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Physiological stress in flat and uphill walking with different backpack loads in professional mountain rescue crews

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ABSTRACT

This study aimed to determine the interactive physiological effect of backpack load carriage and slope during walking in professional mountain rescuers. Sixteen mountain rescuers walked on a treadmill at 3.6 km/h for 5 min in each combination of three slopes (1%, 10%, 20%) and five backpack loads (0%, 10%, 20%, 30%, and 40% body weight). Relative heart rate (%HRmax), relative oxygen consumption (%VO_2max), and rating of perceived exertion (RPE, Borg 1–10 scale) were compared across conditions using two-way ANOVA. Significant differences in %VO_2max, %HRmax, and RPE across slopes and loads were found where burden increased directly with slope and load (main effect of slope, $p < 0.001$ for all; main effect of load, $p < 0.001$ for all). Additionally, significant slope by load interactions were found for all parameters, indicating an additive effect ($p < 0.001$ for all). Mountain rescuers should consider the physiological interaction between slope and load when determining safe occupational walking capacity.

1. Practitioner summary

The propose of this study was to determine the interactive physiological effect of backpack load carriage and terrain slope during walking in professional mountain rescuers. Our results indicate that there is interaction effect between backpack load and slope. Mountain rescuers should consider the physiological interaction to manage safe occupational walk.

2. Introduction

Mountain activities and mountain accidents have increased in the last decades (Ballesteros Peña et al., 2019). Therefore, interventions from mountain rescue teams have also risen. Since the survival of an injured person depends very often on the effectiveness of mountain rescuers (Pietsch et al., 2019), the rescuers have to perform effectively in difficult terrain and hostile situations (Pietsch et al., 2019; Tomazin et al., 2012) whilst carrying heavy occupational loads (Godhe et al., 2020; Drain et al., 2016). The combination of natural environmental hazards and complex job tasks can directly influence the success of the rescue effort as well as compromise the rescuers' safety (Carlton and Orr, 2014). In many cases, rescue teams need to move quickly without any vehicle or aircraft support (Callender et al., 2012), thus emphasizing the importance of their fitness level to carry heavy loads efficiently on challenging and often steep terrain.

Several factors influence the occupational burden of rescue efforts. One is the backpack load that needs to be carried, which may include medical equipment for attending to patients, protection equipment to overcome natural obstacles, or equipment to aid in navigating difficult terrain during adverse weather conditions. Some studies have analyzed the effects of backpack carriage on physiological and psychophysical variables (Pandoff et al., 1977; Drain et al., 2017; Quesada et al., 2000; Huang and Kuo, 2014; Holewijn, 1990; Beekley et al., 2007; Simpson et al., 2011b; Godhe et al., 2020; Gordon et al., 1983; Pimental and Pandolf, 1979). Simpson et al. (2011b) reported significantly increased heart rate (HR) and rating of perceived exertion (RPE, Borg 1–10) when

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participants carried 20%, 30%, and 40% body weight (BW) compared to 0% BW (ΔHR: 7.4%; RPE: 1.6; ΔHR: 6.5%; RPE: 1.5; ΔHR: 8.3%; RPE: 3.5, respectively). Moreover, the authors observed significant differences in RPE between 20% and 30% BW as well as between 30% and 40% of BW loads. Furthermore, Gordon et al. (1983) demonstrated that RPE, VO_2 and HR had a significant correlation with added load (0%, 20%, 30%, 40, 50% of BW%).

According to the rescue crew participants some rescue last longer than 4h. Knowing the limits of backpack weight and the effects can help to rescue operations. Recent literature suggests that backpack loads for hiking and mountain walking carried should not exceed 30% of BW (Simpson et al., 2011a; Haisman, 1988; Chatterjee et al., 2017; Nag et al., 1978), because this weight might induce a relative intensity between 35% and 40% of VO_2max (Nag et al., 1978; Haisman, 1988; Chatterjee et al., 2017) and be hard to sustain for periods longer than 4–8 h (Wu and Wang, 2001).

Prior research suggests that VO_2 increases over time when initial work intensity elevates above 50% of VO_2max while carrying a backpack load (Epstein et al., 1988). Epstein et al. (1988) showed that oxygen consumption (VO_2) remained constant at 45.5% VO_2max after 120 min of walking with 37% BW load. However, oxygen consumption increased from 52.3% VO_2max to 65.2% VO_2max at the end of 120 min of walking while carrying 59% BW load.

Walking surface conditions can also influence human walking energetic demands (Richmond et al., 2015) and, in particular, the slope of the walking surface has been shown to have a direct effect on RPE, VO_2, and HR (Sagiv et al., 2000; Crowder et al., 2007; Pellegrini et al., 2015; Hinde et al., 2017; Pal et al., 2014; Minetti et al., 2002). Pellegrini et al. (2015) observed that VO_2 has a significant two-fold increase when walking at 15% slope compared to 0% slope (3.85 ± 0.42 METs versus 9.18 ± 1.08 METs, $p < 0.05$). Hinde et al. (2017) also found that when walking at 4 km/h with 10% slope, VO_2 increased by 66% compared to 0% slope. It has also been found that HR significantly increases ($p < 0.05$) between 0%, 5%, and 10% slope with no load (Sagiv et al., 2000).

Previous literature has demonstrated that walking on a steeper slope or carrying heavy loads results in greater physiological stress and perceived exertion. In addition, as Pimental and Pandolf (1979) suggested, additive or interaction effects between slope and load carried may exist. It may be practically important when considering the real-world effects on mountain rescuers. It may be that changes to slope in the environment could modify an individual's capacity to carry varying loads and thus affect occupational performance; however, this has not been explored widely. Hinde et al. (2017) found an interaction effect on VO2 between slope and load but the author only analyzed two loads (without load and 18.5 kg) and two slopes (0% and 10%). Abe et al. (2008) also reported an interaction effect but they only analyzed with 15% of BW.

Additionally, the worker's level of experience with occupational load transport may play an important role in the physiological response to load carrying (Godhe et al., 2020), the experience using a backpack can help to have good mechanical efficiency (Liew et al., 2016). It should be considered that the success of emergency operations is often dependent on rescuer physical performance (Sumann et al., 2020). Especially when considering the duration, typology of task, and occupational loads specific to mountain rescuers, the questions regarding the additive impact of load carriage and slope on physiological and perceptual responses remain unanswered.

Thus, the aim of this study was to determine the effect of the backpack load carriage and walking slope on physiological responses as well as perceived effort in professional mountain rescuers. Therefore, we hypothesized that 1) interaction effects between backpack loads and slopes during walking are expected and are likely to be additive with increasing load and slope and 2) the physiological strain could be severe (>60% VO_2 max) due to the additive effects of backpack load and slope.

3. Methods

3.1. Participants

Sixteen males of the Basque Country Professional Mountain Rescue Team (Table 1) participated in the present study. Inclusion criteria were that participants were professional mountain rescuers with no reported health problems or physical injuries. This research was approved by the Ethics Committee for Research on Human Subjects at the University of the Basque Country (CEISH/GIEB) (Ref. 107/2018), and all the participants provided informed consent before starting their participation.

3.2. Procedure

Participants were tested on three different days. The day before measurements, participants were asked to abstain from performing any vigorous physical activity. Participants were also asked to not intake any solids nor liquids 2 h prior to the testing session. Laboratory tests were performed under stable conditions (temperature = 20C° −26C°, relative humidity 45%–55%, and at 539 m above sea level). On the first day, participants completed anthropometric measurements and a maximal incremental running test (MIRT). After resting for 72 h without moderate or vigorous physical activity, on days 2 and 3, the load carriage test (LCT) was conducted. Between day 2 and 3 the participants rested for 48 h. During this time rescuers did not perform moderate or vigorous physical activity.

3.2.1. Preliminary trial

Anthropometry was measured following instructions and general fundamentals of bioimpedance analysis (Khalil et al., 2014). For body mass, the Tanita bioimpedance scale model was used (Tanita, BF-350, Tanita Corp., Tokyo) and for height, the Seca tallimeter (Hamburg, Germany).

The MIRT was performed on a treadmill (ERGelek EG2, Vitoria-Gasteiz, Spain) at 1% slope. After a 7-min warm-up, participants started the test at 8 km/h, and thereafter the speed was increased by 1 km/h every 3 min until volitional exhaustion. A 1-min pause was included between stages (Bentley et al., 2007). All the participants wore t-shirt, shorts, and sports shoes. VO_2max and HRmax were determined during an incremental test.

3.2.2. Load carriage test (LCT)

On days 2 and 3, each participant completed the LCT which consisted of walking at a constant speed (3.6 km/h) for 5 min (Pandoff et al., 1977; Gomeñuka et al., 2016) on the treadmill (ERGelek EG2, Vitoria-Gasteiz, Spain) while carrying different backpack loads (0%, 10%, 20%, 30%, and 40% of each participant's BW) at three different slopes (1%, 10%, and 20%). Loads were individualized to measure metabolic cost with the same fixed proportion within each individual (Taylor et al., 2016).

Subjects walked for 5 min (Lyons et al., 2005) and rested for 3 min between stages of each combination of load and slope. The testing order of the slopes and loads were the same for all participants. The test with a fixed backpack load was performed across all slopes. Next, another backpack load was tested across all slopes and so on. The slope and load order were the lowest to the highest. Rescuers did the first 8

Table 1
Characteristics of mountain rescuers.

	Mean	SD	Range
Age (years)	44.2	5.9	33.0–55.0
Height (cm)	176.3	5	167.5–185.9
Weight (kg)	75.3	7.4	65.2–90.4
BMI (kg/m^2)	25.5	2.1	24–27
VO2max (ml/kg/min)	53.4	5.4	44.2–63.8
HRmax (beats/min)	181.7	11.1	168.0–208.3

combinations of the LCT test on the first day and the remaining 7 combinations of the LCT on the second day. The mass of the load was made up of sandbags which were added into the same brand backpack for each participant (Sherpa, Altus, Zaragoza, Spain). In order to reduce the known effect of the mass position (Taylor et al., 2016), sandbags were always put in the same location in the backpack, directly in the bottom. To reduce the risk of injury and increase comfort, all participants used the backpack hip belt (Knapik et al., 2004; Lafiandra and Harman, 2004). Participants were not allowed to use any external help (e.g., holding onto the treadmill handrails) during testing and wore the same clothes across all tests.

3.3. Measurements

Volume of oxygen consumed (VO_2, ml/kg/min) was measured continuously in both the MIRT and LCT using the Ergocard breath-by-breath gas analyzer (Ergocard, Medisoft, Sorinnes, Belgium). Before each test, the gas analysis system was calibrated for gas volume and concentration with reference gasses using a 1L syringe (nSpire Koko, nSpire Health Inc., Longmont, CO, USA). The VO_2 was normalized to each participant's body mass without any extra load (ml/kg/min) and then reported as percent of each participant's maximal oxygen consumption (%VO_2max). The VO_2 max values were obtained during MIRT and was considered maximal when three of the following criteria were reached: (1) Respiratory Exchange Ratio >1.1, (2) a plateau in VO_2, (3) HR within 5 bpm of theoretical maximal HR (220-age), (4) RPE = 10 (Howley et al., 1995). HR was monitored continuously using a pulsometer (Suunto Spartan Sport, Vantaa, Finland) in MIRT test and LCT. In MIRT, the highest HR value was considered maximal HR. In LCT VO_2 and HR were calculated as mean of the last minute at each stage (Austin et al., 2018). RPE was assessed using the Borg scale (0–10) (Borg, 1982) at the end of each stage for LCT.

3.4. Statistical analysis

All values are expressed as mean ± standard deviation (SD). Data

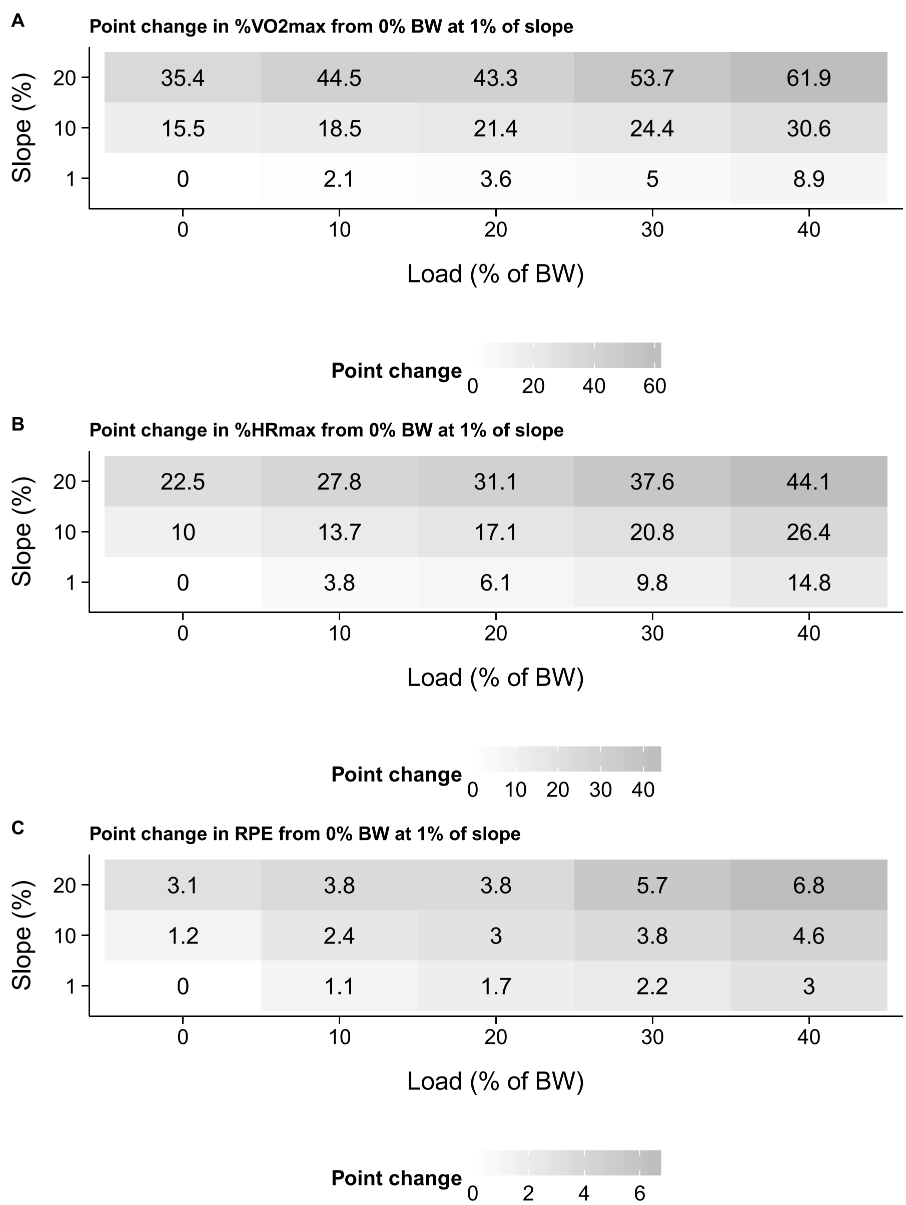

Fig. 1. Point changes in %VO_2max (A), %HRmax (B) and RPE (C) from 0%BW without slope across all combinations. %BW = percentage of body weight; RPE = rating of perceived exertion; %VO_2max = percentage of maximal volume of oxygen consumption; %HRmax = percentage of maximal heart rate.

analyses were performed using IBM SPSS statistical version 23 (SPSS, Inc, Chicago, Illinois). Normality of data was assessed using the Shapiro-Wilks test. A repeated measures two-way analysis of variance (ANOVA) test was applied to evaluate the effect of slopes (1%, 10%, and 20%) and load (0%, 10%, 20%, 30%, and 40% BW) as well as their interaction effect (slope*load) on $\%VO_2max$, %HRmax, and RPE. Bonferroni correction was used for post-hoc pair-wise comparisons. The effect size (ES) of two-way ANOVA effects were calculated using partial eta squared (ηp^2). ESs of ≥0.8, between 0.8 and 0.5, between 0.5 and 0.2, and >0.2 were considered as large, moderate, small, and trivial, respectively (Cohen, 1988). For all tests, statistical differences were considered significant when $p < 0.05$.

4. Results

Fig. 1 displayed the interaction between load and slope and indicate a potential additive effect on $\%VO_2max$, %HRmax, and RPE.

The Interaction effects between load*slope were significant for $\%VO_2max$ ($p < 0.001$; $\eta p2 = 0.576$). It was observed that $\%VO_2max$ increased with increasing load carriage and slope (Fig. 1A). $\%VO_2max$ at 40% BW and 1% slope was 1.4 times larger than with no load and at 1% slope. Additionally, $\%VO_2max$ at 40% BW at 10% and 20% of slope were 2.5 times and 4 times larger than at 1% slope, respectively. Also, additive effects were observed where the rate of increase in $\%VO_2max$ progressively raised as the slope increased. Specifically, the average rate of change in $\%VO_2max$ between load conditions for 1% slope was 2.2 points whereas the average rate of change was 3.8 points and 6.6 points for the 10% and 20% slope conditions respectively. (Fig. 1A).

The %HRmax showed interaction effects between load*slope (%HRmax $p < 0.001$; ES = 0.430). %HRmax was 1.6 times higher in 40% BW and 10% slope, 2.1 time higher in 40% BW and 10% slope compared to 0% BW load and 1% slope. In addition, results suggested that there was an additive effect in %HRmax where the average rate of change in %HRmax from one load condition to the next was 3.7, 4.1, and 5.4 points at 1%, 10%, and 20% slopes respectively. (Fig. 1B).

The last variable, RPE, represented interaction effects between load*slope (RPE $p < 0.001$; $\eta p2 = 0.330$). The measurements were 6.8 points higher in the 40% BW and 20% slope condition compared to 0% load and 1% slope (Fig. 1C). Also, there was an additive effect for RPE where it appears that the rate of increase between load conditions was higher in the high slope conditions than the lower. Specifically, the average rate of increase in RPE at 1% slope was 0.75 points for every increase in load condition while the rate of increase for 10% and 20% slopes was 0.85 and 0.93 points respectively (Fig. 1C).

Table 2, 3 and 4 displayed a main effect of each backpack load and each slope in each variable. The oxygen consumption (Table 2), heart rate(Table 3) and rating of perceived exertion (Table 3) increased with each incremental addition of load and slope. The results of the two-way ANOVA showed significant differences between load ($\%VO_2max$ $p < 0.001$; $\eta p2 = 0.880$; %HRmax $p < 0.001$; $\eta p2 = 0.906$; RPE $p < 0.001$; $\eta p2 = 0.879$) and slope ($\%VO_2max$; $P < 0.001$; $\eta p2 = 0.980$; %HRmax $p < 0.001$; $\eta p2 = 0.978$; RPE $p < 0.001$; $\eta p2 = 0.953$). The post-hoc pairwise comparisons between load at each slope is shown in Tables 2–4. The physiological variables and RPE showed significant increases with +10% BW load increases between 0% and 40% BW at 1%, 10%, and 20% slopes. For all three slopes, it was observed that RPE, $\%VO_2max$, and %HRmax had significant differences ($p < 0.05$) between 10% BW compared to the unloaded (0% BW) conditions. It was observed that significant differences in $\%VO_2max$ started from 20% BW at 10% of slope (Table 2) in comparison with no load. As for the differences between slopes, the results showed that all variables were significantly different across the three slopes at all loads ($p < 0.05$ for all).

5. Discussion

This is the first study which analyzed the interactive influence of various backpack loads and slopes during walking in professional mountain rescuers. From a practical point of view, information that clarifies this interactive influence specifically in mountain rescuers could contribute to the success of complex emergency rescue procedures in that occupational tasks may require a combination of load carriage and varying terrain. To disentangle this research gap, we compared physiological and perceived exertion responses across various load and slope conditions.

Overall, we observed a direct association between $\%VO_2max$, %HRmax, and RPE with backpack load and walking slope, which is unsurprising given previous research showing similar direct effects for load (Sagiv et al., 2000; Crowder et al., 2007; Pellegrini et al., 2015; Hinde et al., 2017; Pal et al., 2014; Minetti et al., 2002) and slope (Pandoff et al., 1977; Drain et al., 2017; Quesada et al., 2000; Huang and Kuo, 2014; Holewijn, 1990; Beekley et al., 2007; Simpson et al., 2011b; Godhe et al., 2020). However, adding to the previous literature, we observed significant interaction effects between load and slope conditions across all three variables measured ($\%VO_2max$, %HRmax, and RPE).

At 1% slope, when participants carried loads between 0% BW and 40% BW, we observed that $\%VO_2max$ increased from 20 ± 2.4% to 28.9 ± 5.9% ($p < 0.05$). The $\%VO_2max$ results measured in our participants were similar to those reported by Godhe et al. (2020), where both experienced and unexperienced volunteers took part in the study. In this study, work rates were 22 ± 3% and 26 ± 3% of VO_2max while participants carried backpack loads of approximately 20% BW and 40% BW, respectively, while walking at 3 km/h without slope. Likewise, Quesada et al. (2000) observed that VO_2 raised from 30% of VO_{2max} without load to 41% of VO_2max when 12 military soldiers walked at 6 km/h speed with 30% BW load on 0% slope. Additionally, Pandoff et al. (1977), Gordon et al. (1983) and Drain et al. (2017) found a positive relationship between backpack load and VO_2. Another study has shown a positive linear relationship ($p < 0.001$; $R^2 = 0.83$) between backpack load and rate of metabolic energy expenditure, where metabolic power

Table 2
Effects of different backpack loads on oxygen consumption.

		Oxygen consumption ml/kg/min % of BW					Oxygen consumption $\%VO_2max$ % of BW				
		0%	10%	20%	30%	40%	0%	10%	20%	30%	40%
Slope	1%	10.6 ±1.2	11.7 ±1.7	12.5 ±2.1	13.2 ±1.2	15.2 ±2.3	20.0 ±2.4	22.1 ±3.3*	23.5 ±4.3*	25.0 ±4.1*✣	28.9 ±5.9*✣▾❖
	10%	18.8 ±2.6	20.4 ±2.8	21.9 ±2.9	23.5 ±2.4	26.8 ±3.1	35.5 ±5.8	38.5 ±6.4	41.4 ±7.1*	44.3 ±6.1*✣	50.6 ±7.2*✣▾❖
	20%	29.3 ±2.4	34.1 ±2.7	33.6 ±2.0	39.1 ±3.3	43.5 ±3.2	55.3 ±6.6	64.4 ±9.1*	63.3 ±6.3*	73.6 ±8.0*✣▾	81.8 7.1*✣❖

Note: Values mean ± SD; %BW = percentage of body weight; $\%VO_2max$ = percentage of maximal volume of oxygen consumption; Significance <0.05 indicate * (comparison with 0%BW), ✣ (comparison with 10%BW), ▾ (comparison with 20%BW), ❖ (comparison with 30%BW).

Table 3
Effects of different backpack loads on heart rate.

		Heart rate									
		Beats/min % of BW					%HRmax % of BW				
		0%	10%	20%	30%	40%	0%	10%	20%	30%	40%
Slope	1%	72.4 ±4.9	79.1 ±7.0	83.6 ±7.9	90.1 ±9.1	99.3 ±11.9	39.9 ±3.2	43.6 ±3.8*	45.9 ±3.9*✣	49.7 ±4.8*✣▼	54.7 ±5.2*✣▼❖
	10%	90.2 ±5.9	97.5 ±7.8*	103.5 ±10.1*✣	109.9 ±10.1*✣▼	120.5 ±15.5*✣▼❖	49.9 ±3.7	53.6 ±4.3*	56.9 ±5.2*✣	60.7 ±5.2*✣▼	66.3 ±7.4*✣▼❖
	20%	113.1 ±8.6	123.0 ±10.4	128.4 ±11.1	140.5 ±13.9	152.1 ±15.9	62.4 ±5.0	67.7 ±5.9*	70.9 ±6.8*✣	77.5 ±7.1*✣▼	83.9 8.2*✣▼❖

Note: Values mean ± SD; %BW = percentage of body weight; %HRmax = percentage of maximal heart rate; Significance <0.05 indicate * (comparison with 0%BW), ✣ (comparison with 10%BW), ▼ (comparison with 20%BW), ❖ (comparison with 30%BW).

Table 4
Effects of different backpack loads on rating of perceived exertion.

		RPE				
		Borg (0–10) %BW				
		0%	10%	20%	30%	40%
Slope	1%	1.8 ±0.8	3.0 ±0.9*	3.6 ±1.0*✣	4.4 ±1.0*✣▼	5.1 ±1.2*✣▼❖
	10%	1.8 ±0.8	3.0 ±0.9*	3.6 ±1.0*✣	4.4 ±1.0*✣▼	5.1 ±1.2*✣▼❖
	20%	3.7 ±0.7	4.3 ±0.9*	4.4 ±1.0*	6.3 ±1.1*✣▼	7.3 ±1.3*✣▼❖

Note: Values mean ± SD; %BW = percentage of body weight; RPE = rating of perceived exertion; Significance <0.05 indicate * (comparison with 0%BW), ✣ (comparison with 10%BW), ▼ (comparison with 20%BW), ❖ (comparison with 30%BW).

increased by 7.62 W for each additional 1 kg added to the backpack load (Huang and Kuo, 2014). At 10% slope, the current study observed that the physiological burden was higher in 40% BW loads compared to 0% BW (0% BW: %VO_2max = 35.5 ± 5.8, 40% BW: %VO_2max = 50.6 ± 7.2). Additionally, Sagiv et al. (2000) observed that walking at 5 km/h with 25 kg and 35 kg at 10% slope caused a raise in VO_2 (25 kg load, +90% VO_2; 35 kg load, +112% VO_2). In the current study, the intensity was 55.3% VO_2max without load at 20% slope and raised to 81.8 % VO_2max with a 40% BW load.

The HR at 1% slope HR raised from 39.9 ± 3.2 (without load) to 54.7 ± 5.2 %HRmax (40% of BW)($p < 0.001$). A similar result has been observed where HR increases with added loads (Quesada et al., 2000; Gordon et al., 1983). At 10% slope, the current study observed that HR burden was higher in 40% BW loads compared to 0% BW (0% BW: %HRmax = 49.9 ± 3.7; 40% BW: %HRmax = 66.3 ± 7.4). One previous study observed that walking at 5 km/h with 25 kg and 35 kg at 10% slope caused a raise in HR (25 kg load, +23% HR; 35 kg load, +38% HR) (Sagiv et al., 2000). Moreover, HR increased from 62.4%(without load) to 83.9% of HRmax (40% of BW) when walking at 20% of slope.

When considering RPE, the results showed that increases in RPE were not more than 3.6 even when participants carried 40% BW compared to 0% BW when walking without slope. At 10% of slope, there was also an increase in RPE across load conditions that reached "heavy" at 40% BW. Also, RPE reached "strong" at 40% of BW in the steepest slope. In a similar study, RPE increased incrementally with added load. Simpson et al. (2011b) compared different loads (0%, 20%, 30%, and 40% BW) and found significant differences in RPE between all loads at 0% slope. Also, Gordon et al. (1983) showed that RPE had a significant correlation with the added load when walking.

In our research, we found that successive increases of 10% slope increases physiological variables and RPE, independently of the backpack load (i.e., 0%, 10%, 20%, 30%, and 40% BW). These results are consistent with findings from previous studies (Sagiv et al., 2000; Crowder et al., 2007; Pellegrini et al., 2015; Hinde et al., 2017; Pal et al., 2014). Crowder et al. (2007) observed a similarly significant raise of HR and VO_2 ($p < 0.05$) across conditions when participants walked at 6 km/h on different slopes (0%, 5%, and 10%) with approximately 30% BW load. Moreover, Pellegrini et al. (2015) observed that $\dot{V}O_2$ increased two-fold (15 vs. 30 ml/kg/min) when changed from walking at 4 km/h at 0% slope to 15% slope.

These increases in physiological demands when walking at increased slopes might be due to a decrease in mechanical walking efficiency, by affecting the kinetic and gravitational potential energy exchanged (Ludlow and Weyand, 2017). As a result, there is poor walking economy when slope increases, as previously studied (Ludlow and Weyand, 2017). For instance, walking at 9% slope caused a 63% decrease in walking economy that represented a 1.77 J/kg/step increase in energy expenditure (Gottschall and Kram, 2006). Nevertheless, positive slopes affect walking mechanics in a way that changes hip, knee, and ankle extension and associated muscle activation compared to walking on flat terrain (Franz and Kram, 2012).

In order to simulate real-world scenarios that likely have dynamic slope and load conditions, analyzing the interaction between slope and backpack load is considered of paramount importance. We observed significant interactions between slope*load on %VO_2max, %HRmax, and RPE. Furthermore, an additive effect was observed in the interaction where the increase in burden from increasing slope may be further aggerated by higher loads and vice versa. The results from the present study are also in agreement with previous findings (Abe et al., 2008; Abe et al., 2008; Hinde et al., 2017), where interaction effect was found on VO_2 between slope (0% and 10%) and load (without load and 18.5 kg) walking at 4 km/h. The current study's findings expand on these previous findings by using more diverse slope and load conditions as well as utilizing a sample of professional mountain rescuers. Thus, the result of this study also supported our first hypothesis showing a significant interaction effect between backpack loads and slope.

The results for 1% slope suggest that the effect of backpack loads at 10% slope may be more impactful on work performance than at 1% slope due to the greater influence in physiological and perceptive stress. Epstein et al. (1988) recommended not exceeding 50% VO_2max to maintain stable oxygen consumption; however, in long-duration tasks (4–8 h), other researchers recommended that work rate should be maintained below 43.5% and 34% VO_2max, respectively (Wu and Wang, 2001). When considering our results within the context of these recommendations, at 10% slope it would not be advisable to carry more than 30% of BW to maintain stable oxygen consumption (<50% VO_2max) across long-duration work tasks.

According to our results, time to exhaustion would be limited to less than 4 h when walking at 20% slope with 40% BW because the initial work intensity is well above 50% VO_2max (Epstein et al., 1988). It is known that above to 60% VO_2 max intensity, starting different physiological events has the potential for severe consequences (e.g. Hydrogen ions accumulation, glycogen depletion). As a result, the events directly affect athlete fatigue and compromise effort duration (e.g. 1–3 h duration time at 60–70% VO_2 max).

The result of this study supported in part the second hypothesis, depending on the combination of slope and backpack load the physiological and perceptual strain change from light to heavy.

In summary, during mountain rescue activities, the slopes that rescuers are exposed to are unpredictable, highly variable, and often out of the rescuer's control. Nevertheless, backpack loads of each rescuer can be changed via administrative and policy controls that could minimize total operator fatigue. For this reason, the results of this study suggest that rescuers not carry more than 20% of BW on the backpack so their performance would not be compromised when working at any slope tested within the current study (0%, 10%, or 20%). However, other factors must also be considered. For example, characteristics of the rescue activities (speed, duration, terrain, clothing, and weather) could change the effect of 20% of BW across varying slopes (Haisman, 1988). Maximal work duration at a given intensity may also be affected by other factors such as muscle discomfort without being reflected in VO_2 (Drain et al., 2016).

6. Limitations

There are several limitations to this research that must be considered. First, we used a convenience sample of only participants representing one professional mountain rescue team. This male only sample population may not be representative of the global mountain rescuer population, therefore limiting the external validity of this study. Experience level may also play a role on how these loads and slopes impact individual physiological responses. Since all participants in this study were professional mountain rescuers, the results may not apply directly to new recruits or inexperienced workers. Secondly, to limit potential participant fatigue, the protocol may have benefited from being divided across more than two days. While this was not practically feasible in the current study, future studies should consider this limitation. Additionally, real-world mountain rescuer tasks may be completed in high-altitude environments, which may significantly impact the physiological responses observed. Future research may consider a similar analysis with the addition of hypoxic or hypobaric conditions. While varying backpack load placement or distribution was not the focus of this study, it may significantly impact the balance and stability of the worker and should be considered in future examinations. The testing order during the LCT was not randomized as to align with previously described procedures (Lyons et al., 2005), and the lack of randomization could have presented bias to the study results. However, according to relative intensity that is shown in the results, only the last three combinations may have been affected by cumulative fatigue. The results of the last three combinations may be overestimated. Thus, the findings at 40% of BW must be taken with caution. It is known that VO_2max with a backpack load (25 kg) may be 2.5% points less than without load (Phillips et al., 2016). Nevertheless, no studies have been found where the effect of loads ranging from 1% to 40% of BW was measured. Unfortunately, it was not practically feasible for us to measure VO_2max with each backpack load. Lastly, this study was limited by short durations of testing at each condition (5 min). While these data are useful as a basis to predict the physiological impact during real-world occupational scenarios, longer durations of effort as would be seen during rescue efforts may have a different impact on the workers' response and therefore should be studied in the future.

7. Conclusions

This study is unique in analyzing the physiological and perceptual effects of load carriage as well as slope in professional mountain rescuers. The increase in load carried and slope significantly and directly impacted both physiological and perceived exertion variables during walking, and subsequently, can be predicted to reduce maximal work capacity. Interestingly, significant slope by load interaction effects revealed a potential additive effect of slope and load that should be considered in occupational application and load recommendations. To demonstrate, while walking at 1% of slope without load and with 40% BW load did not seem to present a meaningful physiological obstacle to completing rescuer worker activities for long durations, walking at 10% and 20% slope when carrying a 40%BW load may present a physiological strain that limits work time. Consideration should be given to these physiological and perceptual implications when developing and implementing administrative policies for load carriage in different environments for professional mountain rescuers.

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Disclaimer

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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