Gait & Posture 97 (2022) 115–121

Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost

Effects of different hydration supports on stride kinematics, comfort, and impact accelerations during running

Álvaro S. Machado [a], Jose Ignacio Priego-Quesada [b,c,*], Irene Jimenez-Perez [b,c], Marina Gil-Calvo [b,d], Felipe P. Carpes [a], Pedro Perez-Soriano [b]

[a] Applied Neuromechanics Group, Laboratory of Neuromechanics, Federal University of Pampa, Uruguaiana, Brazil
[b] Research Group in Sports Biomechanics (GIBD), Department of Physical Education and Sports, University of Valencia, Valencia, Spain
[c] Research Group in Medical Physics (GIFIME), Department of Physiology, University of Valencia, Valencia, Spain
[d] IIS Aragon - iHealthy, Department of physiatry and nursing, University of Zaragoza, Huesca, Spain

ARTICLE INFO

Keywords:
Exercise
Backpack
Accelerometer
Impact forces, gait
Kinematics

ABSTRACT

Background: Different supports for hydration can influence total body mass and affect running biomechanics.
Research question: Do different hydration supports affect the perceived exertion and comfort, stride kinematics, and impact accelerations during running?
Methods: This was a crossover study design. Thirteen trail runners completed a treadmill running test divided into four different durations and randomized hydration supports conditions, lasting 8 min each at moderate intensity: A) waist bag (0.84 kg); B) medium load backpack (0.84 kg); C) full load backpack (3.40 kg); and D) a control condition without water support. Impact accelerations were measured for 30 s in 4, 6, and 8 min. The rate of perceived exertion and heart rate were registered on minutes 4 and 8. At the last minute of each condition, comfort perception was registered
Results and significance: No condition affected the stride kinematics. Full load backpack condition reduced head acceleration peak (−0.21 g; $p = 0.04$; ES=0.4) and head acceleration magnitude (−0.23 g; $p = 0.03$; ES=0.4), and increased shock attenuation (3.08 g; $p = 0.04$; ES=0.3). It also elicited higher perceived exertion ($p < 0.05$; ES>0.8) being considered heavier ($p < 0.01$; ES > 1.1). The waist bag condition was more comfortable in terms of noise ($p = 0.006$; ES=1.3) and humidity/heat ($p = 0.001$; ES=0.8). The waist bag was the most comfortable support. On the other hand, the full backpack elicited lower comfort and was the only generating compensatory adjustments. These results may help to improve design of full load backpack aiming at comfort for runners.

1. Introduction

Running benefits physical and mental health [1], reduces mortality from all causes [2] and is a low investment to start and stay physically active [3]. For these reasons, there is a continuous growth in adhesion and permanence in running training programs and a range of different configurations of competitions [4]. For competitions like mountain trails, ultra-endurance mountain trails, or ultramarathons, continuous and adequate hydration are performance determinants [5,6]. It is common to observe runners carrying extra hydration using hand implements, full or medium load backpacks, and waist belts. These implements can alter the total body mass [7], and the additional mass can affect the running economy as observed with sports footwear [8].

Adding moderate to high additional load to the individual body mass during gait affects kinematics and kinetics of locomotion. For example, carrying a backpack with a moderate load (20% of body mass) can increase the variability of spatiotemporal parameters of running [9]. In military personnel, heavy backpacks (up to 40 kg) increased the ground reaction forces and altered the arm swing [10]. These modifications can affect the magnitude of impact and increase the risk of injury [11]. However, despite the evidence for heavy loads, it remains unclear if adding smaller magnitudes of mass to the individual total body mass affects movement characteristics such as impact accelerations and stride spatiotemporal variables [12,13]. Although a recent study did not observe alteration on stride length and step frequency after increase the body mass in a 5 or 10%, they did not assess impact accelerations [14]. In this sense, the analysis of impact shock waves in terms of magnitude, loading rate, and shock attenuation has become of great importance to

---

* Correspondence to: Department of Physical Education and Sports, Faculty of Physical Activity and Sport Sciences, St: Gascó Oliag, 3, 46010 Valencia, Spain.
E-mail address: j.ignacio.priego@uv.es (J.I. Priego-Quesada).

https://doi.org/10.1016/j.gaitpost.2022.07.234

the running research community due to its association with overuse injuries [15,16], performance [17], and comfort [18].

Among additional factors that might influence movement patterns are the characteristics of sports equipment regarding comfort. Comfort has attracted attention in sports sciences due to its relationship with performance and injury risk [19–21]. Nigg et. al. [22] proposed the "comfort filter paradigm", which places comfort as an important element in the choice of running shoes aiming to reduce injury risk. In the same sense, comfort has been assessed in runners considering the use of different equipment such as foot orthosis [23], compression garments [24], and footwear, among others [19]. However, it is not clear whether the comfort perception changes when wearing extra different hydration supports during running and how it could interact with factors related to impact.

In this study, we determine the effects of using different hydration supports on the rate of perceived exertion, comfort, and spatiotemporal variables related to stride kinematics, and impact accelerations during running. We hypothesize that by using hydration supports that add mass to the participant, although it cannot affect running spatio-temporal parameters (stride length and stride frequency) based in a previous study [14], it can negatively affect impact acceleration by the increase of tibia and forehead peak and magnitude accelerations. Additionally, we hypothesize that a medium-loaded backpack more firmly attached to the individual body would elicit lower effort perception and better comfort.

2. Methods

2.1. Participants

Thirteen trail runners participated in this study (12 males, age of 25 ± 8 years, body mass of 71 ± 11 kg, and height of 179 ± 8 cm). To be included they should (i) perform 3–4 running workouts per week, (ii) have a weekly running volume higher than 25–30 km/week, (iii) be free from severe injuries in the lower extremity in the last 6 months, and (iv) not report any discomfort at the time of the study. All participants signed a consent term following the Declaration of Helsinki and approved by the local University Ethics Committee (registration number 1252705).

2.2. Protocol

The participants completed a laboratory test running on a motorized treadmill lasting 37 min in total [24]. They ran at a self-selected speed and moderate-intensity with the treadmill set at 1% slope [25]. The running test was divided into 4 conditions considering different configurations of hydration supports, randomized for each runner, and lasting 8 min each: A) waist bag (WB); B) medium load backpack (MLBP); C) full load backpack (FLBP); and D) a control condition with no hydration support (NWS). A short interval (less than one minute) was considered between the conditions for changing or removing the hydration support.

The running test started with a 5-min warm-up in which participants selected the speed that they would maintain during the entire test [26]. Warm-up started with running 2 min at 8 km/h followed by 3 min increasing the speed by 1 km/h every 30 s until the participant reported 12 points (intensity between "light" and "somewhat hard") in the Borg's Scale [27]. Once the speed was set, it was kept unchanged for the entire test, and participants were orientated to run keeping their eyes focused on a screen in front of them. The mean and standard deviation of the speed was 10.2 ± 0.6 km/h. For each condition, impact accelerations were measured for 30 s on the 4th, 6th, and 8th minute of the conditions. Perceived exertion and heart rate were registered on minutes 4 and 8. Comfort perception was registered at the last minute of each running condition.

2.2.1. Hydration supports

The hydration supports were a waist bag (WB, Fig. 1a) filled with 600 milliliters of water adding a total mass of 0.84 kg; a medium load backpack (MLBP, Fig. 1b) filled with the amount of water to have the same total mass as the waist bag; and a full load backpack (FLBP, Fig. 1c) filled with 3 liters of water equally distributed between the recipients adding a total mass of 3.40 kg. Both the backpack and the waist bag were adjustable to the body dimensions of each runner. The chosen models allowed comparisons between different amounts of added mass and different positions where it was loaded.

Fig. 1. Different hydration supports (total mass): a) waist bag (0.84 kg); b) medium load backpack (0.84 kg); and c) full load backpack (3.4 kg).

2.2.2. Analysis of acceleration signals

Acceleration signals were acquired using 3 triaxial wireless accelerometers (Pikkulab, Blautic Design, Valencia, Spain; total mass: 50 g; dimensions: 50 ×20×10 mm; range: ± 16 g). The accelerometers were placed over anatomical references of the distal anteromedial portion of the right (RTib) and left tibia (LTib) and forehead, being comfortably fixed with medical adhesive tape together with neoprene straps [28]. Vertical acceleration data were sampled at 180 Hz using software Pikkulab APP (Blautic Design, Valencia, Spain) through Bluetooth connection with a tablet (Samsung Electronics Ltd., Seoul, South Korea). Signals were offline filtered with an 8th order low-pass digital Chebyshev type II filter, stop-band edge frequency 120 Hz, and stop-band ripple 40 dB using a custom-made routine (Version Matlab R2017a, Math Works Inc., Natick, MA, USA). The following variables were determined: acceleration peak (g, maximal amplitude), acceleration magnitude (g, the difference between the maximum and the minimum peak), acceleration rate (g/s, slope from ground contact to peak acceleration, calculated as the 20–80% of the acceleration peak amplitude), shock attenuation (%, reduction in peak acceleration from the tibia to the head as a percentage of the tibial peak acceleration), stride length (m), and stride frequency (Hz).

2.2.3. Rate of perceived exertion and heart rate

The rate of perceived exertion (RPE) was quantified by the Borg 6–20 Scale [27]. The heart rate (HR) was continuously monitored using a heart rate monitor with a chest strap (Polar V800, Polar Electro Oy, Kempele, Finland).

2.2.4. Perception of comfort

A 15 cm visual analog scale (VAS) [29] was used to evaluate the perception of comfort for each hydration support condition. The scale included 8 items: general comfort, weight, balance, noise, grip/support, rubbing, humidity/heat, and design/aesthetics. Participants draw a vertical line on a horizontal scale printed in paper to indicate their perception from the left (worse comfort) to the right (best comfort) for each item of the scale.

2.3. Statistical analysis

We analyzed the data using SPSS v25 software (IBM Corp., Armonk, NY, USA). The normality of data distribution was verified using the Shapiro-Wilk test. All variables except the RPE showed a normal distribution. We analyzed the effects of the intra-subjects' factors (hydration packs and vest and instant) on each dependent variable with analysis of variance (ANOVA) for repeated measures for the variables showing a normal distribution. We then adjusted the significance levels in the pairwise comparison using Bonferroni corrections (with alpha level set at $p < 0.05$). The sphericity assumption was verified using the Mauchly test. In those cases that assumption was not fulfilled, the Huynh-Feldt adjustment was used. For RPE, the effects of the intra-subjects factors (hydration packs and vest and instant) on each of the dependent variables were analyzed using the Friedman test. We performed the Wilcoxon test for the pairwise comparison when significant differences were found. Furthermore, to reduce the risk of type I error, the significance level was adjusted using the Bonferroni correction, settling at $p < 0.02$. For significant pair differences, Cohen's effect sizes (ES) were computed and classified as small (ES 0.2–0.5), moderate (ES 0.5–0.8), or large (ES>0.8) [30]. Data are reported as mean ($\overline{X}$) ± standard deviation (SD). To validate the results obtained and to verify any influence of another factors, multivariable linear regression mixed models were applied for each acceleration variable. The participant was considered a random factor fitted by the intercept, and we analyzed the main effects for the following factors: support condition, instant, stride length, stride frequency, heart rate, and RPE. The assumptions of the mixed models were evaluated by checking the standardised residuals in relation to the fitted values, observing a normal distribution, and similar variance within and between groups. Standardised ES were also calculated for the significant factors obtained in the mixed models.

3. Results

3.1. Impact acceleration

Impact accelerations did not differ between the time instants (minutes 4 vs. 6 vs. 8, $p > 0.05$), and the mean of all the recorded instants was analyzed. Full load backpack elicited lower head acceleration peak ($p = 0.04$ and ES=0.4) and head acceleration magnitude compared to the condition with no hydration ($p = 0.03$ and ES=0.4, Table 1). Full load backpack also elicited higher shock attenuation compared to the condition with no hydration support ($p = 0.04$ and ES=0.3). Concerning time interactions and spatio-temporal variables, we observed no significant differences between the hydration supports ($p < 0.05$, Table 2).

3.2. Rate of perceived exertion and heart rate

RPE was affected by the different hydration supports and instants

Table 2

Mean ($\overline{X}$) and standard deviation (SD) of spatio-temporal variables [Stride Length (SL) and Stride Frequency (SF)] by the instant of time and condition: No water support (NWS); Waist bag (WB); Medium load backpack (MLBP); Full load backpack (FLBP).

Condition	Instant		Variables	
			SL (m)	SF (Hz)
NWS	Min. 4	$\overline{X}$	2.09	1.36
		SD	0.17	0.08
	Min. 6	$\overline{X}$	2.08	1.36
		SD	0.18	0.08
	Min. 8	$\overline{X}$	2.09	1.36
		SD	0.17	0.08
WB	Min. 4	$\overline{X}$	2.07	1.37
		SD	0.18	0.09
	Min. 6	$\overline{X}$	2.09	1.36
		SD	0.17	0.08
	Min. 8	$\overline{X}$	2.09	1.36
		SD	0.18	0.08
MLBP	Min. 4	$\overline{X}$	2.09	1.36
		SD	0.17	0.09
	Min. 6	$\overline{X}$	2.09	1.36
		SD	0.17	0.09
	Min. 8	$\overline{X}$	2.09	1.36
		SD	0.18	0.09
FLBP	Min. 4	$\overline{X}$	2.09	1.36
		SD	0.17	0.08
	Min. 6	$\overline{X}$	2.08	1.36
		SD	0.18	0.08
	Min. 8	$\overline{X}$	2.07	1.37
		SD	0.18	0.09

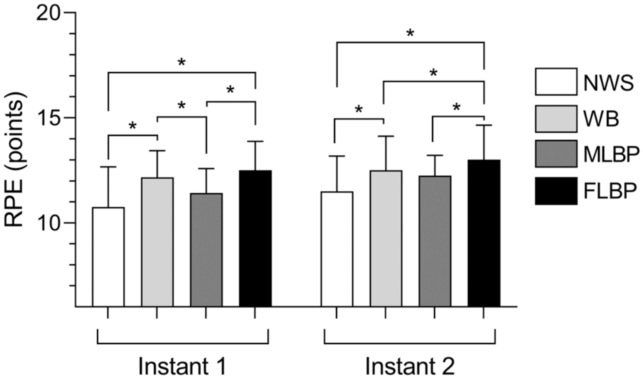

Fig. 2. Rate of perceived exertion (RPE) at instant 1 (min 4) and instant 2 (min 8) for each hydration support condition: No water support (NWS); Waist bag (WB); Medium load backpack (MLBP); Full load backpack (FLBP). * $p < 0.05$.

Table 1

Mean ($\overline{X}$) and standard deviation (SD) for acceleration variables at the right tibia (RTib), the left tibia (LTib), and the forehead for each condition. No water support (NWS); Waist bag (WB); Medium load backpack (MLBP); Full load backpack (FLBP). * Significant difference compared to NWS.

		NWS		WB		MLBP		FLBP	
		$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD
Acceleration peak (g)	RTib	6.36	1.75	6.34	1.84	6.32	1.70	6.33	1.86
	LTib	6.43	2.15	6.48	2.38	6.58	2.44	6.52	2.43
	Forehead	2.71	0.48	2.58	0.41	2.67	0.46	2.50*	0.46
Acceleration magnitude (g)	RTib	7.60	2.52	7.64	2.77	7.49	2.55	7.51	2.69
	LTib	7.72	3.41	7.68	3.69	7.84	3.80	7.78	3.63
	Forehead	2.92	0.58	2.78	0.51	2.88	0.56	2.69*	0.55
Acceleration rate (g/s)	RTib	285.54	116.56	285.13	120.47	285.28	113.40	301.02	133.49
	LTib	288.12	189.77	288.72	211.33	300.98	222.66	298.75	204.93
	Forehead	60.45	15.49	58.09	14.71	59.87	15.47	59.08	18.49
Shock attenuation (%)		55.77	8.76	57.46	9.00	56.43	9.45	58.85*	9.18

(Fig. 2). On min 4, condition with no hydration support elicited lower RPE than waist bag ($p = 0.007$; ES=0.9) and full load backpack ($p = 0.004$; ES=1.1). Among the support conditions, RPE for waist bag was higher than medium load backpack ($p = 0.047$; ES=0.6), and full load backpack elicited higher RPE than medium load backpack ($p = 0.012$; ES=0.8). On min 8, condition with no hydration support also elicited lower RPE than waist bag ($p = 0.026$; ES=0.6) and full load backpack ($p = 0.007$; ES=0.9). Both waist bag ($p = 0.014$; ES=0.3) and medium load backpack ($p = 0.021$; ES=0.6) resulted in lower RPE than full load backpack.

HR did not differ between the hydration supports and between the instants of measure (Table 3).

3.3. Comfort perception

Full load backpack elicited lower comfort score for weight than the waist bag ($p = 0.001$; ES=1.1) and the medium load backpack ($p = 0.001$; ES=1.5). Waist bag was more comfortable than full load backpack considering noise ($p = 0.006$; ES=1.3) and humidity/heat items ($p = 0.001$; ES=0.8; Fig. 3).

3.4. Multivariable linear regression mixed models for acceleration variables

Table 4 shows the results of the multivariable linear regression mixed models. Support condition factor was not significant for tibia acceleration peak, tibia acceleration magnitude, and tibia acceleration rate ($p > 0{,}05$). However, the coefficients of the models showed that, compared to the condition without water support, the three support conditions evaluated reduced the forehead acceleration peak (NWS vs. WB ES=0.4; NWS vs. MLBP ES=0.3; NWS vs. FLBP ES=0.7), reduced the forehead acceleration magnitude (NWS vs. WB ES=0.4; NWS vs. MLBP ES=0.3; NWS vs. FLBP ES=0.7), and increased the shock attenuation (NWS vs. WB ES=0.2; NWS vs. MLBP ES=0.1; NWS vs. FLBP ES=0.3). In the case of the forehead acceleration rate, only the waist bag showed a reduction of this parameter compared with the condition without water support (ES=0.2).

4. Discussion

In this study we found that kinematics (spatiotemporal) was not modified in response to the different water support conditions. Furthermore, analyzing the perceptual and acceleration responses together, there was a change in the responses to the full backpack condition. It should also be noted that in other conditions with additional mass where the acceleration/attenuation did not change, the dynamic load was greater. We argue that it happens because acceleration is part of the imposed dynamic and did not consider inertial information separately. Interestingly, only when the additional mass was higher, we noted a motor compensatory adjustment, also remarked by changes in perceptions. By adding load higher up the spine, there is a perceptual price and need for altered dynamic responses that can be noted in accelerometer measurements. Our first hypothesis was partially accepted because as no effect on spatio-temporal parameters was observed as hypothesized, the forehead presented lower head acceleration and higher shock attenuation at the full load backpack which is contrary to our initial hypothesis. However, it is important to consider that the magnitude of these effects was small. Regards to effort perception and comfort, our hypothesis was also partially accepted, since although it cannot be said that the medium-loaded backpack was the most comfortable, it was not the most uncomfortable either, which was the full load backpack.

Table 3
Mean ($\overline{X}$) and standard deviation (SD) for heart rate (bpm) at instant 1 (min 4) and instant 2 (min 8) for each support condition: No water support (NWS); Waist bag (WB); Medium load backpack (MLBP); Full load backpack (FLBP).

	NWS		WB		MLBP		FLBP	
	$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD
Instant 1	155.7	16.2	154.3	13.8	157.2	13.1	156.0	13.8
Instant 2	156.0	17.0	157.1	14.4	160.1	13.0	159.0	12.9

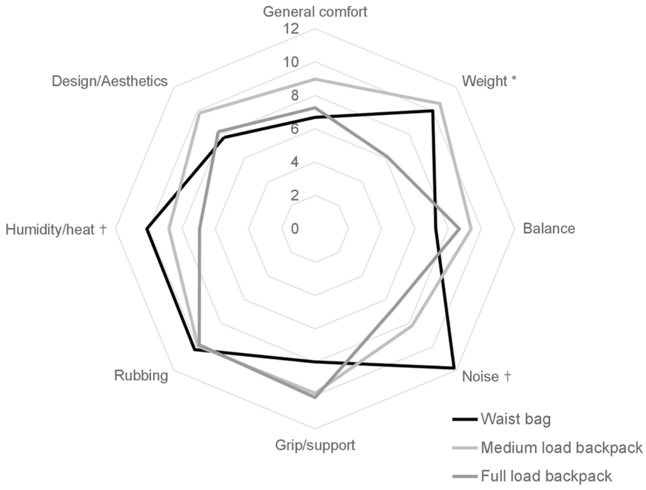

Fig. 3. Perception of comfort for the different hydration support conditions: Waist bag, medium load backpack, and full load backpack. * means full load backpack different of waist bag and medium load backpack ($p < 0.05$); † means waist bag different of full load backpack ($p < 0.05$).

Previous studies addressing the effects of carrying additional mass during running have predominantly focused on describing how backpacks with military material and heavier loads affect the energy economy in soldiers [31,32]. When considering lower magnitudes of additional mass, research has investigated energy consumption and gas exchange, finding no difference between carrying water by hand, a backpack, or a waist bag [33]. Studies considering kinetic and kinematic analysis are scarce. We evaluated impact acceleration variables for both the right and left tibia and found no changes in peak magnitude, magnitude, rate, or shock attenuation in response to the different hydration supports. This result was also supported by multivariable linear regression mixed models. Tibial acceleration is intrinsically related to the vertical load rate associated with a risk of various lower limb injuries [34]. Therefore, we suggest a relative safety in the use of the equipment tested since different hydration supports did not affect any of the tibia acceleration variables analyzed. On the other hand, the head acceleration was lower when using the full load backpack than the control condition. Moreover, the multivariable linear regression mixed models assessed showed, in general, that the three support conditions evaluated, compared with the control condition without water support, reduced the head acceleration variables, and improved the shock attenuation. However, it is important to consider that, in most of the cases, there was small effect size for this modification, except for the full load backpack in which the effect size was moderate. The head peak acceleration indicates a rapid deceleration promoted by transmitting a shock wave through the skeletal system, from the foot to the head [35]. The reduced head acceleration contributes to keeping a stable visual field that may help avoid stumbling or other unexpected circumstances when running on an uneven track [36]. We speculate that the highest mass addition may have improved perception of load, and therefore contributed to the adjustments in the running gesture aiming to mitigate the transmission of impact to the head by altering leg stiffness, as discussed in Silder et al. [37]. Additional measurements considering lower extremity angular kinematics could support this hypothesis.

The different hydration supports did not change stride length and

Table 4
Multivariable linear regression mixed models for each acceleration variable considering support condition Waist bag (WB), Medium load backpack (MLBP), Full load backpack (FLBP), instant (min 4, 6, 8), stride length, stride frequency, heart rate and perceived exertion (RPE).

	Tibia acceleration peak			Forehead acceleration peak			Tibia acceleration magnitude			Forehead acceleration magnitude			Tibia acceleration rate			Forehead acceleration rate			Shock attenuation		
Predictors	*Estimates*	*CI*	*p*	*Estimates*	*CI*	*p*	*Estimates*	*CI*	*p*	*Estimates*	*CI*	*p*	*Estimates*	*CI*	*p*	*Estimates*	*CI*	*p*	*Estimates*	*CI*	*p*
Intercept	9.07	-21.57, 39.72	0.56	-3.09	-8.94, 2.77	0.30	14.35	-30.41, 59.11	0.53	-4.23	-10.95, 2.50	0.22	-730.06	-4350.50, 2890.39	0.69	-46.43	-300.76, 207.90	0.72	89.43	-97.80, 276.65	0.34
Support condition [WB]	0.00	-0.12, 0.13	0.96	-0.11	-0.15, − 0.07	**< 0.01**	0.00	-0.17, 0.17	0.98	-0.12	-0.17, − 0.08	**< 0.01**	0.06	-16.49, 16.60	0.99	-2.53	-4.62, − 0.43	**0.02**	1.54	0.53, 2.54	**< 0.01**
Support condition [MLBP]	0.03	-0.09, 0.15	0.63	-0.08	-0.12, − 0.03	**< 0.01**	-0.01	-0.18, 0.15	0.87	-0.08	-0.13, − 0.04	**< 0.01**	13.68	-2.48, 29.84	0.10	-1.71	-3.75, 0.33	0.10	1.1	0.11, 2.09	**0.03**
Support condition [FLBP]	0.04	-0.10, 0.19	0.53	-0.2	-0.25, − 0.15	**< 0.01**	0.01	-0.18, 0.20	0.94	-0.22	-0.28, − 0.17	**< 0.01**	9.12	-9.27, 27.50	0.33	-1.77	-4.09, 0.55	0.13	3.24	2.12, 4.36	**< 0.01**
Instant	0.03	0.01, 0.05	**0.04**	0.00	-0.01, 0.01	0.47	0.04	0.00, 0.07	**0.03**	-0.01	-0.01, 0.00	0.29	2.31	-1.06, 5.69	0.18	-0.02	-0.44, 0.41	0.94	0.21	0.01, 0.41	**0.04**
Stride length	0.00	-0.01, 0.01	0.91	0.00	0.00, 0.00	**< 0.01**	0.00	-0.01, 0.01	0.97	0.00	0.00, 0.00	**< 0.01**	0.34	-0.53, 1.21	0.43	0.03	-0.03, 0.09	0.35	-0.01	-0.06, 0.03	0.61
Stride Frequency	-3.26	-14.61, 8.09	0.57	0.49	-1.74, 2.71	0.67	-6.41	-22.95, 10.13	0.45	0.71	-1.84, 3.25	0.58	195.34	-1149.44, 1540.11	0.77	22.8	-74.57, 120.17	0.64	-3.65	-73.62, 66.32	0.92
Heart rate	0.00	-0.01, 0.01	0.55	0.01	0.00, 0.01	**< 0.01**	0.01	-0.01, 0.02	0.46	0.01	0.00, 0.01	**< 0.01**	-0.10	-1.60, 1.39	0.89	0.09	-0.09, 0.27	0.34	-0.04	-0.13, 0.05	0.33
RPE	0.00	-0.06, 0.05	0.88	-0.01	-0.03, 0.01	0.37	0.01	-0.07, 0.09	0.80	-0.01	-0.03, 0.01	0.44	1.54	-5.86, 8.94	0.68	0.24	-0.68, 1.17	0.61	0.02	-0.43, 0.47	0.93
Marginal R^2 of the model		0.66			0.59			0.75			0.60			0.66			0.51			0.59	

Note: Tibia acceleration variables were calculated by the mean of the right and left tibia. Support condition levels were compared with the condition without water support. Significant factors in the models are in bold letters.

frequency. It is possible that the total mass added by the hydration equipment was not sufficient to disturb these variables. Silder et al. [37] imposed a larger additional mass to the runners and observed longer stance time. In the same sense, carrying 20% of their body mass also affect trunk-pelvis coordination in well-trained runners [38]. Although not observed here, the amount of mass may determine kinematic changes, especially when higher magnitudes of mass are carried. In studies adding a lower amount of mass (227–627 g), which are more similar to what the athlete can carry during the running, the kinematics remain mostly unchanged [26]. As the load increases and exceeds the typical values of bottles, backpacks, and standard equipment, the running economy at moderate to high intensity deteriorates. It seems that the athletes must choose to carry small amounts of water to maintain their run quality [7], which agrees with our results, but may not be the real condition for prolonged efforts and some specific competitions like the ultra-marathons. Our findings agree with previous evidence suggesting that only carrying loads greater than 10% of the body mass will lead to compensatory adjustments in spatio-temporal parameters (in our present study, the magnitudes of additional mass were between 4% and 6% of the individual body mass).

The waist bag and the full load backpack resulted in higher rate of perceived exertion than observed for the medium load backpack and condition without water support. The only change that occurs at the final moment of the running (instant 2) is that we no longer found the difference between waist bag and medium load backpack. In comparing the two different hydration supports that generated higher rate of perceived exertion, there was no difference between them at the instant 1. Still, at instant 2, the fully loaded backpack caused a greater perceived exertion, although with a smaller effect size. Our results agree with the expected, where the more significant mass additions increases effort in running [7].

When running is intense enough to generate fatigue, it can change kinematic and kinetic patterns [39,40]. We found that rate of perceived exertion increased according to the instant and the condition, but it always remained below the high intensity [27]. In the same sense, the present protocol was not enough to affect heart rate, which indicates that the effects on acceleration parameters were due to the addition of mass with the different hydration supports rather than the development of fatigue.

The assessment of comfort perception is critical in running. A conflicting relationship between the athlete and the sports equipment can induce an unwanted modification in the sports gesture [22]. Also, athletes reporting low comfort during competition tend to show inferior performance [20]. We found the worst comfort score in the weight perception when using the full load backpack. Moreover, discomfort from sports equipment noise can also be a problem. Rochat [41] pointed out how the runners reported as less comfortable the splashing water noise when they used support for hydration with two full bottles on the pectoral straps. In our study, the participants reported the noise they perceived using the full load backpack as more disturbing. The fact that the water is far from the ears in the waist bag condition is advantageous. Although a previous study addressed this question, the noise resultant from the sports equipment may alter attention focus causing shifts from internal to an external focus, which is known to influence aspects related to impact absorption [42].

The waist bag was perceived as more comfortable in terms of humidity/heat. This is most likely a result of this support having more significant contact with the body and hinder sweat elimination. Higher humidity perception may indicate that the sweating mechanism is not being effective in reducing heat [43]. These results indicate a disadvantage of the backpacks that could affect thermoregulation, a performance determinant even in well-trained athletes [44].

Our study has limitations. Our conclusions are limited to male runners because we were able to include only one female in the sample. Data collection of additional participants was not possible due to the coronavirus pandemic. We have performed a post- hoc analysis using GPower software to assess the power achieved by our study and observed a 63% of power (considering an α error of 10%) for ANOVA repeated measures considering the results of head acceleration peak. To archive a power of 80%, 16 participants would be necessary. The indoor measure allowed us to control some environmental factors that may affect running performance, but it prevented us from estimating the effects of longer runs, therefore limiting our results to the acute effects of the hydration supports. We also did not control the foot strike characteristics of the participants, which can affect impact absorbing patterns. However, we consider this effect was minimized by the configuration of the repeated measures. Finally, although we discuss some variables recognized as related to risk factors for injury among runners, we cannot assume that the runners' responses determine a higher risk of injury for a given condition.

5. Conclusions

None of the hydration supports conditions affected the spatio-temporal variables of running. The waist bag support improves comfort considering noise and humidity/heat, while the full backpack was perceived as heavier and elicited higher rate of perceived exertion. Although all hydration supports imposed greater dynamic load, only the full backpack promoted compensatory adjustments interpreted as an strategy to minimize impact. We consider that these results can be of interest to improve full load backpack design aiming at comfort for runners.

CRediT authorship contribution statement

Alvaro S. Machado: Conceptualization, Data curation, Formal analysis, Investigation, Writing – original draft. **Jose I. Priego-Quesada**: Conceptualization, Methodology, Supervision, Writing – review & editing. **Irene Jimenez-Perez**: Conceptualization, Investigation, Methodology, Writing – review & editing. **Marina Gil-Calvo**: Conceptualization, Investigation, Methodology, Writing – review & editing. **Felipe P. Carpes**: Conceptualization, Supervision, Writing – review & editing. **Pedro Perez-Soriano**: Conceptualization, Methodology, Resources, Formal analysis, Software, Supervision, Writing – review & editing.

Declaration of interest

None.

Acknowledgements

We are grateful to our volunteers for participating in this preliminary study. We would also like to thank Ms Maria Cortes Serrano and Mr Javier García Pelacho (BSc students of Physical Activity and Sport Sciences) for their work throughout the experimental phase of the study. FPC acknowledges the support from the National Council for Scientific and Technological Development – CNPq – Brazil. ASM acknowledges funding from the Coordenaçâo de Aperfeiçoamento de Pessoal de Nível Superior - Brazil (CAPES) - Finance Code 001.

References

[1] C.E. Garber, B. Blissmer, M.R. Deschenes, B.A. Franklin, M.J. Lamonte, I.-M. Lee, D. C. Nieman, D.P. Swain, American College of Sports Medicine, American College of Sports Medicine position stand. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: guidance for prescribing exercise, Med. Sci. Sports Exerc. 43 (2011) 1334–1359, https://doi.org/10.1249/MSS.0b013e318213fefb.

[2] W.L. Haskell, I.-M. Lee, R.R. Pate, K.E. Powell, S.N. Blair, B.A. Franklin, C. A. Macera, G.W. Heath, P.D. Thompson, A. Bauman, Physical activity and public health: updated recommendation for adults from the American College of Sports Medicine and the American Heart Association, Med. Sci. Sports Exerc 39 (2007) 1423–1434, https://doi.org/10.1249/mss.0b013e3180616b27.

[3] D.-C. Lee, A.G. Brellenthin, P.D. Thompson, X. Sui, I.-M. Lee, C.J. Lavie, Running as a key lifestyle medicine for longevity, Prog. Cardiovasc. Dis. 60 (2017) 45–55, https://doi.org/10.1016/j.pcad.2017.03.005.

[4] L.L. Ridinger, D.C. Funk, J.S. Jordan, K. (Kiki) Kaplanidou, Marathons for the masses: exploring the role of negotiation-efficacy and involvement on running commitment, J. Leis. Res. 44 (2012) 155–178, https://doi.org/10.1080/00222216.2012.11950260.

[5] P. Belinchón-deMiguel, P. Ruisoto, B. Knechtle, P.T. Nikolaidis, B. Herrera-Tapias, V.J. Clemente-Suárez, Predictors of Athlete's Performance in ultra-endurance mountain races, Int. J. Environ. Res. Public. Health 18 (2021), https://doi.org/10.3390/ijerph18030956.

[6] C. Lavoué, J. Siracusa, É. Chalchat, C. Bourrilhon, K. Charlot, Analysis of food and fluid intake in elite ultra-endurance runners during a 24-h world championship, J. Int. Soc. Sports Nutr. 17 (2020) 36, https://doi.org/10.1186/s12970-020-00364-7.

[7] V. Scheer, L. Cramer, H.-C. Heitkamp, Running economy and energy cost of running with backpacks, J. Sports Med. Phys. Fit. 59 (2019) 555–560, https://doi.org/10.23736/S0022-4707.18.08407-4.

[8] W. Hoogkamer, S. Kipp, B.A. Spiering, R. Kram, Altered running economy directly translates to altered distance-running performance, Med. Sci. Sports Exerc. 48 (2016) 2175–2180, https://doi.org/10.1249/MSS.0000000000001012.

[9] G.C. Lehnen, R.M. Magnani, G.S. de Sá e Souza, F.B. Rodrigues, A. de, O. Andrade, M.F. Vieira, Effects of backpack loads and positions on the variability of gait spatiotemporal parameters in young adults, Res. Biomed. Eng. 33 (2017) 277–284, https://doi.org/10.1590/2446-4740.03517.

[10] S.A. Birrell, R.H. Hooper, R.A. Haslam, The effect of military load carriage on ground reaction forces, Gait Posture 26 (2007) 611–614, https://doi.org/10.1016/j.gaitpost.2006.12.008.

[11] A.G. Schubert, J. Kempf, B.C. Heiderscheit, Influence of stride frequency and length on running mechanics: a systematic review, Sports Health 6 (2014) 210–217, https://doi.org/10.1177/1941738113508544.

[12] J.P. Folland, S.J. Allen, M.I. Black, J.C. Handsaker, S.E. Forrester, Running technique is an important component of running economy and performance, Med. Sci. Sports Exerc. 49 (2017) 1412–1423, https://doi.org/10.1249/MSS.0000000000001245.

[13] S.J. Warden, W.B. Edwards, R.W. Willy, Preventing bone stress injuries in runners with optimal workload, Curr. Osteoporos. Rep. 19 (2021) 298–307, https://doi.org/10.1007/s11914-021-00666-y.

[14] G.A. Couture, K.D. Simperingham, J.B. Cronin, A.V. Lorimer, A.E. Kilding, P. Macadam, Effects of upper and lower body wearable resistance on spatio-temporal and kinetic parameters during running, Sports Biomech. 19 (2020) 633–651, https://doi.org/10.1080/14763141.2018.1508490.

[15] A. Hreljac, Impact and overuse injuries in runners, Med. Sci. Sports Exerc. 36 (2004) 845–849, https://doi.org/10.1249/01.mss.0000126803.66636.dd.

[16] C.E. Milner, R. Ferber, C.D. Pollard, J. Hamill, I.S. Davis, Biomechanical factors associated with tibial stress fracture in female runners, Med. Sci. Sports Exerc. 38 (2006) 323–328, https://doi.org/10.1249/01.mss.0000183477.75808.92.

[17] B.A. MacRae, J.D. Cotter, R.M. Laing, Compression garments and exercise: garment considerations, physiology and performance, Sports Med. Auckl. Nz. 41 (2011) 815–843, https://doi.org/10.2165/11591420-000000000-00000.

[18] A.G. Lucas-Cuevas, P. Pérez-Soriano, J.I. Priego-Quesada, S. Llana-Belloch, Influence of foot orthosis customisation on perceived comfort during running, Ergonomics 57 (2014) 1590–1596, https://doi.org/10.1080/00140139.2014.938129.

[19] G. Luo, P. Stergiou, J. Worobets, B. Nigg, D. Stefanyshyn, Improved footwear comfort reduces oxygen consumption during running, Footwear Sci. 1 (2009) 25–29, https://doi.org/10.1080/19424280902993001.

[20] M. Kinchington, K. Ball, G. Naughton, Relation between lower limb comfort and performance in elite footballers, Phys. Ther. Sport J. Assoc. Chart. Physiother. Sports Med. 13 (2012) 27–34, https://doi.org/10.1016/j.ptsp.2011.02.001.

[21] J.I. Priego Quesada, P. Pérez-Soriano, A.G. Lucas-Cuevas, R. Salvador Palmer, R. M. Cibrián Ortiz de Anda, Effect of bike-fit in the perception of comfort, fatigue and pain, J. Sports Sci. 35 (2017) 1459–1465, https://doi.org/10.1080/02640414.2016.1215496.

[22] B.M. Nigg, J. Baltich, S. Hoerzer, H. Enders, Running shoes and running injuries: mythbusting and a proposal for two new paradigms: "preferred movement path" and "comfort filter,", Br. J. Sports Med. 49 (2015) 1290–1294, https://doi.org/10.1136/bjsports-2015-095054.

[23] A.G. Lucas-Cuevas, A. Camacho-García, R. Llinares, J.I. Priego Quesada, S. Llana-Belloch, P. Pérez-Soriano, Influence of custom-made and prefabricated insoles before and after an intense run, PLoS One 12 (2017), e0173179, https://doi.org/10.1371/journal.pone.0173179.

[24] A.G. Lucas-Cuevas, J.I. Priego-Quesada, I. Aparicio, J.V. Giménez, S. Llana-Belloch, P. Pérez-Soriano, Effect of 3 weeks use of compression garments on stride and impact shock during a fatiguing run, Int. J. Sports Med. 36 (2015) 826–831, https://doi.org/10.1055/s-0035-1548813.

[25] A.M. Jones, J.H. Doust, A 1% treadmill grade most accurately reflects the energetic cost of outdoor running, J. Sports Sci. 14 (1996) 321–327, https://doi.org/10.1080/02640419608727717.

[26] H.K. Vincent, L.A. Zdziarski, K. Fallgatter, G. Negron, C. Chen, T. Leavitt, M. Horodyski, J.G. Wasser, K.R. Vincent, Running mechanics and metabolic responses with water bottles and bottle belt holders, Int. J. Sports Physiol. Perform. 13 (2018) 977–985, https://doi.org/10.1123/ijspp.2017-0184.

[27] G.A. Borg, Psychophysical bases of perceived exertion, Med. Sci. Sports Exerc. 14 (1982) 377–381.

[28] P. Pérez-Soriano, A.G. Lucas-Cuevas, J.I. Priego-Quesada, R. Sanchis-Sanchis, M. Cambronero-Resta, S. Llana-Belloch, F. Oficial-Casado, A. Encarnacion-Martinez, An 8-week running Training program modifies impact accelerations during running, J. Athl. Enhanc. 07 (2018), https://doi.org/10.4172/2324-9080.1000283.

[29] A. Mündermann, B.M. Nigg, D.J. Stefanyshyn, R.N. Humble, Development of a reliable method to assess footwear comfort during running, Gait Posture 16 (2002) 38–45, https://doi.org/10.1016/s0966-6362(01)00197-7.

[30] J. Cohen. Statistical Power Analysis for the Behavioral Sciences, Second ed., Routledge, 1988.

[31] R.J. Simpson, S.M. Graham, C. Connaboy, R. Clement, L. Pollonini, G.D. Florida-James, Blood lactate thresholds and walking/running economy are determinants of backpack-running performance in trained soldiers, Appl. Ergon. 58 (2017) 566–572, https://doi.org/10.1016/j.apergo.2016.04.010.

[32] L. Huang, Z. Yang, R. Wang, L. Xie, Physiological and biomechanical effects on the human musculoskeletal system while carrying a suspended-load backpack, J. Biomech. 108 (2020), 109894, https://doi.org/10.1016/j.jbiomech.2020.109894.

[33] A. de, O. Fagundes, E.P. Monteiro, L.T. Franzoni, B.S. Fraga, P.D. Pantoja, G. Fischer, L.A. Peyré-Tartaruga, Effects of load carriage on physiological determinants in adventure racers, PLoS One 12 (2017), e0189516, https://doi.org/10.1371/journal.pone.0189516.

[34] A.S. Tenforde, T. Hayano, S.T. Jamison, J. Outerleys, I.S. Davis, Tibial acceleration measured from wearable sensors is associated with loading rates in injured runners, PM&R. 12 (2020) 679–684, https://doi.org/10.1002/pmrj.12275.

[35] T.R. Derrick, The effects of knee contact angle on impact forces and accelerations, Med. Sci. Sports Exerc. 36 (2004) 832–837, https://doi.org/10.1249/01.mss.0000126779.65353.cb.

[36] M.A. Busa, J. Lim, R.E.A. van Emmerik, J. Hamill, Head and tibial acceleration as a function of stride frequency and visual feedback during running, PLoS One 11 (2016), e0157297, https://doi.org/10.1371/journal.pone.0157297.

[37] A. Silder, T. Besier, S.L. Delp, Running with a load increases leg stiffness, J. Biomech. 48 (2015) 1003–1008, https://doi.org/10.1016/j.jbiomech.2015.01.051.

[38] B.X.W. Liew, S. Morris, K. Netto, Trunk-pelvis coordination during load carriage running, J. Biomech. 109 (2020), 109949, https://doi.org/10.1016/j.jbiomech.2020.109949.

[39] R. Le Bris, V. Billat, B. Auvinet, D. Chaleil, L. Hamard, E. Barrey, Effect of fatigue on stride pattern continuously measured by an accelerometric gait recorder in middle distance runners, J. Sports Med. Phys. Fit. 46 (2006) 227–231.

[40] B. Bazuelo-Ruiz, J.V. Durá-Gil, N. Palomares, E. Medina, S. Llana-Belloch, Effect of fatigue and gender on kinematics and ground reaction forces variables in recreational runners, PeerJ 6 (2018), e4489, https://doi.org/10.7717/peerj.4489.

[41] N. Rochat, L. Seifert, B. Guignard, D. Hauw, An enactive approach to appropriation in the instrumented activity of trail running, Cogn. Process. 20 (2019) 459–477, https://doi.org/10.1007/s10339-019-00921-2.

[42] X. Phan, T.L. Grisbrook, K. Wernli, S.M. Stearne, P. Davey, L. Ng, Running quietly reduces ground reaction force and vertical loading rate and alters foot strike technique, J. Sports Sci. (2016) 1–7, https://doi.org/10.1080/02640414.2016.1227466.

[43] D. Gagnon, C.G. Crandall, Sweating as a heat loss thermoeffector, in: Handbook Clinical Neurology, Elsevier, 2018, pp. 211–232, https://doi.org/10.1016/B978-0-444-63912-7.00013-8.

[44] A.M. Che Muhamed, K. Atkins, S.R. Stannard, T. Mündel, M.W. Thompson, The effects of a systematic increase in relative humidity on thermoregulatory and circulatory responses during prolonged running exercise in the heat, Temp. Austin Tex. 3 (2016) 455–464, https://doi.org/10.1080/23328940.2016.1182669.