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ORIGINAL

HYDRATION STRATEGIES AT 4000 M ALTITUDE SOJOURN IN A MARATHONER

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

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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 wakening (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 (± 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 ≥ 2,85). Resulta interesante destacar que, siguiendo las recomendaciones de hidratación para atletas a pie, el equilibrio hídrico (HB) no fue el ideal (± 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 *et al*., 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, Matoush, Johnson & Daws, 1968; Milledge, 1992).

Up to 4000 m altitude, incrased ventilation contributes to respiratory water loss (Butterfield, Gates, Fleming, Brooks, Sutton & Reeves, 1992) along with urinary water loss which may reach 500 mL per day (Butterfield, 1996). Consequently, rapid fluid rehydration, my be utilized during altitude training to compensate for water loss, greater diuresis, and incrased 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 (Dennis, Noakes & Hawley, 1997), in order to prevent dehydration and overdrinking (± 2 % body mass after training session), which could lead to hyperthermia and hyponatremia, respectively (Kenefick, 2018). In this regard, Urdampilleta and Gómez-Zorita, (2015) suggest the intake of 500 to 1000 $\text{mL} \cdot \text{h}^{-1}$ of a carbohydrate solution with a 4-8 % concentration, a sodium (Na^{+}) content of 0.5 to 1 $\text{g} \cdot \text{L}^{-1}$, and a frequency of intake ranging from 15 to 30 minutes. 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).

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 (Milleadge, 1992). Therefore, a minimum quantity of Na^{+} has been recommended for endurance athletes during long training session (0.5 – 0.7 $\text{g} \cdot \text{L}^{-1}$) (von Duvillard, Braun, Markofski, Beneke & Leithäuser, 2004; Sawka, Burke, Eichner, Maughan, Montain & Stachenfeld, 2007), occurring at high temperatures (≥ 22.3° 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). 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, 2001; Speedy et al., 1999; Vrijens & Rehrer, 1999; Shirreffs, Casa & Carter, 2007). 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 ± 34 $\text{mEq} \cdot \text{d}^{-1}$) in the acute exposure phase (427 ± 46 $\text{mEq} \cdot \text{d}^{-1}$). Furthermore, four weeks after arrival at altitude, values did not differ significantly from sea level (257 ± 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.

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 reccomendations 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 ± 0.4 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 et al. 2009). Importaly, 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 perturbance 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 (Bonetti and Hopkins, 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.

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 ocurring 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). 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. 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 et al. (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 Laborarories, 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 = (ingested fluid volume) - (sweat loss)* (Armstrong, Johnson, McKenzie, Ellis & Williamson, 2015) were 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 (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 (±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, Marshall, Batterham & Hanin, 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}	$52.6 \pm 0.4^{\text{b*** c*** d***}}$	1.020 ± 0.003	1.014 ± 0.004	4280.8 ± 723.0	2249 ± 845	3504.3 ± 652.4
W_1	$50.7 \pm 0.5^{\text{f***}}$	$1.014 \pm 0.006^{\text{a* c*}}$	1.012 ± 0.006	$5552.2 \pm 1302.6^{\text{a*}}$	1980 ± 681	$4448.0 \pm 444.3^{\text{a*** c*** d*** e***}}$
W_2	50.5 ± 0.2	1.019 ± 0.002	$1.008 \pm 0.003^{\text{a*}}$	4834.7 ± 850.7	1601 ± 244	$3815.0 \pm 382.9^{\text{b***}}$
W_3	50.8 ± 0.4	1.018 ± 0.004	1.012 ± 0.004	4628.8 ± 839.6	1921 ± 568	$3610.7 \pm 476.1^{\text{b***}}$
W_4	$50.9 \pm 0.3^{\text{a***}}$	1.018 ± 0.003	$1.016 \pm 0.003^{\text{c***}}$	$4257.1 \pm 499.9^{\text{b*}}$	2033 ± 656	$3141.4 \pm 471.0^{\text{c***}}$
W_5	$51.2 \pm 0.3^{\text{a*** c***}}$	1.018 ± 0.004	$1.015 \pm 0.004^{\text{c***}}$	$4213.1 \pm 460.4^{\text{b*}}$	1838 ± 656	$3206.4 \pm 518.1^{\text{c***}}$
W_{+1}	$52.1 \pm 0.5^{\text{a*** b*** c*** d*** e*** f***}}$	$1.023 \pm 0.006^{\text{b*}}$	$1.017 \pm 0.006^{\text{c***}}$	$3763.6 \pm 1321.9^{\text{b* c*}}$	2379 ± 750	$2526.0 \pm 517.3^{\text{a*** b*** c*** d*** e*** f***}}$

W_{-1}, pre-altitude week; W_{1-5} weeks at altitude; W_{+1}, post-altitude week.

a, Differences from W_{-1}.

b, Differences from W_1.

c, Differences from W_2.

d, Differences from W_3.

e, Differences from W_4.

f, Differences from W_5.

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

Table 2. Sessions 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; W_{1-5} weeks at altitude; W_{+1}, post-altitude week.
a, Differences from W_{-1}.
b, Differences from W_1.
c, Differences from W_2.
d, Differences from W_3.
e, Differences from W_4.
f, Differences from W_5.
$^*p < 0.05$.

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 ($d \geq 1.24$).

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 ≥ 2.5 % of body mass in two training sessions, where ambient temperature was ≤ 5º C and relative humidity was ≤ 46 %. In those sessions the Fluid rate was (820.4 mL · h^{-1} and 597.2 mL · 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 · h^{-1}.

According to each type of session, average fluid intake per hour was: 586.8 ± 102.7 mL · h^{-1} for 20 km <VT1 sessions; 749 ± 86.5 mL· h^{-1} for 16 km <VT1 sessions; 495.4 ± 175.6 mL· h^{-1} for strength sessions; 834.4 ± 17.9 mL · h^{-1} for A sessions; 704.9 ± 130 mL · h^{-1} for B sessions; 642.2 ± 34.7 mL · 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.

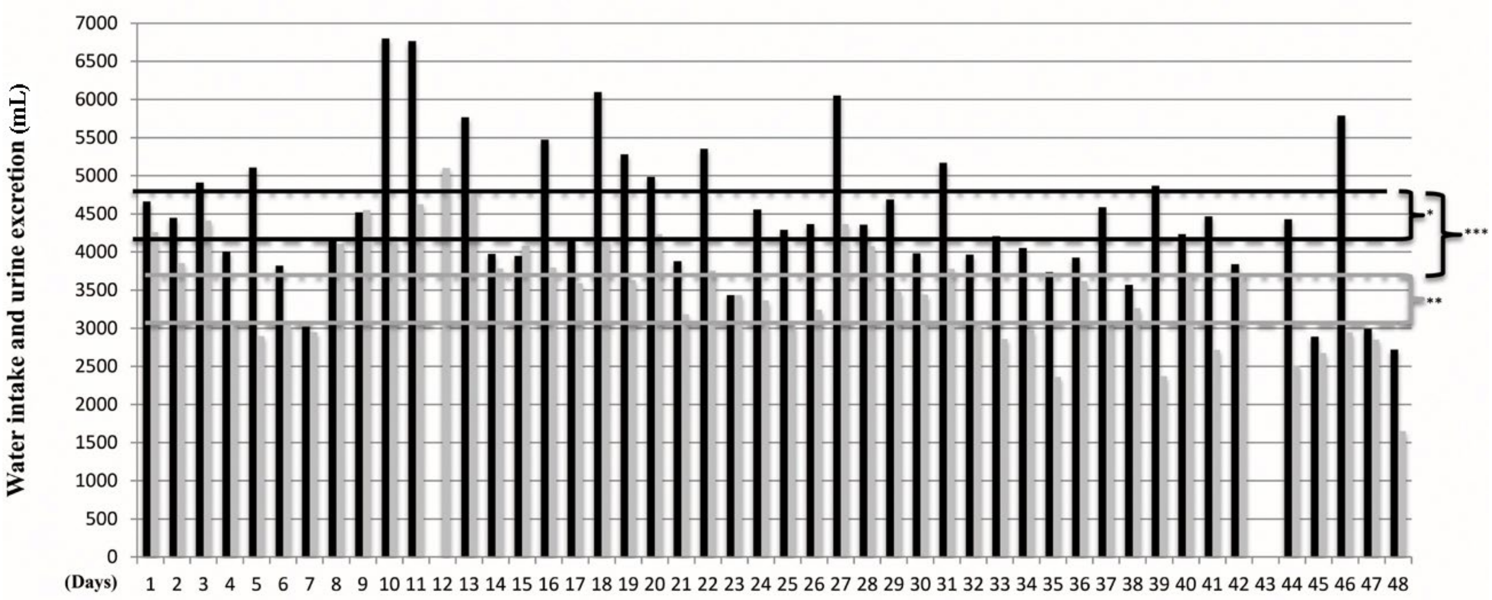
Date	Day	Phase	Altitude (m)	AM Session (km)	PM Session (km)	Duration (h-min-s)	Temp. (C)	Hum. (%)	Fluid Vol. (mL)	Intake Rate $(mL \cdot h^{-1})$	Water Loss (mL)	HB (mL)
6/01/16	3	W_{-1}	16	19.9 <VT1		1:06:30	13	56	700	631.6	500	200
6/01/16	3	W_{-1}	16		16.8 <VT1	0:59:38	16	61	700	704.3	300	400
7/01/16	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 <VT1		1:03:06 Rain	11	51	775	736.9	300	475
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
25/01/6	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		0:55:41	9	54	775	831.1	300	475

				<VT1								
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.



Mileage	128 km							128 km							146 km							134 km						
Sessions	6							6							9							8						
Type of session	G	G	D	D	D	F	G	G	G	D	D	D	F	G	E	A	D	E	B	C	G	E	A	B	E	C	A	G
Day	M	T	W	Th	F	S	Sn	M	T	W	Th	F	S	Sn	M	T	W	Th	F	S	Sn	M	T	W	Th	F	S	Sn
Week	B_N							B_H							W_1							W_2						

Mileage	140 km							116 km							128 km						
Sessions	8							8							6						
Type of session	E	B	C	E	A	B	G	G	D	D	E	C	F	G	G	G	D	D	D	F	G
Day	M	T	W	Th	F	S	Sn	M	T	W	Th	F	S	Sn	M	T	W	Th	F	S	Sn
Week	W_3							W_4							Post						

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 altitide training scennarious are not well described well in the literature, particularly above 4000 m elevation (Burkirk, Kollias, Akers, Prokop & Reategui, 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 leaded by professors Reeves and Grover). Ultmately, 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 (Dennis, Noakes & Hawley, 1997), expressed in $mL \cdot h^{-1}$ at sea level and altitude. Importantly, to sustain performance while minimizing the occurance 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, Stephenson, Price & Goosey-Tolfrey, 2020).

In the current study at high-altitude (3500 to 5500 m) greater ventilation (Butterfield et al., 1992) and increased urinary water loss (Butterfield, 1996), 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 4º C), which reportedly causes decreased sweating rate when exercising at low ambient temperatures (Périard, Cramer, Chapman, Caillaud & Thompson, 2011). Therefore, a reduction in Fluid intake during training of about 200 $mL \cdot h^{-1}$ in one session, in which average Fluid rate was 820.4 $mL \cdot h^{-1}$, would have guaranteed the minimum Fluid intake reccomended (Dennis et al., 1997). Nevertheless, in the other session, the Fluid rate was below reccomendations (597.2 $mL \cdot h^{-1}$), suggesting posible 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 et al, 2009). Thus, a possible solution could be to follow recommendations from Urdampilleta & Gómez-Zorita, (2015) for drinking 500 $mL \cdot h^{-1}$.

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. Specificlly, that following hydration strategies suggested for able-bodies athletes, would minimize the negative impact of high-altitude on body mass, and hydration status markes as HB would be optimized, as it is true that among elite-marathoners dehydration rates are over 4 % of body mass (Beis, Wright-White, 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, Rennie, Hofmeister, Grover, Grover & Reeves, 1982; Milledge, 1992). Noteworthy, this enhancement of diuresis might be facilitated by the daily fluid intake target (4 L · 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 ºC, all occurring without gastrointestinal issues (GI). This supports the notion that optimal hydration levels were achieved. In fact, a lower rate of 600 mL · h^{-1} (Dennis et al. 1997) would have been effective for maintaining hydration. Finally, Na^{+} did not reach the minimum quantity recommended during workouts at <VT1 (0.13 g · L^{-1}) and “A”, “B”, “C” specific sessions (0.17 g · L^{-1}) (von Duvillard et al. 2004; Sawka et al. 2009), 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 (Hackett et al 1982; Milleadge, 1992).

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 20º C, all occurring without GI. This supports the notion that optimal hydration levels were achieved. In fact, a lower rate of 600 mL · h^{-1} (Dennis et al., 1997) would have been effective for maintaining hydration. Finally, Na^{+} did not reach the minimum quantity recommended during workouts at <VT1 (0.13 g · L^{-1}) and “A”, “B”, “C” specific sessions (0.17 g · L^{-1}) (von Duvillard et al., 2004; Sawka et al., 2009).

On the other hand, the participant exhibites a body mass loss of 2 % after a session performed at sea level (16º C, 61 % relative humidity), which is notoriously lower than the one reported among elite able-bodied marathoners (-8 %) (Cheuvront, Montain & Sawka, 2007), however, we have previously mentioned that over 4 % is normal among elite marathoners (Beis, Wright-White, Fudge, Noakes & Pitsiladis, 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 betwee both studies. In fact, lower liquid intake than the 600 mL · h^{-1} suggested for endurance athletes (Dennis et al., 1997) 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, Stephenson, Price & Goosey-Tolfrey, 2020).

It is very important to consider that Na^+ did not reach the recommended amount during workouts <VT1 (0.13 g · L^{-1}) and specific sessions (0.17 g · L^{-1}) (von Duvillard et al., 2004). 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 mg · 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 strictily 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 reccomended 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 ~500 mL · h^{-1} or 8 mL · min^{-1} during training and 4 L · d^{-1}
5. To monitor the ambient temperature, particularly if it decreases below 5º C

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

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