led us to the belief that our participant should reduce his fluid intake rate compared to conventional able-bodied athletes (C. Dennis et al., 1997), expressed in $\text{mL} \cdot \text{h}^{-1}$ at sea level and altitude. Importantly, to sustain performance while minimizing the occurrence of hyponatremia and cardiovascular and thermoregulatory strain during long continuous and intervalic sessions, we recommend wheelchair athletes follow hydration strategies deeply described in our study. However, special attention should be applied to athletes with spinal cord injury levels above C7 as they display perturbations in their sudomotor capacity (Griggs et al., 2020).

In the current study at high-altitude (3500 to 5500 m) greater ventilation (Butterfield et al., 1992) and increased urinary water loss (Butterfield et al., 1992), could explain the nearly 2 kg weight loss observed from W_{-1} to W_1 , and the return to pre-altitude body mass levels after returning to sea level (W_{+1}) (Table 1). In fact, from acclimatization, hydration levels appeared optimal (Stover, Petrie, Passe, Horswill, Murray & Wildman R, 2006), as reflected by a lower AM SG at W_1 compared to W_{-1} , and a positive HB during all training sessions. However, an excessive positive HB (2.57 %) observed in two sessions, may have been influenced by low ambient temperature (2 to 4° C), which reportedly causes decreased sweating rate when exercising at low ambient temperatures (Chapman & Levine, 2007). Therefore, a reduction in Fluid intake during training of about 200 $\text{mL} \cdot \text{h}^{-1}$ in one session, in which average Fluid rate was 820.4 $\text{mL} \cdot \text{h}^{-1}$, would have guaranteed the minimum Fluid intake recommended (C. Dennis et al., 1997). Nevertheless, in the other session, the Fluid rate was below recommendations (597.2 $\text{mL} \cdot \text{h}^{-1}$), suggesting possible differences in hydration needs between able-bodied athletes and wheelchair athletes. Those differences may be explained by lower mobilization of muscle mass among wheelchair athletes, as muscle mass is associated with an increase in metabolic heat production (Kenny & Flouris, 2014), which may have been even more pronounced in our participant who has greater upper limb muscles atrophy due to his disability (Banchs, 2009). Thus, a possible solution could be to follow recommendations from (Urdampilleta & Gómez-Zorita, 2015) for drinking 500 $\text{mL} \cdot \text{h}^{-1}$.

The fact that our athlete was able to maintain his body mass at ± 2 % after training sessions (Kenefick, 2018) with a lower fluid intake than the recommended for able-bodied athletes, support our hypothesis previously posed. Specifically, that

following hydration strategies suggested for able-bodied athletes, would minimize the negative impact of high-altitude on body mass, and hydration status markers as HB would be optimized, as it is true that among elite-marathoners dehydration rates are over 4 % of body mass (Beis, Wright-Whyte, Fudge, Noakes, & Pitsiladis, 2012).

An interesting observation was evident in the lower or equal PM SG compared to AM SG, reflecting an optimal SG throughout the entire day, week by week (Table 1). Moreover, there were no reported AMS symptoms, which might be explained by an increase in the diuresis observed upon altitude arrival in W_1 , as water retention has been associated with AMS (Hackett et al., 1982; Milledge, 1992). Noteworthy, this enhancement of diuresis might be facilitated by the daily fluid intake target ($4 \text{ L} \cdot \text{d}^{-1}$), recommended for altitude sojourns by Randy Wilber (Wilber, 2004). Our athlete demonstrated less than 2 % sweat loss, compared with runners (Kenefick, 2018), at sea level with temperatures close to $20 \text{ }^\circ\text{C}$, all occurring without gastrointestinal issues (GI). This supports the notion that optimal hydration levels were achieved. In fact, a lower rate of $600 \text{ mL} \cdot \text{h}^{-1}$ (C. Dennis et al., 1997) would have been effective for maintaining hydration.

Finally, Na^+ did not reach the minimum quantity recommended during workouts at $<VT_1$ ($0.13 \text{ g} \cdot \text{L}^{-1}$) and “A”, “B”, “C” specific sessions ($0.17 \text{ g} \cdot \text{L}^{-1}$) (Cheuvront et al., 2007; Von Duvillard et al., 2004), except on one occasion, where the athlete was encouraged to drink *ad libitum* due to unexpectedly high temperatures. To reach the 4 L daily fluid consumption goal, researchers utilized a strategy where the athlete was encouraged to avoid feeling thirsty. Ultimately, this practice led to lower or equal PM SG values compared to AM SG, and beyond an optimal PM SG week by week (Table 1).

Furthermore, no AMS symptoms were reported by the athlete, which could be due to an increase in diuresis at B_H (Table 1), as retention of water has been related to AMS (BEDCA, 2016 ; Hackett et al., 1982). An interesting observation was evident in that our athlete demonstrated less than 2 % sweat loss, compared with runners (Kenefick, 2018), at sea level with temperatures close to 20°C , all occurring without GI. This supports the notion that optimal hydration levels were achieved. In fact, a lower rate of $600 \text{ mL} \cdot \text{h}^{-1}$ (C. Dennis et al., 1997) would have been effective for maintaining hydration. Finally, Na^+ did not reach the minimum quantity recommended during workouts at $<VT_1$ ($0.13 \text{ g} \cdot \text{L}^{-1}$) and “A”, “B”, “C” specific sessions ($0.17 \text{ g} \cdot \text{L}^{-1}$) (Cheuvront et al., 2007; Von Duvillard et al., 2004).

On the other hand, the participant exhibits a body mass loss of 2 % after a session performed at sea level (16°C , 61 % relative humidity), which is notoriously lower than the one reported among elite able-bodied marathoners (-8 %) (Cheuvront et al., 2007), however, we have previously mentioned that over 4 % is normal among elite marathoners (Beis et al., 2012). This observation might be explained due to the lower muscle mass of our participant, the lower metabolic demand associated with physical activities performed with the upper limbs, and the intensity differences between both studies. In fact, lower liquid intake than the 600

$\text{mL} \cdot \text{h}^{-1}$ suggested for endurance athletes (C. Dennis et al., 1997; Périard, Cramer, Chapman, Caillaud, & Thompson, 2011) may have effectively preserved optimal hydration status, avoiding overhydration which could lead to hyponatremia (Kenefick, 2018). Apart from that, in high ambient temperature conditions, the heat storage from wheelchair athletes will be greater than able-bodied athletes due to an increase in radiation mechanisms, and also by the limitation to remove heat by convection mechanism in the body surfaces covered by wheelchair frame (Griggs et al., 2020; Sawka et al., 2007).

It is very important to consider that Na^+ did not reach the recommended amount during workouts $< \text{VT}_1$ ($0.13 \text{ g} \cdot \text{L}^{-1}$) and specific sessions ($0.17 \text{ g} \cdot \text{L}^{-1}$) (Von Duvillard et al., 2004) (Köse et al., 2017). However, researchers have demonstrated hyponatremia leading to lower diuresis, where a lower rate of urine production correlated with a greater rate of Na^+ decrease ($r = -0.478$; $p = 0.0447$) (Vrijens & Rehrer, 1999). As this was not observed in the current study (Table 1), it leads us to believe that our participant Na^+ requirements were met. In addition, our results regarding Na^+ in W_1 are not in line with (Zaccaria et al., 1998), however, our participant sessions intensity were lower compared to Zaccaria's study, where sessions were conducted until exhaustion. Ultimately our athlete's daily intake of Na^+ (1500 to $2300 \text{ mg} \cdot \text{d}^{-1}$) met suggested quantities (Cook et al., 2014).

5. CONCLUSIONS

We have observed in our study that a professional wheelchair athlete increased his HB in several training sessions performed at altitude when he strictly followed hydration strategies recommended for endurance able-bodied athletes, despite the fact that his hydration needs may be lower compared to able-bodied marathoners. However, at sea level with high ambient temperatures, a wheelchair athletes limited ability to disperse heat might impose a greater metabolic demand then we can adjust fluid intake for, therefore adjusting to HB levels reported previously in several sessions may suffice.

It is recommended in future studies with similar features that participants, who train at high-altitudes consider:

1. The type and duration of session
2. The implementation of the assessment of non-invasive variables which allow for the observation of hydration status (SG, Na^+ , ...)
3. Assessment of diuresis
4. Guarantee $\sim 500 \text{ mL} \cdot \text{h}^{-1}$ or $8 \text{ mL} \cdot \text{min}^{-1}$ during training and $4 \text{ L} \cdot \text{d}^{-1}$
5. To monitor the ambient temperature, particularly if it decreases below 5°C

All with the aim of maintaining performance, while reducing cardiovascular strain, and the occurrence of hyponatremia during long training sessions.

6. REFERENCES

- Abremski, D., & Roben, P. (2021). UC San Diego, The Military and Building a Unique, Diversified Economic Growth Ecosystem. *Journal of Commercial Biotechnology*, 26(1). doi:<https://doi.org/10.5912/jcb974>
- Abreu, B. F., Duarte, M. L., Grande, M. G., Lima Neto, N. M., & Ottoni, E. F. (2020). Eosinophilic granuloma: an unusual finding in adults. *Jornal Brasileiro de Patologia e Medicina Laboratorial*, 56. doi:<https://doi.org/10.5935/1676-2444.20200025>
- AKYOL, O., CEYHAN, T., & CAPAPÉ, C. (2020). The second record of marlin sucker, *Remora osteochir* (Echeneidae) from the Turkish waters (eastern Mediterranean Sea). *FishTaxa*, 17, 12-14.
- Armstrong, L. E., Johnson, E. C., McKenzie, A. L., Ellis, L. A., & Williamson, K. H. (2015). Ultraendurance cycling in a hot environment: thirst, fluid consumption, and water balance. *The Journal of Strength & Conditioning Research*, 29(4), 869-876.
- Banchs, I., Casasnovas, C., Alberti, A., De Jorge, L., Povedano, M., Montero, J., Martínez-Matos, J. A. & Volpini, V. (2009). Diagnosis of Charcot-Marie-Tooth Disease. *BioMed Research International*, 1-10. doi:10.1155/2009/985415
- BEDCA. (2016). Spanish Ministry of Science and Innovation [Internet]. Madrid: Base de Datos Española de Composición de Alimentos (BEDCA). Retrieved from <http://www.bedca.net/bdpub/index.php>
- Beis, L. Y., Wright-Whyte, M., Fudge, B., Noakes, T., & Pitsiladis, Y. P. (2012). Drinking behaviors of elite male runners during marathon competition. *Clinical Journal of Sport Medicine*, 22(3), 254-261.
- Burke, L. (1995). Practical issues in nutrition for athletes. *Journal of Sports Sciences*, 13(S1), S83-S90.
- Buskirk, E., Kollias, J., Akers, R., Prokop, E., & Reategui, E. P. (1967). Maximal performance at altitude and on return from altitude in conditioned runners. *Journal of Applied Physiology*, 23(2), 259-266.
- Butterfield, G. E., Gates, J., Fleming, S., Brooks, G. A., Sutton, J. R., & Reeves, J. T. (1992). Increased energy intake minimizes weight loss in men at high altitude. *Journal of Applied Physiology*, 72(5), 1741-1748.
- C. Dennis, S., Noakes, T., & Hawley, J. (1997). Nutritional strategies to minimize fatigue during prolonged exercise: fluid, electrolyte and energy replacement. *Journal of Sports Sciences*, 15(3), 305-313.
- Carlson, S. J., & Marriott, B. M. (1996). Nutritional needs in cold and high-altitude environments: applications for military personnel in field operations.
- Chapman, R., & Levine, B. D. (2007). Altitude training for the marathon. *Sports Medicine*, 37, 392-395.
- Cheuvront, S. N., Montain, S. J., & Sawka, M. N. (2007). Fluid replacement and performance during the marathon. *Sports Medicine*, 37, 353-357.
- CONSOLAZIO, C. F., Matoush, L. O., JOHNSON, H. L., & DAWS, T. A. (1968). Protein and water balances of young adults during prolonged exposure to

- high altitude (4,300 meters). *The American Journal of Clinical Nutrition*, 21(2), 154-161.
- Cook, N. R., Appel, L. J., & Whelton, P. K. (2014). Lower levels of sodium intake and reduced cardiovascular risk. *Circulation*, 129(9), 981-989.
- Griggs, K. E., Stephenson, B. T., Price, M. J., & Goosey-Tolfrey, V. L. (2020). Heat-related issues and practical applications for Paralympic athletes at Tokyo 2020. *Temperature*, 7(1), 37-57.
- Hackett, P. H., Rennie, D., Hofmeister, S. E., Grover, R. F., Grover, E. B., & Reeves, J. T. (1982). Fluid retention and relative hypoventilation in acute mountain sickness. *Respiration*, 43(5), 321-329.
- Hopkins, W., Marshall, S., Batterham, A., & Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Medicine+ Science in Sports+ Exercise*, 41(1), 3.
- Kakamu, T., Wada, K., Smith, D. R., Endo, S., & Fukushima, T. (2017). Preventing heat illness in the anticipated hot climate of the Tokyo 2020 Summer Olympic Games. *Environmental health and preventive medicine*, 22, 1-6.
- Kayser, B. (1994). Nutrition and energetics of exercise at altitude: theory and possible practical implications. *Sports Medicine*, 17, 309-323.
- Kenefick, R. W. (2018). Drinking strategies: planned drinking versus drinking to thirst. *Sports Medicine*, 48(Suppl 1), 31-37.
- Kenny, G., & Flouris, A. (2014). The human thermoregulatory system and its response to thermal stress. In *Protective Clothing* (pp. 319-365): Elsevier.
- Köse, E., Moore, S., Ofodile, C., Radunskaya, A., Swanson, E. R., & Zollinger, E. (2017). Immuno-kinetics of immunotherapy. *Letters in Biomathematics*, 4(1), 39-58. doi:<https://doi.org/10.30707/LiB4.1Kose>
- Maughan, R. J. (2013). Fluid and electrolyte loss and replacement in exercise. *Foods, Nutrition and Sports Performance*, 147-178.
- Milledge, J. (1992). Salt and water control at altitude. *International journal of sports medicine*, 13(S 1), S61-S63.
- Périard, J. D., Cramer, M. N., Chapman, P. G., Caillaud, C., & Thompson, M. W. (2011). Cardiovascular strain impairs prolonged self-paced exercise in the heat. *Experimental physiology*, 96(2), 134-144.
- Rosety, M. A., Brenes-Martin, F., Pery, M., Elosegui, S., Rosety-Rodríguez, M., Diaz, A., . . . Rosety, I. (2016). Riesgo de deshidratación entre deportistas y sedentarios con discapacidad intelectual. *Revista Internacional de Medicina y Ciencias de la Actividad Física y del Deporte/International Journal of Medicine and Science of Physical Activity and Sport*, 16(63), 487-495.
- Rusko, H., Tikkanen, H., & Peltonen, J. (2004). Altitude and endurance training. *Journal of Sports Sciences*, 22(10), 928-945.
- Sanz-Quinto, S., López-Gruoso, R., Brizuela, G., Flatt, A. A., & Moya-Ramón, M. (2019). Influence of training models at 3,900-m altitude on the physiological response and performance of a professional wheelchair athlete: A case study. *The Journal of Strength & Conditioning Research*, 33(6), 1714-1722.
- Sawka, M. N., Burke, L. M., Eichner, E. R., Maughan, R. J., Montain, S. J., & Stachenfeld, N. S. (2007). American College of Sports Medicine position stand. Exercise and fluid replacement. *Medicine and Science in Sports and Exercise*, 39(2), 377-390.

- Shirreffs, S. M., Casa, D. J., & Carter III, R. (2007). Fluid needs for training and competition in athletics. *Journal of Sports Sciences*, 25(S1), S83-S91.
- Speedy, D. B., Noakes, T. D., Rogers, I., Thompson, J., Campbell, R., Kuttner, J. A., . . . Hamlin, M. (1999). Hyponatremia in ultradistance triathletes. *Medicine and Science in Sports and Exercise*, 31(6), 809-815.
- Taha, N. H., & Dizaye, K. F. (2022). Impact of Zingiber Officinale on Symptoms and Hormonal Changes During the Menopausal Period—A Clinical Trial in Duhok, Iraq. *Journal of Natural Science, Biology and Medicine*, 13(2).
- Taneva, G. T., Karaolanis, G., Pipitone, M., Torsello, G., & Donas, K. P. (2019a). Combined Less-invasive Surgical and Endovascular Technique to Minimise Operative Trauma and Treat Excessive Aortoiliac Thrombotic Obliteration with Popliteo-crural Involvement and Acute Limb Ischaemia. *Vascular & Endovascular Review*, 2.
- Taneva, G. T., Karaolanis, G., Pipitone, M., Torsello, G., & Donas, K. P. (2019b). Combined Less-invasive Surgical and Endovascular Technique to Minimise Operative Trauma and Treat Excessive Aortoiliac Thrombotic Obliteration with Popliteo-crural Involvement and Acute Limb Ischaemia.
- Urdampilleta, A., & Gómez-Zorita, S. (2015). Aspectos ergonutricionales e interacciones fármaco-alimentarias en el alpinismo. *Revista Internacional de Medicina y Ciencias de la Actividad Física y del Deporte/International Journal of Medicine and Science of Physical Activity and Sport*, 15(58), 387-404.
- Vesterinen, V., Nummela, A., Heikura, I., Laine, T., Hynynen, E., Botella, J., & Häkkinen, K. (2016). Individual endurance training prescription with heart rate variability. *Medicine and Science in Sports and Exercise*, 48(7).
- Von Duvillard, S. P., Braun, W. A., Markofski, M., Beneke, R., & Leithäuser, R. (2004). Fluids and hydration in prolonged endurance performance. *Nutrition*, 20(7-8), 651-656.
- Vrijens, D., & Rehrer, N. (1999). Sodium-free fluid ingestion decreases plasma sodium during exercise in the heat. *Journal of Applied Physiology*, 86(6), 1847-1851.
- Wilber, R. L. (2004). *Altitude training and athletic performance: Human Kinetics*.
- Zaccaria, M., Rocco, S., Noventa, D., Varnier, M., & Opocher, G. (1998). Sodium regulating hormones at high altitude: basal and post-exercise levels. *The Journal of Clinical Endocrinology & Metabolism*, 83(2), 570-574.