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Review article

Protocols used to determine the influence of backpack load on physiological variables. Systematic review

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A R T I C L E I N F O

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A B S T R A C T

Professional mountain rescue mountain groups use backpack equipment in their professional activities. The velocity of ambulation, gradient, load and the participant's physical characteristics have been described in the scientific literature as influential factors on response to exercise. The purpose of the present systematic review is to assess the protocols used to investigate the effects of backpacks and their influence on physiological responses at laboratory. A total of 14 articles were included in the review. Most research studies indicated participants were not experienced with backpack carriage. We observed a certain threshold on physiological changes in response to exercise was between 20 and 40 kg of backpack load. In conclusion, there is a heterogeneity of protocols used at the laboratory, hampering the comparison between different results. Future research should focus on the design of protocols that reproduce real scenarios of targeted populations.

Relevane to industry: Rescue groups, firefighters and military personnel carry load with backpack in emergency interventions. This review analyzes different types of methodological protocols that investigate the influence of backpack load on physiological responses during exercise. The result will help manufacturer design backpacks considering the physiological burden of backpack carriage.

1. Introduction

Medical practitioners, rescue groups, firefighters and military personnel are accustomed to carrying different equipment loads during their day to day activities (Faghy and Brown, 2014; Knapik et al., 1996; Phillips et al., 2016c; Pal et al., 2020). Likewise, other individuals in recreational to sports pursuits also have to combine ambulation with weighted materials in demanding activities such as climbing, hiking or mountaineering (Hinde et al., 2017).

The backpack carrying system seems to be the most efficient way to carry the equipment as well as the best method to avoid injuries (Golriz and Walker, 2011). The load carried in a backpack will be an important factor in the physiological response to exercise and performance during longer periods of exercise. The backpack load has also a direct impact on the energy expenditure (EE) (Faghy et al., 2016; Huang and Kuo, 2014; Chatterjee et al., 2017). Huang and Kuo (2014) estimated a 7.62 W increase in gait power for every kg of mass added to the backpack.

During physical activity the monitoring of load, can help to minimize the risk of injury and to optimize performance (Liew et al., 2016; Simpson et al., 2011; Li et al., 2019). The load severity appears to have little or no decisive impact in short periods of exercise. However, during longer duration exercise the importance of the load on athlete's performance and well being increases. Therefore, optimally controlling these loads, could help to influence different physiological parameters that are closely related to performance or injury prevention (Cole et al., 2006; Alamoudi et al., 2018).

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Several studies have reported the EE during exercise when backpack load differs in combination with different approaches and protocols. Epstein et al. (1987) used 18 different combinations of slope and weight during running. However, Simpson et al. (2010) used a walking exercise incremental test with 20 kg weight in the backpack and they observed the develop of heart rate and rating of perceived exertion (RPE). These studies analyze the effect of the backpack load in combination with different variables in their experimental design such as ambulation speed, inclination, weight and participant profiles.

One of the variables affecting field simulation protocols is the severity of incline (Cole et al., 2006; Phillips et al., 2016c). Some authors have observed a rise in metabolic cost (W/Kg) rate of 113 ± 32% at 10% inclination in comparison to 0% slope (Silder et al., 2012). It has also been demonstrated that these variables may have an impact on the performance in different body aspects, such as physiology or biomechanics (Knapik et al., 1996; Phillips et al., 2016c; Pal et al., 2014, 2020).

Regarding gait speed, the variation of velocity is as a critical influence on experimental findings. In some cases, the speed used was moderate, ranging from 1.44 km/h to 3.6 km/h. In other experiments, these speeds were two folds higher, reaching velocities of 4.82 km/h to 6.5 km/h, which inflicted different physiological responses and on the participant's performance (Faghy et al., 2016; Phillips et al., 2016c).

The diversity of experimental designs related to speed used in these protocols, makes the comparison between studies difficult. At different intensities, the physiological responses can vary substantially (Gomeñuka et al., 2016). Some authors justify no normalization of the backpack load to the individual weight because of the pre-established equipment they need to manage in their operations (Holewijn, 1990; Phillips et al., 2016d), whilst Liew et al. (2016) considered normalization of an inclusion criteria in their review with preliminary meta-analysis. Nevertheless, another influential factor was the previous experience of the person relative to the load transported in the backpack, which was associated with biomechanical adaptation and efficiency improvement (Liew et al., 2016).

The diversity of experimental designs, especially the protocols used to analyze the influence of the backpack transportation, impair decision making when choosing the optimal load relative to the objective of the exercising person. The loads were chosen in order to replicate different stress scenarios during rescue operations. Therefore, it would be of great interest for researchers and rescue teams to know what the impact is of each variable in order to design more accurate experimental protocols. Thus, we aimed to perform a systematic review to summarize the protocols used to determine the influence of backpack load on physiological variables.

For that purpose, a systematic review was designed. Firstly, a description of different treadmill protocols used to measure the impact of the backpack on performance was performed. Secondly, backpack load as an independent variable and oxygen uptake and energy expenditure as dependent variables were analyzed. As a result of the latter, we tried to determine the influence of the load on physiological parameters, specifically on VO_2 and EE.

2. Methods

2.1. Scientific literature identification

This systematic review followed the protocol assessed by *Preferred Reporting Items for Systematic Reviews and Meta-Analyses* (PRISMA) (Moher et al., 2009). The review work done by Liew et al. (2016) was used as reference for backpack carrying analysis.

The search method was performed in the following databases: *PubMed, Sportdiscuss and Web of Science*, on the Jun 30, 2020, including all documents published until this date for: *(backpac* AND load AND walk*) NOT child* NOT school*. During the searching process no filter for database was used.

For selected items, the inclusion and exclusion criteria were as follows:

Inclusion criteria:

1. English language literature.
2. Age of participants, 18 to 65.
3. Research works that included oxygen uptake analysis.
4. The use of symmetric backpacks with both shoulders on posterior plane.
5. Studies performed on treadmills in normoxic conditions.
6. Backpack load as independent variable.
7. The studies must compare at least the gait with backpack vs. with no backpack (control condition).
8. Quasi-experimental studies.

Exclusion criteria:

1. Research works that include any type of pathology.
2. Research works that investigate injury risk.
3. Research works that compare backpack materials.
4. Besides backpack transportation, other loads that could influence the results from backpack carrying (accessories, etc.).

2.2. Selection procedure

Firstly, a search on databases mentioned previously was performed. Once the search was completed, the relevant studies were imported to the software Endnote X 7.5 (Thomson, Reuters, Carlsbad, CA) At this stage, duplicated references were discarded according to *Digital Object Identifier* (DOI), title and authorship. Coincidence analysis was manually completed.

As a preliminary screening mechanism, title and abstract were evaluated by a single investigator. In case of doubt, articles were included. In the next step, full text articles were evaluated by two independent investigators that considered the exclusion criteria. The external investigator was consulted in case of disagreement. Selection process results are shown in Fig. 1.

2.3. Quality analysis

Each selected article was evaluated by the *Physiotherapy Evidence Database* (PEDro) (de Morton, 2009) and the *Oxford levels of evidence* (OCEBM, 2009). In PEDro scale, 11 criteria were taken into account.

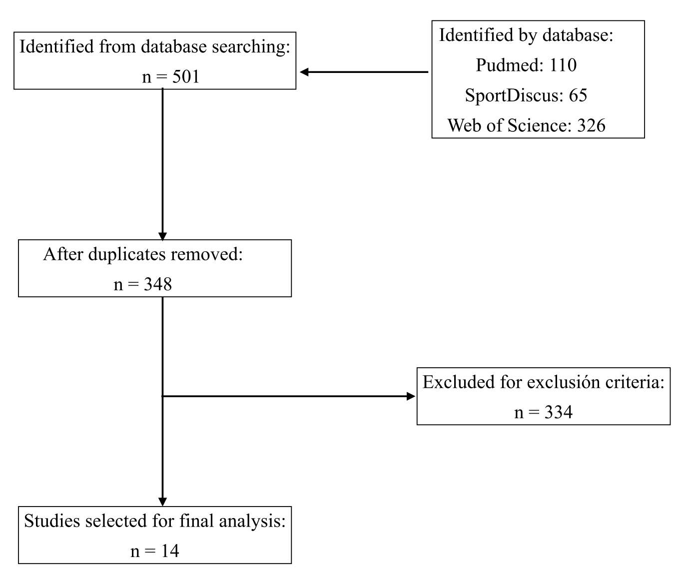

Fig. 1. Selection process.

From the second to the tenth rating scales the evidence can be rated as one or zero points with a potential sum of maximum 10 points. The Oxford Centre for Evidence-based Medicine classifies rates from 1 to 5. The level 1a is the maximum evidence, which is based on meta analyses with randomized studies. Level 5 corresponds to the lowest level and includes opinions of experts. These quality criteria can be seen in Table 1. Quality analysis were evaluated by two independent investigators. Any disagreement was resolved by consultation with external investigator until a final consensus was achieved.

2.4. Data extraction

The information extracted was as follows: authorship and year of publication, sample, experience in backpack carrying, age, body mas and height. Another table was designed in order to extract the characteristics of the studies used in the experiment procedure (Table 3). In this table, the following variables can be seen: type of backpack, backpack mass in absolute values (kg), backpack relative mass to body weight (% BW), inclination (%), speed, duration and results of the studies. The variable speed has been converted to metric values expressed in km/h.

In those cases, where the studies did not show the value, this number has been replaced by means registered in the same study.

3. Results

The searching strategy produced a total amount of 501 references amongst the 3 databases. From these references, 348 was the number of studies excluding the duplicated articles (Fig. 1). Once finalized the eligibility process, 14 studies were finally selected. Exclusion criteria was based on one of the following reasons: type of study, comparison of load method, other accessories added, sample type, analyzed variables and used protocol. In total, 334 studies were excluded.

3.1. Evidence level and level of quality

All selected studies had the same evidence level 3b according to Oxford Scale for Evidence Based Medicine. The quality of the studies was determined by the PEDro Scale obtaining an average of 3.5 points framed in a range between 3 and 4 (Table 1).

3.2. Characteristics of the participants

The samples of selected studies were registered and described in Table 2. Analyzed studies resulted in data from 265 participants aged between 19 and 29 yr, 74.7 ± 7.3 kg. 58 individuals (21.8%) had previous experience with backpack transportation. More detailed characteristics of the participants can be seen in Table 2.

3.3. Protocols

Each study was conducted using a specific protocol (Table 3). Regarding to load carrying, different approaches/methods were observed.

Some studies focused on the relationship between backpack and BM below 30% of it (Faghy et al., 2016; Faghy and Brown, 2014; Gomeñuka et al., 2016) (Phillips et al., 2016c, 2016d) whilst others instead, analyzed the effect of the load greater than 30% of BM. (Epstein et al., 1988; Lyons et al., 2005; Pandoff et al., 1977; Phillips et al., 2016a; Sagiv et al., 2000). A third group was found, using different loading strategies (Gordon et al., 1983) (Goslin and Rorke, 1986; Huang and Kuo, 2014; Phillips et al., 2016c) (Table 2).

With respect to speed, there were two different type of studies, those using constant speeds, and others using a combination of different velocity (Table 3). In studies using constant speeds, there was a common velocity from 3 km/h to 5.4 km/h, showing some higher paces within the same research groups, with some reaching 6.5 km/h (Faghy et al., 2016; Faghy and Brown, 2014). When inclination was analyzed, such pace changing trend was not observed.

In all the studies, 5 min workloads were utilised for each combination of variables. In addition, these combinations were performed on different days. In this type of protocols, maximal incremental tests were excluded.

3.4. Results of the studies

According to results observed in Table 3, VO_2 increased in relationship with the load in the majority of the cases (Epstein et al., 1988; Faghy et al., 2016; Faghy and Brown, 2014; Gordon et al., 1983; Lyons et al., 2005; Phillips et al., 2016a, 2016c, 2016d). In some reports, this relationship is highly related, showing a relative VO_2 relationship with the workload of $r = 0.995$ ($p < 0.05$) (Gordon et al., 1983).

In the analyzed sample, backpack loads changes ranged from 20 kg

Table 1
Quality of studies.

Included Study	PEDro escale criterion												Evidence levels
	1	2	3	4	5	6	7	8	9	10	11	Total	
Epstein et al. (1988)	No	0	0	0	0	0	0	1	0	1	1	3	3b
Faghy et al. (2016)	No	0	0	0	0	0	0	1	0	1	1	3	3b
Faghy and Brown (2014)	No	0	0	0	0	0	0	1	0	1	1	3	3b
Gomeñuka et al. (2016)	No	0	0	1	0	0	0	1	0	1	1	4	3b
Gordon et al. (1983)	No	0	0	0	0	0	0	1	0	1	1	3	3b
Goslin and Rorke (1986)	No	0	0	0	0	0	0	1	0	1	1	3	3b
Huang and Kuo (2014)	No	0	0	0	0	0	0	1	0	1	1	3	3b
Lyons et al. (2005)	No	0	0	1	0	0	0	1	0	1	1	4	3b
Pandoff et al. (1977)	No	0	0	1	0	0	0	1	0	1	1	4	3b
Phillips, Ehnes, et al. (2016c)	No	0	0	0	0	0	0	1	0	1	1	3	3b
Phillips, Stickland, Lesser, et al. (2016b)	Si	0	0	1	0	0	0	1	0	1	1	5	3b
Phillips, Stickland, and Petersen (2016a)	No	0	1	0	0	0	0	1	0	1	1	4	3b
Phillips, Stickland, and Petersen (2016d)	No	0	0	1	0	0	0	1	0	1	1	4	3b
Sagiv et al. (2000)	No	0	1	0	0	0	0	1	0	1	1	4	3b

Note. PEDro scale criteria: 1. Eligibility criteria were specified; 2. Random allocation to groups.; 3. Concealed allocation; 4. The groups were similar at baseline regarding the most important prognostic indicators; 5. Blinded participants; 6. Researchers administrating therapy were blinded; 7. Evaluators were blinded at least in one of the key outcomes; 8. Measures of at least one key outcome were obtained from more than 85% of the subjects initially allocated to groups; 9. All subjects for whom outcome measures were available received the treatment or control condition as allocated or, where this was not the case, data for at least one key outcome was analyzed by "intention to treat"; 10. The results of between-group statistical comparisons are reported for at least one key outcome; 11. The study provides both point measures and measures of variability for at least one key outcome.

Table 2
Characteristics of the participants.

Authorship (year)	M/F	Fitness level	Experience	Age (yr)	BM (kg)	Height (m)
Epstein et al. (1988)	M = 6	Highly trained (endurance)	N/A	19.1 ± 0.1	66.8 ± 4.4	1.83 ± 0.06
Faghy et al. (2016)	M = 8	Active	Recreational	20.9 ± 0.8	75.1 ± 11.6	1.81 ± 0.09
Faghy and Brown. (2014)	M = 19	Active students	N/A	24.7 ± 7.5	83.3 ± 8.9	1.80 ± 0.06
Gomeñuka et al. (2016)	M = 10	Non trained	N/A	23.1 ± 2.9	71.6 ± 6.0	1.78 ± 0.06
Gordon et al. (1983)	M = 10	N/A	N/A	22.2 ± 0.1	71.8 ± 0.8	
Goslin and Rorke (1986)	M = 10	N/A	N/A	24.3 ± 2.8	72.7 ± 7.5	1.78 ± 0.04
Huang and Kuo (2014)	8 (M = 6 F = 2)	N/A	N/A	22.5	71.1 ± 12.0	
Lyons et al. (2005)	M = 28	N/A	N/A	30 ± 4	80.3 ± 9.2	1.77 ± 0.06
Pandoff et al. (1977)	M = 6	Trained	N/A	20 ± 0.8	78.2 ± 1.6	1.75 ± 0.02
Phillips, Ehnes, et al. (2016)	M = 19	Active	N/A	27 ± 5	86.9 ± 15.1	1.80 ± 0.07
	M = 18	Active	N/A	27 ± 5	86.9 ± 15.1	1.80 ± 0.07
Phillips, Stickland, Lesser et al. (2016)	M = 50	Active	Recreational	28 ± 3	85.4 ± 12.1	1.83 ± 0.06
Phillips, Stickland, y Petersen (2016a)	M = 24	Active	N/A	24 ± 4	65.5 ± 6.1	1.69 ± 0.07
	M = 14	Active	N/A	24 ± 4	65.1 ± 6.5	1.70 ± 0.05
Phillips, Stickland, y Petersen (2016b)	M = 15	Active	N/A	29 ± 3	83.5 ± 9.5	1.82 ± 0.05
Sagiv et al. (2000)	M = 20	Endurance athletes	N/A	19 ± 1	73 ± 6	1.79 ± 0.05

Note. M/F = Male/Female; N/A: not applicable/specified.

to 40 kg (Epstein et al., 1988) (Lyons et al., 2005), representing a range from the 30% BM to 45% of BM. Similarly, Epstein et al. (1988) found significant differences ($p < 0.01$) in the EE between 25 kg and 45 kg. Furthermore, an increase in EE was observed during the whole protocol, whereas 25 kg load remained stable. In agreement with previously mentioned results, Goslin and Rorke (1986) registered changes between 20% and 40% of the BM. Phillips et al. (2016c) obtained results that showed significant differences ($p < 0.05$), and 18% increase in VO_2 between 30 kg and 45 kg as well as 14.5% when the load was between 15 kg and 30 kg.

EE is clearly affected by variables such as speed, inclination and load (Gomeñuka et al., 2016). In the study of Pandoff et al. (1977) there were no differences in the EE between different loads; 32 kg, 42 kg and 50 kg at speeds ranging from 0.72 km/h to 3.66 km/h. However, when examining at EE at different speeds, significant differences were found. For example, at speeds of 0.72 km/h to 3.66 km/h, there was an increase of the 84.6% of the EE. Phillips et al. (2016c) pointed out the increase of the inclination as a triggering factor for changes in the VO_2. Precisely, in slopes of 0%, 4% and 10% respectively, the same authors found differences up to 43%, 47% and 55% in the VO_2 between 45 kg and without load (data extraction with *WebPlotDigitalizer* 4.1 from the original paper. Phillips et al. (2016b) reported small differences ($p < 0.05$) in the absolute VO_2 between 6% and 8% steepness. Sagiv et al. (2000) observed instead that there are significant differences in values of VO_2 related to the BM ($p < 0.05$) regardless the loads between different slopes.

4. Discussion

The results of this review suggest that the majority of the selected studies, in order to detect changes in physiological parameters, used individuals non familiarized with backpack carrying. Regarding the protocols used, different combinations of variables were found such as inclination and weight loads. A trend to use speeds between 3 km/h and 5.4 km/h was observed. All the protocols **assessed** in this review had a minimum duration of 5 min, where different variables where combined in order to look at changes in different physiological parameters. These physiological demands, appeared to increase when adding carrying loads. Furthermore, VO_2 seems to be closely related to load increase. Likewise, EE **increased to a greater extent** when loads increased between 20 kg and 40 kg.

In agreement with our initial observation, Liew et al. (2016) stated in their systematic review with meta analysis focused on biomechanical analysis, that most of the studies lacked a sample with experience in backpack carrying. Most of them were students non familiarized with intense backpack activities. Several research have been done with participant accustomed to carrying backpack (Christie and Scott, 2005; Legg et al., 1992; Paul et al., 2015; Simpson et al., 2010). However, these studies recruited professional soldiers, and often, other carrying accessories, might mask the loading effects on the analyzed parameters.

The lack of specificity for backpack carrying, may be due to the fact that little research has been done on groups carrying backpacks without further accessories, since these accessories might mask the isolated effect of backpack carrying.

Besides, the experience on backpack load carriage (Liew et al., 2016) could play a major role, and should be taken into account when the analyzing the results.

The range of speeds of the studies, appears to coincide with those used in experiments with healthy participants 2.6 km/h - 6.12 km/h (Bohannon and Williams Andrews, 2011). However, it could be more accurate to use speeds in which analyzed participants carry out activities with backpacks in order to simulate scenarios that are more realistic (Gomeñuka et al., 2016; Pandoff et al., 1977). This is in concordance when the effect of the incline is analyzed. The inclination has impact on biomechanical parameters (Paul et al., 2016) as well as on physiological responses (Phillips et al., 2016c). Therefore, it could be of interest to simulate slopes that will be more likely to reproduce real scenarios of the targeted groups (rescue teams, hikers etc). In this regard, Gordon et al. (1983) simulated an inclination of 10% because it is what participants of the experiment will face in real scenarios.

Respect to physiological demand, results showed a consensus in VO_2 increasing as carrying load increased. The results are in concordance with those reported by Quesada et al. (2000), showing that for every 15% of increase in the BM, the EE augmented up to 5–6%. Military personnel equipped with military outfit carried out this research work. Plausible explanation for this result, could be that the muscle mass needed to increase its activity in order to keep up the load. Simpson et al. (2011) looked at the muscle activation with different loads, concluding that muscle recruitment increased as the load did. In this study, the activity of vastus lateralis, gastrocnemius and semitendinosus was higher. More specifically, gastrocnemius experimented an increase in its activity of 7%, with a load of 40% of the BM in comparison with

Table 3
Characteristics of the studies.

Author (year)	Dependent variables	Backpack load (kg)	Backpack load to BM (%)	Inclination (%)	Speed (km/h)	Duration of the protocol (min)	Backpack type described	Study results
Epstein et al. (1988)	1/2/3	25/40	37.42/59.88	5	4.32	120 min per combination	N/A	Higher energy expenditure (EE) with 40 kg load than 25 kg ($p < 0.01$). With 40 kg load significantly higher EE ($r = 0.99$ $p < 0.05$). With 25 kg EE was stable at 560 ± 10 W
Faghy et al. (2016)	1/3	0/10/15/20	0/13.3/ 19.9/26.6	0	6.5	60 min per combination	N/A	Increased of absolute VO_2 as load increased. Change occurred ($p < 0.05$) between 0 and 20 kg.
Faghy and Brown. (2014)	1/3	0/25	0/30	0	6.5	60 min per combination	N/A	Changes in the absolute VO_2 ($p < 0.05$) between 0 and 25 kg
Gomeñuka et al. (2016)	1/2	17.9 ± 1.52	0/25	0	2/3/4.6/ 6	6 min per combination	N/A	EE is affected by the inclination, speed and load in all conditions ($p < 0.01$)
		17.9 ± 1.52	0/25	7/15	1/2/3/4/ 5			
Gordon et al. (1983)	1/3	0/14.3/ 21.5/28.7/ 35.9	0/20/30/ 40/50	10	4.8	10 min per combination	YES	Relative VO_2 showed a lineal relationship with the load increase ($p < 0.05$; $r = 0.995$)
Goslin and Rorke (1986)	1/3	0/14.5/ 29.08	0/20/40	SE	4.86/ 6.08	10 min per combination	N/A	%VO_2 increased with the work load There is a change between 20% and 40% of the relative BM for both speeds
Huang and Kuo (2014)	1/2	0/6.82/ 11.36/ 15.91/20.45	0/9.59/ 15.97/ 22.37/28.7	SE	4.5	8 min per combination	N/A	Participants increased their metabolic power in approximately 7.62 W for every other kg of load
Lyons et al. (2005)	1	0/25/40	0/31.13/ 49.81	0/3/6/9	4	5 min per combination	N/A	Differences ($p < 0.01$) between 20 and 40 kg in all inclinations on the Energy demand.
Pandoff et al. (1977)	2	32/40/50	40.92/ 51.15/63.93	SE	0.72/ 1.44/ 2.16/ 2.88/3.6	15 min per combination	YES	No significant differences found in the EE at low speeds in different loads. Differences observed between different speeds ($p < 0.01$).
Phillips, Ehnes, et al. (2016c)	1/3	0/45	0/51.7	Incremental$	4.82	Incremental test every 2 min.	YES	VO_2 was significantly higher with higher loads. The steeper the inclination, the higher the difference in VO_2 values.
	1/3	15/30/45	17.26/ 34.52/51.78	4	4.82	10 min per combination	YES	VO_2 in relationship with the BM + backpack mass: reduction of 4.4% ($p < 0.05$) between 0 and 15 kg and increases ($p < 0.05$) 5.6%, between 0 and 45 kg. In absolute values, the VO_2 showed differences ($p < 0.05$) of 11% (0–15 kg), 14.5% (15–30 kg) and 18% (30–45 kg) respectively.
Phillips, Stickland, Lesser et al. (2016b)	1/3	0/25	0/29.7	Increase	4.82	Blake Modified Incremental every 2 min	YES	No differences load and none loads in inclinations between 0 and 4%, in VO_2 absolute values. Differences ($p < 0.05$) at 6 and 8%.
Phillips, Stickland, and Petersen (2016a)	1/3	0/25	0/38.16	Increase	5.4	Blake Modified Incremental every 2 min	YES	Decrease ($p < 0.05$) in VO_2max (absolute) and relative.
	1/3	0/25	38.4	Constant	5.4	45 min per combination	YES	Increase ($p < 0.05$) absolute VO_2 in both loads between 5 and 25 min.
Phillips, Stickland, and Petersen (2016d)	1/3	0/25	0/29.94	Increase	5.4	Blake Modified Incremental every 2 min	YES	Decrease ($p < 0.05$) in VOmax (absolute) and relative.
	1/3	0/25	29.94	Constant	5.4	45 min	YES	Higher absolute VO_2 ($p < 0.05$) when compared load vs. no load at 45 min. Between 25 and 45 ($p < 0.05$) min also increased in load conditions.
Sagiv et al. (2000)	1/3	0/25/35	0/34.24/ 47.94	Constant	5	45 min.	N/A	Increase of relative VO_2 ($p < 0.05$) when inclination increased at 0-5-10%, with and without load.

Note. N/A = Not applicable; %BM = Body mass percentage; 1 = Oxygen uptake; 2 = Energy expenditure; 3 = Heart rate; VO_2 = Oxygen uptake; VO_2 max = Maximal oxygen uptake.
* Individually assessed for an intensity equivalent to the 67% of the VO_2max of the participant. $ Inclination increases by +2% every 2 min # Inclination increases by +5% every 15 min & Not specified what mass is in relationship with.

unloaded condition. These variations might be related to the stability of the lower limb and the impact absorption. In contrast, Al-Khabbaz et al. (2008) showed no changes in muscle activation in relationship with the load. However, it is difficult to compare both studies, due to the differences in participants' state. In the case of the latter, subjects were standing still whereas in the case of Simpson et al. (2011) the sample was in motion i.e. walking.

For loads between 20 kg and 40 kg, it was found that the maximum recommended load should not excess the 30% of the BM, representing 22.4 kg in the present study (Haisman, 1988; Simpson et al., 2011). This mass, fits the parameters of the present review for physiological changes. Bigger loads exceeding 40% of the BM, are associated with injury risk according to some authors (Simpson et al., 2011). It is important to mention that all reviewed studies are shorter than real scenarios and the assessment of optimal loads could vary on the field.

5. Conclusion

In summary, it has been found that a variety of protocols used in the studies make comparison of the data difficult. It seems important for future research works to take into account the characteristics of the real scenario of the targeted groups, in order to improve the design of the protocols, so these protocols can reproduce what participants will face in actual activities.

As a limitation of the present review, occurs due to the inclusion criteria: the use of a treadmill. Field studies would offer more realistic results, but also would deeply affect the interpretation of these studies due to the huge amount of potentially influential factors. Another limitation found, was the exclusion criteria of the impact of backpacks in children. Given our specific interest in leisure and professional activities, targeted samples obligated us to discard underage groups.

The participation of subjects familiarized with the backpack carrying activity also appears to be a critical factor to obtain applicable results.

On the other hand, there appears to be a clear relationship between load and both VO_2 and EE, with a critical load increase point of between 20 kg and 40 kg. This could be an accurate starting point for future research works focusing on the effects of backpack load on specific physiological responses and performance outcomes.

In conclusion, this systematic review can help advance new research pathways for more accurate outcomes in the area of backpack load research.

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Declaration of competing interest

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