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Review Article

Can load carriage system weight, design and placement affect pain and discomfort? A systematic review

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Abstract. *Purpose*: A systematic review of the literature was conducted to answer the following questions: 1. Does usage or weight of load carriage system cause pain, perceived exertion or discomfort? 2. Can load carriage system placement on the spine influence pain, perceived exertion or discomfort? 3. Can load carriage system design influence the amount of pain, perceived exertion or discomfort caused by their use?
Method: Eight databases were searched. Each included study was analysed and quality appraised by two independent reviewers.
Results: Forty-seven articles that addressed the research questions were included in the study. Significant variability in the study design and populations of the studies prevented data pooling and the evidence is conflicting. However, qualitative synthesis of the studies shows that carrying loads may provoke low back pain; and it may also trigger neck, thoracic and shoulder pain. Backpack weight can influence perceived pain, however other factors are involved.
Discussion: There is conflicting but positive evidence on the correlation between backpack load carrying and experiencing pain during different stages of life. The research to date is lacking with the most commonly identified methodological deficiencies being poor overall design, the lack of justification of sample size, providing training sessions for examiners, and not utilising calibrated, valid and reliable instruments for measurement.

Keywords: Backpack, pain, systematic review, front pack, double pack

1. Introduction

Adult back pain is a significant source of long term dysfunction and absence from work which puts a huge economic, social and emotional burden on individuals and society [56,57]. Additionally, back pain is a current issue among young people with low back pain prevalence in adolescents measured between 20% to 72% [29,38]. Young people commonly use backpacks as they are an effective and most economical way of carrying weight, however, it has been proposed they can also be a significant contributing risk factor for discomfort, fatigue, muscle soreness and musculoskeletal pain especially low back pain [9,29,47–49,57]. It has been speculated that backpacks may cause problems not only for the developing skeletal system but also for a mature spine as a developed spine is also sensitive to load [41,45]. Moreover, experiencing back pain in childhood is a concern as it may lead to more common and severe issues later in life [41].

Various suggested cut off backpack weights have been recommended by researchers in order to reduce the risk associated with backpack use. However, do backpacks really cause pain and discomfort?

The aim of this systematic review is to answer the following questions about a broad range of population groups:

1. Does usage or weight of load carriage system cause pain, perceived exertion or discomfort?

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2. Can load carriage system placement on the spine influence pain, perceived exertion or discomfort?
3. Can load carriage system design influence the amount of pain, perceived exertion or discomfort caused by their use?

2. Methods

2.1. Literature search

A comprehensive search strategy was conducted to identify all relevant publications on load carriage systems and their design. The search strategy is seen below.

Allied health, health-research, health-science and medical databases including Medline, Cochrane library, Science Direct, PubMed, Scopus, CINAHL, MANTIS and EMBASE were used. The search was performed using the combination of the following key indexing terms: (‘backpack’, ‘back pack’, ‘rucksack’, ‘schoolbag’, ‘school bag’, ‘load carriage system’) and (‘pain’, ‘discomfort’, ‘perceived exertion’, ‘comfort’) and (‘design’ or ‘performance’). Google searches were also carried out to find any related articles, meeting proceedings or links. Furthermore, a hand search of the reference lists of existing articles was conducted to find papers that did not appear in the main database searches. The search covered literature from 1966 to February 2010.

2.2. Selection criteria

Studies with the main focus on the human effects of load carriage systems (backpacks, front packs or double packs) on comfort, discomfort, pain or perceived exertion were included. Only studies that were conducted on humans and not manikins were included. Also, studies that focussed on unhealthy subjects (e.g. scoliosis) were excluded from the review. Studies were limited to peer-reviewed journals and conference proceedings. Case reports and clinical opinions were excluded. This led to broad inclusion criteria for study design in order to prevent limitation of potentially relevant articles. All study abstracts meeting these broad criteria were initially included. Subsequent inclusion based on the inclusion criteria was then assessed by two trained reviewers (SG and BW) who reviewed the papers independently. If the eligibility of studies was not clear from the abstracts, then full texts of the articles were obtained and assessed independently by the two authors. If a difference of opinion occurred, consensus was reached on inclusion or exclusion by discussion and reflection. A third party could be used in the event of disagreement.

2.3. Data extraction and management

SG acted as the principal reviewer. Three other reviewers (MW, NM, and WN) were trained by SG and BW (an experienced investigator) and acted as the second reviewers to extract data from the included papers. Training sessions included clarification of all data items and required elements of the quality appraisal tool were provided. Standardisation of the procedure was required to provide consistency in methods used by the reviewers; therefore, before starting to extract data, a trial was conducted on two similar but unrelated papers and the results discussed. Co-investigator (BW) was consulted when there was disagreement between SG and MW, NM or WN.

2.3.1. Data extraction form

This form consisted of descriptive characteristics and a quality appraisal tool. Data were extracted based on the elements of this form which were related to the research questions and aims of this review and seen in Tables 2–9.

2.3.2. Level of evidence

The level of evidence of each paper was assessed based on the National Health and Medical Research Council of Australia guidelines (Table 1). This was based on the proposition that some designs provide more valid and reliable findings than others. The lower the ranking in hierarchy of evidence the greater the risk of bias or error in a study [1].

2.3.3. Quality appraisal

The quality of papers was assessed according to a modified version of the quality appraisal tool by Crombie [11]. In this study, we modified the Crombie tool by adding three extra appraisal items, ‘attention to calibration of equipment/ instrument before use’, ‘Was the person who carried out the measurement trained?’ and ‘Discussion of weaknesses or limitations of the study in the paper’. Moreover, validity and reliability of measurements which were fitted into one item by Crombie, were split up into two questions as these two concepts demonstrate two different aspects in research. The modified Crombie quality appraisal items can be seen in Table 5.

Table 1
NHMRC level of evidence

Level of evidence	Study design (intervention)	Study design (aetiology)
I	A Systematic review of randomised controlled trials	A systematic review of level II studies
II	A randomised controlled trial	A prospective cohort study
III-1	A pseudo randomised controlled trial	All or none
III-2	A comparative study with concurrent controls: – Non-randomised experimental trial – Cohort study – Case-control study – Interrupted time series with a control group	A retrospective cohort study
III-3	A comparative study without concurrent controls: – Historical control study – Two or more single arm study – Interrupted time series without a parallel control group	A case-control study
IV	Case series with either post-test or pre-test/post-test outcomes	A cross-sectional study or case series

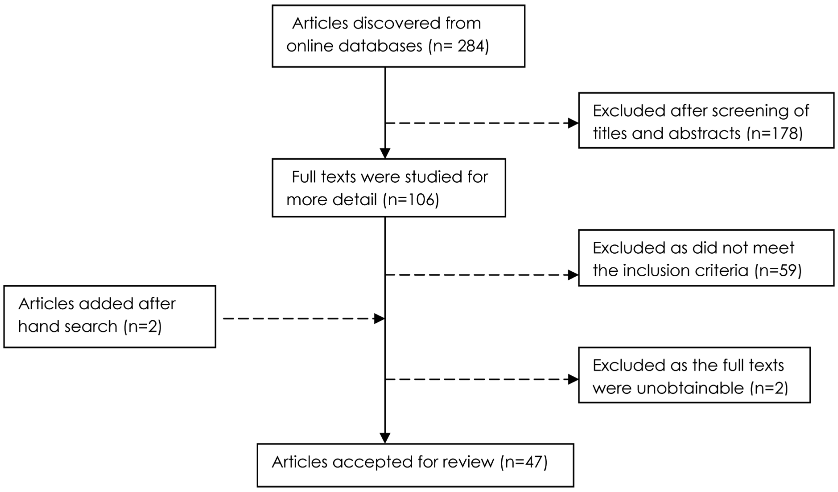

Fig. 1. Inclusion and exclusion of articles.

Answers to the quality appraisal items were defined as Yes, No, Not Applicable or Unclear. In the case that two or more pieces of equipment or instruments were used, details of calibration, validity or reliability of one of instruments was considered an adequate description of the validity or reliability. A score of one was given to each yes answer and zero to no, unclear and N/A answers. The overall score was reported as a tally of all yes answers out of 15, 14 or 13 based on the applicable answers for each study. Often, reviewers add the scores of individual items from the critical appraisal tool to present a total score [51]. However, using this method may be arbitrary as is weighting each item. Instead, it has been recommended that each item be investigated separately, rather than use a combined quality score [23,58]. However, given the dichotomy of views in the literature we chose to simply classify studies with the notation of how many critical appraisal items they satisfied. In this way we believe an estimation of the quality of the study can be gained, with studies that meet less appraisal criteria being treated with more caution.

3. Results

Two hundred and eighty four articles were identified from the databases using the search strategy. Titles and abstracts of these articles were manually screened for relevance and 178 articles were excluded. The remaining articles ($n = 106$) were studied in detail to see if they satisfied the inclusion criteria. A further 59 papers were excluded as did not meet the selection criteria. Two articles were added after reference checking. Two articles were excluded as the full texts were unobtainable by the Murdoch University library staff de-

Table 2

Descriptive characteristics of studies that assessed the correlation between backpack use and pain, perceived exertion and discomfort

Authors, Publication Year	Sample size	Age (range or Mean ± SD)	Gender	Inclusion and exclusion criteria	Instruments of measurements	Task	Complications of wearing backpack have been reported on	Clearly stated aims	Duration of carrying backpack
Marsh et al. 2006 [37]	20	13–16	F:9 M:11	Y	VAS, BS	Walking while wearing BP with and without an abdominal support (10–20% BW)	RPE	Y	5 min for each trial
Siambanes et al. 2004 [48]	3498	11–15	U	N	Digital electronic scale, Q	Q	back pain	Y	–
Navuluri & Navuluri 2006 [40]	61	F: 12.9 M: 13.3	F:32 M:29	N	Q, BS, scale	Q	Back and neck pain	Y	–
Chiang et al. 2006 [10]	55	13.25 ± 0.4	U	N	Q, digital scale	Q	Low back pain	Y	–
Wall et al. 2003 [57]	346	6–18	F:237 M:109	Y	Q	Q	Low back pain	Y	–
Grimmer & Williams 2000 [15]	1193	8–12	U	N	digital electronic scale, Q	Q	Low back pain	Y	–
Moore et al. 2007 [39]	531	8–18	F: 287 M: 244	N	Electronic scale, interview	Questions at interview	Upper and mid back pain	Y	–
Negrini & Carabalona 2002 [41]	202	11.06 ± 0.34	U	N	Q, balance	Q	back pain	Y	–
Madras et al. 1998 [36]	11	25 ± 3.38	U	Y	BS	Walking at 0, 5% & 10% grade wearing no pack, waist pack or BP	RPE	Y	5 min for each trial
Iyer 2001 [18]	351	9–20.6	U	N	Q, BS, meter scale with a height rod	Q	Shoulder and back pain	N	–
Birrell & Haslam 2009 [6]	127	20.61 ± 2.55†	F:29 M:98	N	Comfort Q	Marching while carrying load	RPE	Y	1 h
Birrell & Hooper 2007 [7]	18	21.2 ± 1.4†	U	N	Q, interview	Q	Upper limb	Y	2 h

Table 2, continued

Authors, Publication Year	Sample size	Age (range or Mean ± SD)	Gender	Inclusion and exclusion criteria	Instruments of measurements	Task	Complications of wearing backpack have been reported on	Clearly stated aims	Duration of carrying backpack
Korovessis et al. 2004 [28]	3441	12 ± 1.5	F:1816 M:1625	Y	Q, digital electronic Mettler weightier	Walking for 2 hr while students carried their personal BP	Dorsal pain and Low back pain	Y	–
Haselgrove et al. 2008 [16]	1202	14.1 ± 0.2	F:587 M:615	N	Q	Q	Back and neck pain	Y	–
Korovessis et al. 2005 [29]	1252	12–18	F:664 M:588	Y	VAS, scale	Standing with extended knees & hips, keeping the arms close to the body with and without wearing a BP	Dorsal pain and Low back pain	Y	–
Lockhart et al. 2004 [34]	127	12–13	F:78 M:49	N	Survey	Q	pain	Y	–
Bauer & Freivalds 2009 [4]	20	12.9 ± 1	F:10 M:10	N	BS	Standing & walking while carrying 0, 10, 15 or 20% BW in a BP	RPE	Y	3 min for each trial
Sheir-Neiss et al. 2003 [47]	1122	12–18	U	N	Q, scale	Q	back pain	Y	–
Kirk & Schneider 1992 [26]	11	18–33	F	N	BS	Walking while carrying 33% BW in an internal or external frame BP	RPE	N	1 h
Talbott et al. 2009 [53]	871	9–18	F:511 M:359	N	Q	Q	Pain	Y	–
Al-Hazzaa 2006 [2]	702	6–14	M	N	Q , digital scale	Questions at interview	Shoulder pain	Y	–
Whittfield et al. 2005 [59]	140	17.1	F:70 M:70	N	Electronic scale, Nordic Musculoskeletal Q	Q	Upper body	Y	–
Goodgold et al. 2002 [13]	345	11–14	F:176 M:169	Y	Q, scale	Q	Back pain	Y	–
Van Gent 2003 [54]	745	12–14	F:367 M:378	N	Q, scale	Q	Neck, shoulder and back pain	Y	–

Table 2, continued

Authors, Publication Year	Sample size	Age (range or Mean $\pm$ SD)	Gender	Inclusion and exclusion criteria	Instruments of measurements	Task	Complications of wearing backpack have been reported on	Clearly stated aims	Duration of carrying backpack
Young et al. 2006 [60]	184	11.2 $\pm$ 1.9	M:76 F:108	N	Q, scale	Q	Back pain	Y	–
Puckree et al. 2004 [43]	176	12.2 $\pm$ 0.8	U	N	Scale, Q	Q	Neck, shoulder and back comfort	Y	–
Negrini et al. 2004 [42]	U	10–12	U	N	Scale, Q	Q	Back pain, disability	Y	–
Ling et al. 2004§ [32]	7	24.5 $\pm$ 3.4	F	Y	VAS, modified BS	Marching without load or carrying 20, 30, 40 & 50 pounds	Discomfort	U	1 h
Beekley et al. 2007§ [5]	10	32.4 $\pm$ 1.3†	M	Y	BS	Marching while carrying 30, 50 and 70% of lean body mass	RPE	Y	30 min for each trial
Quesada et al. 2000§ [44]	12	22.4 $\pm$ 2.3†	M	Y	BS	Marching WL or while carrying 15 and 30% of BW	RPE	Y	40 min for each trial
Goslin & Rorke 1986§ [14]	10	24.3 $\pm$ 2.8	M	N	BS	Walking while carrying 0, 20, 40% BW in a BP at 2 different speeds	RPE	Y	10 min for each trial
Kennedy et al. 1999§ [24]	42	9.1 $\pm$ 0.69	F:20 M:22	Y	BS, VAS	Walking under 5 conditions: WL or carrying 5, 10, 15, 20% of BW in a BP	RPE	Y	5 min for each trial
LIoyd et al. 2009§ [33]	32	22.3	F	N	VAS, BS, Likert scale	Walking while carrying a variety of loads until pain led to voluntary cessation of the session or a load of 70% body mass was carried	RPE, pain and regional discomfort	Y	4 min for each trial
Johnson et al. 1995§ [22]	15	21–36†	M	N	Environmental symptoms Q, 6-point scale	Walking while carrying 34, 48 or 61 kg in a standard army BP or prototype double pack	Tiredness, discomfort, back pain	Y	Time needed to finish 20 km

BP, Backpack; BS, Borg Scale; BW, Body weight; H, hour; Min, Minute; N, No; Q, Questionnaire; RPE, Rating of Perceived Exertion; U, Unclear; VAS, Visual Analogue Scale; WL, Without Load; Y, Yes; §, studies that assessed the correlation of pain with increasing load; †, studies that were conducted on soldiers

Table 3
Results of the studies that assessed the correlation between backpack use and pain

Author	Correlation between backpack weight and pain	Comment
Siambanes et al. 2004	Y	Older students and those who walk to and from school experienced more pain
Navuluri & Navuluri 2006	Y	Backpack pain was seen just among girls
Moore et al. 2007	Y	Younger student and girls are more at risk of experiencing pain
Haselgrove et al. 2008	Y	Pain increased in both genders but it was more prevalent between girls
Sheir-Neiss et al. 2003	Y	Girls and students with larger body mass index experienced more pain. Correlations between backpack weight and extent of using backpacks with pain
Talbott et al. 2009	Y	Besides weight, the amount of time carrying was also associated with pain
Van Gent et al. 2003	Y	Girls and younger students reported pain more often
Grimmer & Williams 2000	Y	Pain was associated with weight, time spent carrying backpack, time spent sitting. Girls and younger students were more vulnerable. No correlation was seen between backpack weight and body mass index
Puckree et al. 2004	Y	
Korovessis et al. 2004	Y	Girls experienced more pain than boys
Chiang et al. 2006	N	Association was reported between backpack carrying time and pain
Wall et al. 2003	N	Intensity of pain increased by backpack carrying
Negrini & Carabalona 2002	N	Duration of backpack carrying but not backpack weight was associated with pain
Korovessis et al. 2005	N	Girls reported pain more often and with higher intensity
Goodgold et al. 2002	N	
Al-Hazza 2006	N	Older students reported pain more often
Whittfield et al. 2005	N	No association between backpack weight and incidence of pain
Lyer 2001	N	No association between backpack weight or age with pain
Young et al. 2006	N	No association between backpack weight and back pain. Association between age and back pain (pain was more common in older students)
Negrini et al. 2004	N	Neither backpack weight nor duration of backpack carrying was associated with back pain

N, No; Y, Yes.

Table 4
Results of the studies that assessed the correlation between backpack use and perceived exertion

Author	Correlation between backpack weight and perceived exertion	Comment
Marsh et al. 2006	Y	Abdominal support decreased RPE
Madras et al. 1998	Y	
Kirk & Schneider 1992	Y	Besides weight, the amount of time carrying was also associated with RPE
Bauer and Freivalds 2009	N	Carry 10% bodyweight didn't have influence on RPE

N, No; Y, Yes.

spite genuine efforts [25,55]. Forty-seven articles were included for the final review.

3.1. *Study results*

It is worth noting that noxious human effects in many studies were labelled with different words such as pain, discomfort and perceived exertion. Also, these variables were often assessed using a variety of scales such as regional body diagrams, categorical 5-point or 7-point scales, musculoskeletal discomfort diagrams, soreness and discomfort figures, Visual Analogue Scales (VAS) and Borg Scales (BS). The latter two being the most commonly used. We found 47 suitable trials to include in this review. Of these, 27 trials examined the correlation between backpack use and pain, perceived exertion or discomfort, seven studies assessed the correlation of pain, discomfort and perceived exertion with increasing load, three studies investigated the effect of load placement on pain, perceived exertion or discomfort and 10 studies compared the effect of different designs and features of backpacks on pain, discomfort and perceived exertion.

3.1.1. *What is the relationship between backpack use and pain, perceived exertion or discomfort?*

In this part of the review, 34 papers were included. Twenty-one out of 34 studies used cross-sectional

Table 5
Quality appraisal of studies that assessed the correlation between backpack use and pain

Authors, Publication Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total score
Marsh et al. 2006	N	Y	U	Y	Y	Y	Y	U	Y	Y	Y	N	Y	Y	Y	III-3A	11/15
Siambanes et al. 2004	N	Y	U	Y	N	N	Y	Y	N	Y	Y	N	N	Y	Y	IV	8/15
Navuluri & Navuluri 2006	N	Y	U	N	Y	Y	Y	Y	U	Y	Y	N	Y	Y	U	IV	9/15
Chiang et al. 2006	N	Y	U	N	N	N	Y	Y	Y	Y	Y	N	Y	Y	Y	IV	8/15
Wall et al. 2003	N	Y	U	N/A	N	N	Y	Y	N	N	Y	N	N	Y	N	IV	4/14
Grimmer & Williams 2000	Y	Y	Y	Y	N	N	Y	N	Y	Y	Y	N	Y	Y	Y	IV	11/15
Moore et al. 2007	N	Y	U	N	N	N	Y	Y	N	Y	Y	N	N	Y	Y	IV	8/15
Negrini & Carabalona 2002	N	Y	U	N	Y	N	Y	Y	Y	Y	N	N	Y	Y	U	IV	8/15
Madras et al. 1998	N	N	U	N/A	N	N	Y	Y	N	N	Y	N	Y	Y	Y	III-2A	6/14
Iyer 2001	N	Y	Y	Y	N	N	Y	N	N	Y	N	N	N	Y	Y	IV	7/15
Birrell & Haslam 2009	N	Y	U	N/A	Y	N	Y	Y	Y	Y	Y	N	Y	Y	Y	IV	10/14
Birrell & Hooper 2007	N	Y	U	N/A	N	N	Y	N	N	Y	Y	N	N	Y	N	IV	5/14
Korovessis et al. 2004	N	Y	U	N	N	N	Y	Y	N	N	Y	N	Y	Y	Y	IV	7/15
Haselgrove et al. 2008	N	N	U	N/A	Y	Y	Y	Y	N	Y	Y	N	Y	Y	Y	IV	9/14
Korovessid et al. 2005	N	Y	U	N	N	N	Y	Y	Y	Y	Y	N	Y	N	Y	IV	8/15
Lockhart et al. 2004	N	Y	U	N/A	N	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	IV	10/14
Bauer & Freivalds 2009	Y	Y	U	N/A	N	N	Y	N	Y	Y	Y	N	Y	Y	Y	III-2A	9/14
Sheir-Neiss et al. 2003	N	Y	U	Y	Y	N	Y	N	N	Y	Y	N	Y	Y	Y	IV	9/15
Kirk & Schneider 1992	N	Y	U	N/A	N	N	Y	N	Y	Y	Y	N	Y	Y	Y	III-3	8/14
Talbott et al. 2009	N	Y	U	N/A	N	N	Y	U	N	Y	Y	N	Y	Y	Y	IV	7/14
Al-Hazzaa 2006	N	Y	U	N	N	N	Y	N	N	N	Y	N	Y	Y	Y	IV	6/15
Whittfield et al. 2005	N	Y	U	Y	N	N	Y	U	N	Y	Y	N	Y	Y	Y	IV	8/15
Goodgold et al. 2002	N	N	U	N	U	N	Y	U	Y	Y	Y	N	Y	Y	Y	IV	7/15
Van Gent 2003	N	N	U	N	N	N	Y	Y	Y	Y	Y	N	Y	Y	Y	IV	8/15
Young et al. 2006	N	Y	U	Y	N	N	Y	Y	Y	N/A	Y	N	Y	Y	N	IV	8/14
Puckree et al. 2004	N	Y	U	Y	Y	U	Y	N	Y	Y	Y	N	Y	Y	N	IV	9/15
Negrini et al. 2004	N	U	U	N	Y	Y	Y	N	N	N	Y	N	Y	Y	Y	IV	7/15
Ling et al. 2004§	N	N	U	N/A	N	N	N	Y	N	Y	Y	N	Y	Y	Y	III-2	6/14

Table 5, continued

Authors, Publication Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total score
Beekley et al. 2007§	N	Y	U	N/A	N	N	Y	N	Y	N	Y	N	N	Y	Y	III-3A	6/14
Quesada et al. 2000§	N	Y	U	N/A	N	N	Y	N	Y	N	Y	N	Y	Y	Y	III-2A	7/14
Goslin & Rorke 1986§	N	Y	U	N/A	N	N	Y	N	Y	Y	Y	N	N	Y	N	III-2A	6/14
Kennedy et al. 1999§	N	Y	U	N/A	N	N	Y	N	Y	Y	Y	N	N	Y	Y	III-3A	8/15
LIoyd et al. 2009§	N	Y	Y	N/A	N	N	Y	N	Y	Y	Y	N	Y	Y	Y	III-2A	9/14
Johnson et al. 1995§	N	Y	U	N/A	N	N	Y	Y	N	Y	Y	N	Y	Y	Y	III-2A	8/14

1. Justification of sample size; 2. Consistency in the number of subjects reported throughout the paper; 3. The person who carried out the measurement was trained; 4. Was the equipment/instrument calibrated before use; 5. Adequate description of the validity of the instrument/equipment; 6. Adequate description of the reliability of the instrument/equipment; 7.was the design appropriate for stated aims; 8. Weakness or limitations mentioned; 9. Interpretation of null findings; 10. Interpretations of important effects; 11. Comparison of results with previous reports; 12. Implication in real life/generalisability; 13. Adequate description of statistical method; 14. Adequate description of the data; 15. Assessment of statistical significance; 16. Type of experimental design and level of evidence §, studies that assessed the correlation of pain with increasing load; *, adequate description of reliability of the method was provided; III-2A, a comparative study with concurrent control (an internal control group) _phases randomisation; III-2, a comparative study with concurrent control (an internal control group); III-3A, a comparative study without concurrent control _phases randomisation; III-3, a comparative study without concurrent control; IV, a cross-sectional study

design to collect data through use of various questionnaires and 13 studies utilised longitudinal design. Twenty-seven studies assessed the correlation between backpack use and pain, perceived exertion or discomfort and seven studies assessed the association between pain, perceived exertion or discomfort with increasing load. Twenty-four studies assessed adolescents while in 10 trials adults were investigated. Eight studies studied women or men exclusively. In ten studies, it was not clear if they examined any gender exclusively as they didn't provide the number of male or female subjects. In just 10 studies, subjects were screened for entry into the experiment based on the inclusion and exclusion criteria. Descriptive characteristics of these studies can be seen in Table 2 and results of these studies can be seen in Tables 3 and 4.

The quality appraisal of the studies can be seen in Table 5. Sample size varied from seven to 3498 but just two of the studies justified their sample sizes. Also only three articles declared that the person who carried out the measurements was trained. Eight out of seventeen studies used calibrated equipment and instruments and nine studies didn't provide any detail on the calibration of the equipment they used. Reasonable information and description of the validity and reliability of equipment and instruments used were reported in just seven and four studies, respectively. Also, one paper provided information on the inter-tester and intra-tester reliability of the method they used. The results of none of the papers could be generalised as they just assessed a specific age range or sex.

Seven studies assessed the correlation between pain, discomfort and perceived exertion with increasing load. Ling et al. reported that level of discomfort increased as the load increased in adults [32]. Also, Beekley et al. showed that perceived exertion was significantly higher while carrying 70% lean body mass (LBM) than 30% and 50% LBM in adults; however, no differences in perceived exertion responses were seen between 50% and 30% LBM [5]. Lloyd et al. observed that pain, perceived exertion and regional discomfort increased with increasing load (from 10% to 70% of body mass) in most of the body parts while some other parts such as chest, hips, buttocks and feet only showed significant changes between 15% and 20% body mass load [33]. Quesada et al. stated that 0 and 15% body weight load produced similar results of perceived exertion but subjects perceived the work to be harder during carrying 30% bodyweight [44]. Goslin and Rorke also reported that there is a linear relationship between perceived exertion and increase in the amount of load [14]. Johnson et al. assessed discomfort when soldiers carried 34, 48 or 61 kg loads in a backpack and double pack. It was reported that as load increased, discomfort soared [22]. In the only study that investigated adolescents, Kennedy declared a rise in perceived difficulty

Table 6

Descriptive characteristics of studies that examined the effect of load placement on pain

Authors, Publication Year	Sample size	Age (range or Mean ± SD)	Gender	Inclusion and exclusion criteria	Instruments of measurements	Task	Complications of wearing backpack have been reported on	Clearly stated aims	Duration of carrying backpack
Stuempfle et al. 2004 [52]	10	18-22	F	N	BS	Walking while carrying 25% BW in a high, central or low back position	RPE	Y	10 min for each trial
Brackley et al. 2009 [8]	15	U (grade 5 students)	F:10 M:5	U	Q, body map diagram, Wong-Baker Faces pain scale	Carrying 15% of BW with the centre of BP located on high, mid or low back	RPE	N	Time needed to finish 1000 m walk
Devroey et al. 2007 [12]	20	23.9 ± 2.59	F:8 M:12	N	BS	Standing and walking without pack and with 5, 10 and 15% BW	RPE and discomfort	N	Static: 1 min Dynamic : 5 min

Refer to Table 2.

Table 7
Quality appraisal of studies that examined the effect of load placement on pain

Authors, Publication Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total score
Stuempfle et al. 2004	N	Y	U	N/A	N	N	Y	N	N	N	Y	N	Y	Y	Y	III-3A	6/14
Brackley et al. 2009	N	Y	U	N/A	N	N	Y	Y	N	N	Y	N	N	N	Y	III-3A	5/14
Devroey et al. 2007	N	N	U	N/A	N	N	Y	Y	Y	N	Y	N	Y	Y	Y	III-2A	7/14

1–16, Refer to the legend of Table 5.

with increasing weight [24]. Descriptive characteristics and quality appraisal of these studies can be seen in Tables 2 and 5.

Based on these studies the weight of the evidence suggests that there is a correlation between backpack weight and pain, perceived exertion or discomfort. However, other factors such as gender, age and duration of carrying load can also influence these variables. Further, as the load increases the level of pain, perceived exertion or discomfort raises but the beginning point of the pain can be different in various conditions and between different subjects.

3.1.2. *Determining the effect of load placement on pain*

Three studies assessed the effect of load placement on pain, perceived exertion and discomfort. Stuempfle et al. compared the effect of load placement on perceived exertion in female adults and it was shown that high back load placement could lead to less perceived exertion compared to mid or low back load placement [52]; on the other hand, Brackley et al. and Devroey et al. reported that load placement did not have influence on perceived exertion in adolescents and adults, respectively [8,12]. Tables 6 and 7 shows the descriptive characteristics and quality appraisal of these papers, respectively.

The results of this section are inconclusive so it is not possible to conclude what is the best placement of backpacks on the spine.

3.1.3. *Can different designs of load carriage systems reduce the discomfort?*

Ten studies compared the effect of different designs and features of backpacks on pain, discomfort and perceived exertion. Descriptive characteristics and quality appraisal of these studies can be seen in Tables 8 and 9, respectively. Eight out of 10 studies investigated adults and just two studies were conducted on children. Five studies examined males exclusively. Only Bauer and Freivalds justified the sample size they examined.

Jacobson and Jones reported that there was no significant difference in level of comfort between internal frame and external frame backpacks [20]. Jacobson et al. compared the comfort level of an ordinary backpack with an experimental backpack which had a slanting shelving system and distributed the weight vertically in adults; more local and overall comfort was reported by using this system [19]. Moreover, Jacobson et al. compared the regional and overall comfort of subjects' personal backpacks and an experimental backpack. No significant differences in the comfort of backpacks was seen on a Visual Analogue Scale; however, the experimental backpack was more comfortable for the back on an Anatomical Illustration Rating Scale [21]. Southward and Mirka compared the effect of a basic and an advanced backpack harness system (a backpack which had lateral stiffness rods) on comfort in adults. It was shown that the advanced design which could distribute the weight between shoulders and hips can provide more local and overall comfort [50]. Knapik et al. assessed the effect of backpack and double pack. They reported that double pack caused less discomfort in low back, lower incidence of blisters, but it resulted in pain in neck and hips and it took longer to complete the march with wearing the double pack [27]. Also, Mackie et al. evaluated the influence of four backpacks on perceived exertion and discomfort. In this study a backpack which had two major compartments, back padding and side compression straps became the students' most favoured one [35]. Bauer and Freivalds evaluated the impact of two backpacks with different comfort features on perceived exertion and it was shown that additional comfort features could not provide less perceived pain [3]. Holewijn and Lotens compared the effect of different carrying modes on perceived exertion; they concluded that carrying the same amount of load in a backpack can cause more perceived exertion than waist carrying mode [17].

Table 8

Descriptive characteristics of studies that examined if different designs can reduce pain, perceived exertion and discomfort

Authors, Publication Year	Sample size	Age (range or Mean ± SD)	Gender	Inclusion and exclusion criteria	Instruments of measurements	Task	Complications of wearing backpack have been reported on	Clearly stated aims	Duration of carrying backpack
Jacobson & Jones 2000 [20]	20	24.3 ± 3.6	20	N	BS, 7 point scale	Walking with 16 obstacles while wearing BPs	comfort	Y	Time needed to finish 30 m
Jacobson et al. 2003 [19]	21	20.4 ± 1.41	F:16 M:5	Y	VAS	Carrying different backpacks for the whole day	comfort	Y	10 days
Jacobson et al. 2004 [21]	19	22 ± 1.36	M:10 F:9	N	VAS, anatomical illustration rating scale	Carrying 2 BPs for the whole day	Neck, shoulder, back and overall comfort	Y	10 days
Holewijn & Lotens 1992 [17]	10	NM†(adult)	M	N	Q	Marching with 10 different BPs	RPE	N	1 h
Bauer & Freivalds 2008 [3]	20	11-14	F:10 M:10	Y	BS	Standing & walking WL, wearing a standard BP & a BP with additional comfort features	RPE	Y	3 min for each trial
Southward & Mirka 2006 [50]	15	21-55	M:12 F:3	N	Likert scale	Bending forward while wearing different BPs	comfort	Y	Time needed to gradually bending forward until reaching the designated angle
Knapik et al. 1997 [27]	15	29.7 ± 4.3†	M	Y	soreness and discomfort Q, scale	Marching while carrying BP & double pack	discomfort	Y	Time needed to finish 20 km
Mackie et al. 2003 [35]	12	12.6 ± 1.1	F:6 M:6	N	VAS, Q, BS, scale rating method, musculoskeletal discomfort diagram	Walking while wearing each of 4 BPs	RPE and discomfort	Y	20 min for each BP
Legg et al. 1997 [31]	10	22.5 ± 6.3	M	N	regional body diagram, category ratio scale, Q, VAS	Walking while carrying 20 kg in 2 different BPs	Perceived discomfort	Y	30 min for each BP
Legg et al. 2003 [30]	10	30.8 ± 11.3	M	N	regional body diagram, category ratio scale, Q, VAS	Walking while carrying 15 kg in 2 different BPs	Perceived discomfort	Y	15 min for each BP

Refer to Table 2.

Table 9
Quality appraisal of studies that examined if different designs can reduce the pain

Authors, Publication Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total score
Jacobson & Jones 2000	N	Y	U	N/A	N	N	Y	Y	N	N	Y	N	N	N	N	III-3A	4/14
Jacobson et al. 2003	N	N	U	N/A	N	N	Y	Y	N/A	Y	Y	N	N	Y	N	III-3A	5/13
Jacobson et al. 2004	N	Y	U	N/A	N	N	Y	Y	N	Y	Y	N	Y	Y	Y	III-3A	8/14
Holewijn & Lotens 1992	N	Y	U	N/A	N	N	Y	N	N	N	Y	N	Y	Y	N	III-3	5/14
Bauer & Freivalds 2008	Y	Y	U	N/A	N	N	Y	N	Y	N	N	N	Y	N	N	III-2A	5/14
Southward & Mirka 2006	N	Y	U	N/A	N	N	Y	Y	N/A	N	N	N	Y	Y	Y	III-3	6/13
Knapik et al. 1997	N	N	U	Y	N	N	N	N	N	N	Y	N	Y	N	Y	III-3	4/15
Mackie et al. 2003	N	Y	U	N/A	N	N	N	N	N	Y	Y	N	Y	Y	Y	III-3	6/14
Legg et al. 1997	N	Y	U	N/A	N	N	Y	N	Y	N/A	Y	N	N	Y	Y	III-3	6/13
Legg et al. 2003	N	Y	U	N/A	N	N	Y	N	Y	Y	Y	N	Y	Y	Y	III-3A	8/14

1–16, Refer to the legend of Table 5.

The evidence is conflicting but on balance we can conclude that backpack designs that distribute load between the shoulders and hips or between the front and back of the body provides more local and overall comfort.

4. Discussion

This study is the first comprehensive systematic review looking at load carriage systems and pain, discomfort and perceived exertion. The results of this systematic review show significant variability in the design and study populations of studies. This variability prevented any meaningful statistical pooling of data. However a qualitative synthesis was feasible.

While studies were of various designs, none were randomised controlled trials and there were other widespread deficiencies in the validity, reliability and calibration of equipment and instruments of measurement. These instruments of measurement factors are fundamental to producing meaningful scientific evidence; therefore, we recommend more rigour and explanation in trial design and selection and in the use of reliable and valid instruments for measuring the influence of backpack design on the body. Moreover, providing training sessions for subjects and examiners may have also influence the validity and reliability of the study.

Sample size was just justified in only two papers. A study with a small sample size may not detect significant results. Also there is a chance of random error and publication bias in small studies, because interesting and favourable results from small studies might be reported whereas less interesting findings from small studies remain unreported [11]. If the sample size is too large there are ethical implications in wasting participants' time and in some cases putting them at risk.

In this review, a scoring system was not used and studies were not labelled by low, moderate or high quality; instead, trials were classified with the notation of how many appraisal criteria they satisfied and were assessed for every single item separately. It is worth noting that some studies might be strong in some parts but poor in other aspects. The number of criteria satisfied clearly reflects whether the study should be regarded as having a high risk of bias.

Of the 27 studies that examined the correlation between backpack carrying or backpack weight and pain, discomfort or perceived exertion, 13 trials declared that there is a significant positive correlation between these two factors while 11 studies were of the opinion that there is no association between these two variables. Of particular note was the heterogeneity among studies with respect to study populations, participants' age range and gender, type of the study design, task of the participants during the experiment, habitual differences and outcome measurements. Due to this diversity it was not possible to perform statistical pooling of the data. The strength of evidence of each paper was assessed by the quality appraisal tool by Crombie. Most of the papers that were in favour of the correlation between backpack use and pain, perceived exertion and discomfort had qualities in the range of 6/14 to 11/15 (see Table 5) and the trials that didn't support this correlation showed qualities in the range of 4/14 to 10/14.

From this review it became apparent that factors other than backpack weight can generate pain, perceived exertion or discomfort; the reported factors were gender [15,16,39,40,43,54], age and grade in school [2, 15,39,48,54], subject's body mass index [5,47], the amount of time using the backpack and walking to and from school [10,41,47,48,53]. Girls experience more pain that boys, this could be because, boys have a stronger musculoskeletal system, also they might have higher threshold of pain based on differences between physiological and psychological factors between genders [46].

Mostly it was thought that load carrying provokes low back pain but this review reveals that just less than half of the studies in this review reported feeling low back pain. It should be noted that other complications such as neck pain, thoracic pain, shoulder pain, upper limb discomfort, overall discomfort and perceived exertion are also frequent.

Of the seven studies that examined the effect of increasing load on perceived exertion, it was shown that increasing weight provokes higher intensity of pain and exertion; however, different load thresholds as the start point of feeling discomfort and fatigue were reported in these studies. Subjects start to notice differences in sensation of effort at different load thresholds and also the level of pain and discomfort threshold varies among individuals. It seems that age, gender, the circumstances of the load carrying experience and profession are factors that have an effect on the load threshold [5].

Three studies assessed the effect of load placement on pain, perceived exertion and discomfort but it is not possible to find out where the load should be placed in order to reduce the pain. It is hard to draw a conclusion as these three trials examined different age groups. These studies scored 6/15, 5/14 and 7/14.

5. Conclusion

The results of this review show that there is conflicting evidence on the correlation between load carrying and experiencing pain, exertion and discomfort during different stages of life. However, based on this conflicting evidence we can say that carrying loads does not always provoke low back pain; and that it may trigger neck, thoracic or shoulder pain. In addition the physiological and psychological status of individuals can intensify or reduce the level and threshold of perceived pain.

Also, there is limited evidence on the effect of load positioning and various designs on level of perceived pain and exertion. It seems that so far none of these changes could be helpful in reducing the complications of wearing backpacks. Moreover, the methodological and quality assessments showed that most of the included studies in this review were not strong enough and could not be relied upon. The most commonly identified methodological deficiencies were the lack of justification of sample size, providing training sessions for examiners, utilising calibrated, valid and reliable instruments for measurement.

There are a number of limitations to the current study. This review was not a totally blind review; authors and publication details were disclosed to the reviewers and this can potentially lead to reviewer bias. However, reviewers were not aware of the background and previous works of the authors. A further limitation is that although the search strategy was comprehensive it is possible that some studies were not found. Indeed two studies that were identified could not be located. Also, the validity and reliability of the critical appraisal tool used in this study has not been established but was developed from first principles using previously developed tools from related areas. Although the modified Crombie instrument has face validity, further research is needed to assess its validity and reliability. The suggestion of potential bias in studies using the number of quality appraisal variables achieved is controversial and readers are invited to use this as a guide only.

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