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ARTICLE

One-handed carrying among elderly and obese individuals: a systematic review to identify research gaps

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ABSTRACT
A systematic review of the literature regarding one-handed load carrying was conducted to identify research gaps for future load carrying studies. Twenty-six articles that may be relevant to elderly and obese people were included. Only two studies evaluated the effect of age as an independent variable during one-handed carrying. Obesity was not included as an independent variable in any of the articles. In general, the results suggested that one-handed carrying is more physically demanding than other methods of load carrying. In many cases, physiological responses to carrying a load in one hand were similar to carrying twice the load equally distributed between two hands. Some studies recommended a one-handed carrying weight limit of approximately 9–10 kg for men and 6–7 kg for women. However, more research on the effects of age and obesity during one-handed carrying is needed to determine if these results hold for elderly and obese people.

Practitioner Summary: A systematic review of the scientific literature since 1966 regarding one-handed carrying that may pertain to elderly and/or obese people was performed. Few studies were identified that included aging and none included obesity as independent variables. Areas for future research are identified and discussed.

Abbreviations: BP: blood pressure; EE: energy expenditure; EMG: electromyography; F: female; HR: heart rate; LL: load location; LM: load magnitude; M: male; MALC: maximum acceptable load carried; MMH: manual material handling; MSDs: musculoskeletal disorders; MVIC: maximum voluntary isometric contraction; RPE: ratings of perceived exertion; RPE(A): RPE of the arm; RPE(BK): RPE of the back; RPE(WB): RPE of the whole body; $\dot{V}E$: ventilation; $\dot{V}O2$: oxygen uptake; %$\dot{V}O2max$: percentage of maximum oxygen uptake; WE: estimated load for comfortable carrying; WV: actual carried load comfortably

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KEYWORDS
One-handed; carrying; physiological; psychophysical; biomechanical; elderly; obese

1. Introduction

Elderly and obese people represent a rapidly increasing proportion of the United States population and workforce (He, Goodkind, and Kowal 2016; Jacobsen et al. 2011; Ogden et al. 2006; 2015; Wang and Beydoun 2007). By 2050, 20.9% of the people in the United States are expected to be 65 years of age or older; an increase of 7.2% since 2012 (Ortman, Velkoff, and Hogan 2014). By 2030, obese adults are expected to represent 51% of the American population (Finkelstein et al. 2012; Wang et al. 2008); an increase of 14.5% from the years 2011–2014 (Ogden et al. 2015). The increasing percentage of elderly and obese workers is important as age and obesity have been associated with an increase in the frequency and severity of adverse occupational health outcomes, such as work-related musculoskeletal disorders (MSDs) (Bureau of Labor Statistics 2015; Kouvonen et al. 2013).

Manual material handling (MMH) activities such as lifting, pulling/pushing, and carrying are commonly associated with work-related MSDs, particularly of the low back (Bureau of Labor Statistics 2016; Garg et al. 2014; Natarajan et al. 2008; Tanaka and McGlothlin 1993; Village et al. 2005). While a great deal of research has been devoted to two-handed MMH (Ciriello 2005; Lee and Cheng 2011; Lu et al. 2016; Sevene et al. 2012; Waters et al. 1993; Wu 2000), one-handed carrying has been less commonly studied. For instance, the widely applied Liberty Mutual MMH Tables developed by Snook (1978) and Snook and Ciriello (1991) provide

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Table 1. Search strings used to identify articles.

Search string	Search terms
1	'One-handed lifting' OR 'one-handed carrying' OR 'one-handed manual material handling' OR 'one hand lifting' OR 'one hand carrying' OR 'one hand manual material handling'
2	'elderly' OR 'old' OR 'age' OR 'aging'
3	'obese' OR 'obesity' OR 'body weight'
4	'work' OR 'worker' OR 'employee' OR 'employment' OR 'job' OR 'job analysis' OR 'workload' OR 'occupation' OR 'occupational'

estimates of the maximum acceptable load to be lifted or carried at different handling frequencies and distances using both hands. To our knowledge, no such tables were developed for one-handed carrying tasks.

The objectives of this review were to synthesize the scientific literature regarding one-handed carrying as it may pertain to elderly and obese individuals to identify research gaps for future load carrying studies among this potentially susceptible segment of the working population.

2. Method

Relevant articles from the past 50 years were searched from four scientific databases: Web of Science, Ergonomics Abstracts, PubMed, and Google Scholar (1966 to October 30, 2016). Specifically, different combinations of strings (Table 1) were searched using the logical operators 'AND' and 'OR'. The search string '(1 AND 2) OR (1 AND 3)' was most applicable and provided results for all databases. However, given the relatively small number of articles identified using Web of Science and Ergonomics Abstracts ($n = 2$ each), the first search string was searched alone for these databases to increase the likelihood of identifying relevant articles. Furthermore, the personal databases of the authors were also reviewed.

The initial article search identified 754 documents. Titles of these documents were screened according to the following criteria: (1) Relevance of title to the topic of interest (one-handed carrying in adults); (2) Full-text articles published in peer-reviewed journals; and (3) Written in English. Two independent reviewers (MB and MFC) performed the screening. Documents in which one reviewer suggested inclusion whereas the other suggested to discard ($n = 22$) were included for abstract review. Based on the above three criteria, 537 records were excluded. Redundant articles ($n = 43$) from the 217 remaining articles were then removed, resulting in 174 articles for abstract review.

Review of the 174 abstracts excluded 102 based on relevance. The remaining 72 articles were classified into three main categories: articles that addressed one-handed lifting ($n = 51$), one-handed carrying ($n = 15$), and both one-handed lifting and one-handed carrying ($n = 6$). Those articles involving some one-handed carrying ($n = 21$) were included in the final review (Figure 1). In addition, five articles referenced within those 21 were also included for a grand total of 26. Four of the 26 articles that included one-handed carrying will not be described further. Two of the articles were survey studies that did not involve laboratory experimentation (Nahit et al. 2001; Paudyal et al. 2013). The other two articles were reviews of research regarding lifting/carrying (Lu and Aghazadeh 1994; Mital 1985), including one-handed carrying studies that are included in the reviewed articles in this work. Articles studying one-handed carrying that may not have investigated aging or obesity as independent variables were included in the review as the results may be relevant to elderly and obese people.

3. Results

Three main experimental approaches were used in the reviewed articles to study one-handed carrying: (1) physiological, (2) psychophysical, and (3) biomechanical. These strategies were used as the basis to summarize the results as they may pertain to obese and elderly individuals in the subsequent sections. The purpose and load holding methods described in each article are provided in Table 2. A description of the independent variables as well as the characteristics of the participants are included in Table 3. Table 4 presents the dependent variables and highlights the main results of each article. The independent and dependent variables were identified by the reviewers when not directly identified by the authors of the articles.

3.1. The physiological approach

Physiological responses during one-handed carrying were studied in 11 articles. Each study included one or more of three major physiological measurements: (1) heart rate (HR), (2) blood pressure (BP), and (3) oxygen uptake (VO_2). Other physiological indices included energy expenditure, pulmonary ventilation (V_E), and endurance time. The effects of obesity were not considered in any of the studies. Two of the studies compared physiological responses in elderly and young people while carrying loads (Bampouras and Dewhurst 2016; Wright and Mital 1999). Bampouras and Dewhurst (2016) demonstrated that HR responses were not statistically significantly different between

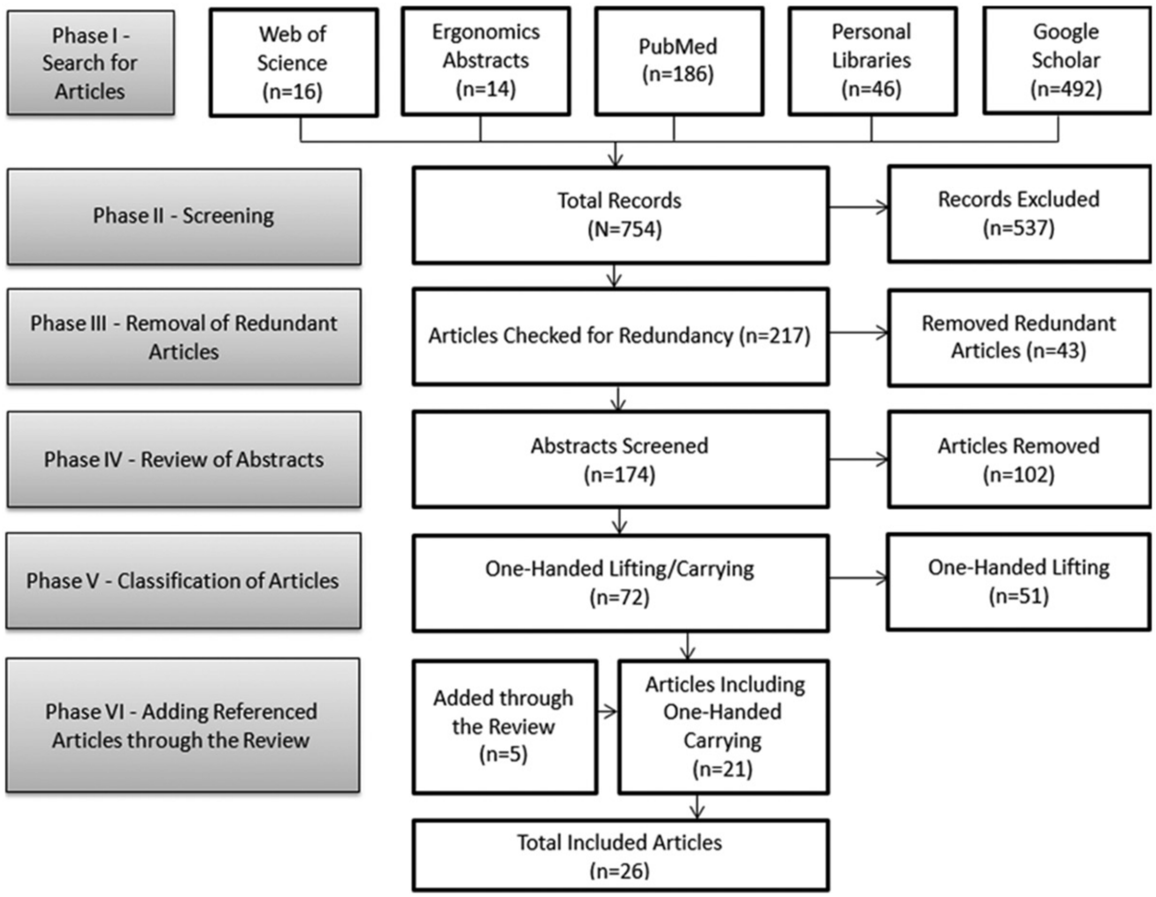

Figure 1. Flow chart of article selection process.

age groups (elderly [68–75 years old] and younger [22–31 years old] females) when carrying relatively small loads (3 kg maximum load in one or in each hand). Wright and Mital (1999) observed similar results regarding the effect of age on VO_2 and HR when self-selected loads were carried unilaterally.

In general, the remaining studies involved young and/or middle-aged individuals while focusing on the effects of load location and magnitude on physiological responses during carrying. Results of these studies suggested that HR, BP, energy expenditure, and the percentage of maximum oxygen uptake (%VO_2 max) increase, and endurance (defined as the time until subjects were no longer willing to hold the load) decreases, more when a load is carried in one hand versus when the load is distributed equally between both hands, carried anteriorly, or carried on the back or the shoulders (Drury 1975; Ganguli and Datta 1977; Jackson et al. 1973; Legg 1985; Lind and McNicol 1968). Carrying a load in one hand was identified to be approximately as physiologically demanding as carrying twice the load equally distributed in both hands (Drury 1975; Ganguli and Datta 1977; Lind and McNicol 1968). It is important to note that the amount of self-selected load carried in two hands was occasionally observed to be larger than that carried in one hand, which may result in larger HR responses during two-handed carrying (Yoon and Smith 1999). However, no clear relationship between HR and cthe arried load was observed (Yoon and Smith 1999). Load magnitude and carrying time also had an impact on physiological performance where increasing load magnitude generally resulted in an increase in physiological responses (Bampouras and Dewhurst 2016; Drury 1975; Kilbom, Hagg, and Kall 1992). The maximum load to be carried in one hand was suggested not to exceed 10 kg in males and 7 kg in females (Ganguli and Datta 1977; Kilbom, Hagg, and Kall 1992; Lind and McNicol 1968).

3.2. The psychophysical approach

A psychophysical approach was used in 6 articles. Two main variables were considered: (1) the maximum acceptable load carried (MALC), and (2) ratings of perceived exertion (RPE). Obesity was not included as an independent variable in any of these studies. The effect of age on psychophysical responses during one-handed carrying was discussed in only one study (Wright and

Table 2. Purpose and load holding methods in each study.

Author(s)	Study Purpose	Experimental Load			
		Unloaded	Unilateral	Bimanual	Posterior
Lind and McNicol (1968)	Estimate HR and BP responses to holding and carrying weights in hand or by a shoulder harness.	N/A	Dominant/non-dominant (20 kg)	20 kg in each hand	Via shoulder harness (40 kg)
Jackson et al. (1973)	Study effects of load and load location on heart rate and blood pressure.	0 kg	18.14 kg	9.07 kg in each hand	18.14 kg
Drury (1975)	Examine the force/duration relationships for 1) Statically holding a load and carrying, and 2) One-handed and two-handed carrying.	N/A	Exp. 1: Static holding/carrying (7.5-41.9 kg) Exp. 2: Carrying (15.9-25 kg)	Exp. 2: 15.9-25 kg in each hand	N/A
Ganguli and Datta (1977)	Study physiological effects of load location in below knee amputees with prostheses.	0 kg	Right/left (7.5 kg)	Walking/stairs climbing (7.5 kg in each hand)	N/A
Garg, Chaffin, and Herrin (1978)	Estimation of metabolic rates for 48 different MMH jobs including one and two-handed carrying.	N/A			N/A
Mital and Manivasagan (1983)	Estimate physiological and psychophysical effects of carrying distance container shape and volume in one-handed carrying.	N/A	Self-selected loads	N/A	N/A
Legg (1985)	Estimate oxygen consumption and energy expenditure of different methods of load carrying.	N/A	One hand/on one shoulder (30 kg)	Waist height/clasped to chest (30 kg)	N/A
Neumann and Cook (1985)	Estimate activity of the gluteus medius muscle while carrying various loads using different carrying methods.	0 kg	Ipsilateral/contralateral (10% and 20% of body weight)	10% and 20% of body weight	10% and 20% of body weight
Cook and Neumann (1987)	Estimate EMG of the paraspinal muscles for different load carrying methods.	N/A	Ipsilateral /contralateral (10% and 20% of body weight)	10% and 20% of body weight	10% and 20% of body weight
Nottrodt and Manley (1989)	Determine the MALC and locomotor patterns of different carrying methods.	0 kg	Dominant hand (self-selected loads)	Bilateral, frontal: elbow angle: 90°, straight arm (self-selected loads)	N/A
Kilbom, Hagg, and Kall (1992)	Estimate local fatigue in hand and forearm during one-handed carrying.	0 kg	Variable loads	N/A	N/A
Smith, Ayoub, and McDaniel (1992)	Assess lifting and carrying capabilities in non-standard postures.	N/A	Ceiling: 40% of stature [crawling] (self-selected loads)	Ceiling: unrestricted, 80%, 60%, and 40% of stature [crawling] (self-selected loads)	N/A
Neumann et al. (1992)	Estimate muscle activity of the hip abductor in one and two-handed carrying.	0 kg	(10% and 20% of body weight)	(10%, 20%, and 40% of body weight total)	N/A
Neumann (1996)	Estimate hip abductor muscle activity for people with hip prosthesis that carry loads in one hand.	N/A	Ipsilateral /contralateral (5%, 10%, and 15% of body weight)	N/A	N/A
Bergmann et al. (1997)	Estimate effects of load magnitude and load location on the forces generated in the hip joints.	0 kg	Ipsilateral /contralateral (up to 30 kg)	Up to 30 kg total	N/A
Yoon and Smith (1999)	Determine physiological and psychophysical responses to combined lifting, carrying, and lowering tasks using one and two hands.	N/A	Combined lift, carry, and lower (self-selected loads)	Combined lift, carry, and lower (self-selected loads)	N/A

(*continued*)

Table 2. Continued

Author(s)	Study Purpose	Experimental Load			
		Unloaded	Unilateral	Bimanual	Posterior
Wright and Mital (1999)	Determine physiological and psychophysical responses to different load carrying methods in older people.	N/A	One-handed carrying and bag carrying (self-selected loads)	Three stairs up and down while walking (self-selected loads)	N/A
An et al. (2010)	Comparison of gait parameters of young females carrying a single-strap bag in one hand, on the forearm, and on one shoulder.	0 kg	Dominant hand, forearm, shoulder (5% of body weight)	N/A	N/A
McGill, Marshall, and Andersen (2013)	Estimate spinal forces due to load carrying one hand and both hands.	N/A	10, 20, and 30 kg	5, 10, 15, and 30 kg in each hand	N/A
Rohlmann et al. (2014)	Compare loads on a vertebral body replacement using different load carrying methods.	N/A	5 and 10 kg	10 kg in each hand	4.5 and 9 kg
Bampouras and Dewhurst (2016)	Examine the impact of carrying shopping bags in older females.	0 kg	1.5 and 3 kg	1.5 and 3 kg in each hand	N/A
Webb and Bratsch (2017)	Examine footfall mechanism while carrying a load unilaterally.	Empty canvas bag	Canvas bag (21% of body weight)	N/A	N/A

Mital 1999). In this study, participants were provided with random loads and were asked to make adjustments to identify the MALC. Then, the participants were asked to walk for 6 m (3 m back and forth). Results indicated no statistically significant effects of age on MALC or RPE during one-handed carrying. However, the study did not specify the MALC by elderly participants or specify their perceived exertion.

The other studies compared psychophysical responses among young and/or middle-aged individuals. One-handed carrying was perceived to be 'somewhat hard' with regard to the exertion of the arm (RPE[A]) and 'fairly light' with regard to the exertion of the whole body (RPE[WB]) for participants carrying self-selected loads (Mital and Manivasagan 1983). Specifically, RPE(A) was approximately equivalent to one-eighth of the measured HR (Mital and Manivasagan 1983). An increase in RPE(A) during one-handed carrying relative to two-handed carrying was associated with a decrease in the MALC (Yoon and Smith 1999). The self-selected carrying capacity of one-handed tasks in young males has been observed to be equivalent to approximately 51–83% of that of a two-handed task (Nottrodt and Manley 1989; Yoon and Smith 1999).

Consistent with the recommendations provided by the physiological studies, males and females were observed to select a MALC of approximately 10 and 7 kg, respectively (Mital 1985; Mital and Manivasagan 1983). However, it is important to note that in the Wright and Mital (1999) study that involved elderly people, females carried approximately 4.6–5.5 kg. It is unknown how much load was carried by the elderly participants; only that the female group that included elderly people carried less than what was recommended previously.

3.3. The biomechanical approach

A biomechanical approach was used in 11 articles. The main interest of the majority of the studies was the effect of unilateral carrying on: (1) forces/muscle activity in the hip, (2) forces/muscle activity on low back muscles, and (3) gait parameters (e.g. stride length, step width, etc.). Obesity was not included as an independent variable in any of these studies. Elderly people were included in five studies (Bampouras and Dewhurst 2016; Bergmann et al. 1997; Neumann 1996; Rohlmann et al. 2014; Webb and Bratsch 2017). However, age was included as an independent variable only in Bampouras and Dewhurst (2016) who concluded that elderly females (68–75 years old) were susceptible to a higher risk of falling while walking with no load. Specifically, the results of the study indicated that carrying a load in one hand decreased the medio-lateral displacement of the elderly females, which increased their stability relative to walking with no load. Webb and Bratsch (2017) demonstrated that, in general, carrying a heavy load in one hand resulted in a decrease of step width in a group of participants ranging in age from 14–55. However, it is unknown how age affected these results.

Table 3. Independent variables and subjects in each study.

Author(s)	Subjects		Mean age (SD) or range		Mean weight kg (SD) or range		Mean height cm (SD) or range		Independent variables
	M	F	M	F	M	F	M	F	
Lind and McNicol (1968)	10	–	31.3	–	N/A	–	N/A	–	LM, LL, loading time
Jackson et al. (1973)	13	–	32	–	N/A	–	N/A	–	LL
Drury (1975)	Exp. 1: 4 Exp. 2: 6	–	Exp. 1: 18–24 Exp. 2: N/A	–	N/A	–	N/A	–	Exp. 1: LM, holding method (lift/carry). Exp. 2: LM, LL
Ganguli and Datta (1977)	9 healthy (M); 5 below-knee amputees with a prosthesis system (gender not specified; however, image of male amputee included)		33.3 (5.27); 23.2 (7.05)	–	50.24 (6.921); 50.19 (7.231)	–	160.9 (5.44); 159.6 (4.72)	–	LL, healthy/below-knee amputee
Garg, Chaffin, and Herrin (1978)	3	3	21	19.7	75.5	66.7	177	173.7	LM, body weight, grade of walking surface (%), walking speed, time
Mital and Manivasagan (1983)	10	5	22.1	22	80	51.82	178	162	Container shape, container size, carrying distance
Legg (1985)	2 (gender not specified; however, image of male soldier included)		22	–	65.1	–	169.1	–	LL
Neumann and Cook (1985)	12	12	26.8	25.1	68.7		173		LL, LM, gender
Cook and Neumann (1987)	12	12	26.8	25.1	69.8	65.7	164	137	LL, LM, gender
Nottrodt and Manley (1989)	10	–	23.1 (3.8)	–	71.8 (5.8)	–	176.3 (6)	–	LL, test session
Kilbom, Hagg, and Kall (1992)	5	11	22–30	24–37	58.5 (3.3)	71.4 (9.6)	163.3 (3)	180 (6)	LM, loading time
Smith, Ayoub, and McDaniel (1992)	20	20	18–30		Stratified sample plan of range 56.6–102.7	Stratified sample plan of range 42.3–81.9	Stratified sample plan of range 164–193	Stratified sample plan of range 148–178	LL, ceiling height, gender
Neumann et al. (1992)	15	15	21.7 (2)		66.5 (13)		170 (9)		LL, LM, gender
Neumann (1996)	16 (with a prosthetic hip at one limb)	9 (with a prosthetic hip at one limb)	63.7 (10.7)		77.42 (16.69)		171 (10)		LM, LL
Bergmann et al. (1997)	6: 5 healthy; 1 with instrumented endo-prostheses in hips	–	37.8; 89	–	75.8; 59	–	N/A	–	Existence of hip implant, LL
Yoon and Smith (1999)	10	–	23	–	75.1 (8.39)	–	173.9 (6.31)	–	LL, frequency
Wright and Mital (1999)	10 young; 10 older	10 young; 10 older	18–35 young; 55–74 older		N/A		N/A		Age, gender, frequency
An et al. (2010)	–	21	–	23 (2.9)	–	52 (3.9)	–	161.5 (4.6)	LL, LM, bag shape
McGill, Marshall, and Andersen (2013)	9 (Results based upon 6 w/ full data)	–	22.7 (2.1)	–	85.7 (16.7)	–	175 (10)	–	LL, LM
Rohlmann et al. (2014)	4	1	66.2		65.4		171		LL, LM
Bampouras and Dewhurst (2016)	–	9 older; 10 young	–	71.6 (6); 26.7 (5.2)	–	66.3 (10.1); 70.2 (15.1)	–	165 (6); 169 (5)	LM, age
Webb and Bratsch (2017)	9	9	25.1 (11.4)	19.1 (2.52)	76.6 (13.7)	61.2 (8.87)	175.5 (5.4)	165.7 (5.9)	LM, carrying practice, gender

F: female; LL: load location; LM: load magnitude; M: male.

Table 4. Dependent variables and main results of each study.

Author(s)	Dependent variables	Main results
Lind and McNicol (1968)	HR, BP	Carrying a load in one hand results in HR and BP responses comparable to carrying twice the load in both hands (the same load in each hand).
Jackson et al. (1973)	HR, BP	HR and BP due to unilateral carrying are larger than those observed during bilateral or posterior carrying.
Drury (1975)	Endurance time	No statistically significant difference in endurance time was observed between unilateral carrying of a load and bilateral carrying of twice the load (the same load in each hand).
Ganguli and Datta (1977)	EE/load carried (kcal/min/kg) – calculated using VO_2	No statistically significant difference in energy expenditure was observed between unilateral carrying of a load and bilateral carrying of twice the load (the same load in each hand).
Garg, Chaffin, and Herrin (1978)	Metabolic rate	A model that predicts metabolic rates during one and two-handed carrying was developed.
Mital and Manivasagan (1983)	HR, WE, WV, RPE(A), RPE(WB)	For self-selected loads, HR responses during one-handed carrying were slightly lower in females than in males. For both genders, one-handed carrying was more strenuous to the arm than to the whole body.
Legg (1985)	$\%VO_2$ max, EE	Compared to other methods of load carrying, one-handed carrying resulted in the largest energy expenditure and oxygen consumption rate.
Neumann and Cook (1985)	%EMG	The largest hip muscle activity was observed at the contralateral side of the body. Gender was not statistically significant.
Cook and Neumann (1987)	%EMG	The erector spinae muscle activity was observed to be statistically affected by the interactions between load size and position as well as gender and position.
Nottrodt and Manley (1989)	MALC, gait parameters	The MALC during one-handed carrying was statistically significantly different from the MALC during two-handed carrying. Walking speed during one-handed carrying was faster than during two-handed carrying, but slower than speed during no-load carrying.
Kilbom, Hagg, and Kall (1992)	HR, BP, V_E, VO_2, endurance time, carried load, RPE	Physiological responses generally increased with the increase in load magnitude. In general, subjects underestimated their endurance.
Smith, Ayoub, and McDaniel (1992)	Maximum load to lift and carry	Load location (in one hand versus two hands) was observed to be insignificant in identifying the load magnitude to be lifted and carried in crawling tasks.
Neumann et al. (1992)	Hip abductor %EMG	Bilateral carrying resulted in lower average of muscle activity of both hips than did the unilateral load carrying.
Neumann (1996)	Hip Abductor %EMG	The largest muscle activity was observed during carrying the load at the contralateral side.
Bergmann et al. (1997)	Hip joint force	Hip joint forces were the largest at the contralateral side of the load.
Yoon and Smith (1999)	HR, tasking time, MALC, RPE(A), RPE(BK), RPE(WB)	During combined lift, carry, and lower tasks of self-selected loads, HR responses were substantially larger in two-handed carrying than in one-handed carrying. Interaction between frequency and load location was observed to be statistically significant in determining RPE(WB), but not for RPE(A) or RPE(BK).
Wright and Mital (1999)	HR, VO_2, MALC, RPE	No significant effect of age on VO_2, HR, MALC, or RPE was observed when self-selected loads were carried unilaterally.
An et al. (2010)	Gait parameters	Carrying a bag in one hand resulted in a less stable and asymmetric toe-out gait compared to other unilateral load carrying methods (on the forearm and on the shoulder).
McGill, Marshall, and Andersen (2013)	Compression and shear forces at L4/L5	Compression forces on the spine were larger when a load was carried in one hand than evenly split between two hands, or even when carrying the same load in both hands (twice the load carried).
Rohlmann et al. (2014)	Forces and moments on a vertebral body replacement	Carrying a load in one hand resulted in forces of the vertebral replacement comparable to those resulted by carrying twice the load in both hands (the same load in each hand).
Bampouras and Dewhurst (2016)	HR, gait parameters	For relatively small loads carried (3 kg maximum load in one or in each hand), HR responses were not statistically different between age groups (older and younger females). Carrying a small load unilaterally may help to stabilize posture in elderly females.
Webb and Bratsch (2017)	Gait parameters	In general, carrying a heavy load in one hand resulted in a decrease of step width.

BP: blood pressure; EE: energy expenditure; EMG: electromyography; HR: heart rate; MALC: maximum acceptable load carried.
RPE: ratings of perceived exertion; RPE(A): RPE of the arm; RPE(BK): RPE of the back; RPE(WB): RPE of the whole body; V_E: ventilation.
VO_2: oxygen uptake; $\%VO_2$ max: percentage of maximum oxygen uptake; WE: estimated load for comfortable carrying; WV: actual carried load comfortably.

Carrying a load in one hand had an effect on gait parameters/postural stability of young people in two other studies (An et al. 2010; Nottrodt and Manley 1989). Nottrodt and Manley (1989) indicated that walking speed during unilateral carrying of self-selected loads was faster than the walking speeds observed for the two-handed carrying situations (bilateral and front), but slower than walking with no load. Moreover, unilateral load carrying resulted in no statistically significantly different stride length or cadence relative to no-load carrying. An et al. (2010) concluded that carrying a bag on the forearm resulted in the least energy-efficient gait due to a substantive restriction in arm swing. In addition, carrying a bag in one hand resulted in a less stable and asymmetric toe-out gait by modifying the base of support. Accordingly, they suggested that when unilaterally carrying a bag, carrying on the shoulder has the least effect on gait parameters in comparison to other carrying methods.

Across different methods of load carrying (ipsilateral, contralateral, and bilateral), the largest hip muscle activity/joint forces were generally noticed while carrying a load contralaterally, and lowest while carrying a load ipsilaterally, for both those with and without hip prosthesis (Bergmann et al. 1997; Neumann 1996; Neumann et al. 1992; Neumann and Cook 1985). Hip joint forces in the frontal plane were calculated using a mathematical model (Bergmann et al. 1997) whereas muscle activity was expressed as normalized electromyography (EMG) (Neumann 1996; Neumann et al. 1992; Neumann and Cook 1985). Normalization was implemented using different methods; percentage of maximum voluntary isometric contraction (MVIC) (Neumann and Cook 1985), the percentage of EMG while walking with no load (Neumann et al. 1992) and percentage of EMG baseline identified before performing the carrying tasks (Neumann, 1996). Forces and muscle activity increased with the increase in load magnitude. Similar results were observed regarding the effect of unilateral load carrying on the back (Cook and Neumann 1987; McGill, Marshall, and Andersen 2013; Rohlmann et al. 2014). Estimates of muscle activity due to contralateral and anterior load carriage were similar to one another and considerably higher than those of no load, posterior, or ipsilateral carrying (Cook and Neumann 1987). Moreover, the mean muscle activity readings increased with the increase in the load magnitude (Cook and Neumann 1987). In addition, carrying a load in one hand was observed to incur larger compression and shear forces on the spine (L4/L5 vertebral segment) than when the load was evenly split between two hands or even when carrying the same load in both hands (twice the load carried) (McGill, Marshall, and Andersen 2013).

4. Discussion

Findings of this systematic review suggest that a relatively limited amount of research has been conducted on one-handed carrying when compared to the body of knowledge on other MMH activities (e.g. two-handed carrying, lifting, etc.), particularly among elderly and obese people. Despite including age and obesity terms in the search strategy, very few studies involved the effects of age or obesity on different physiological, psychophysical and biomechanical responses during one-handed carrying. Age was not observed to be a significant factor in determining physiological responses in the studies conducted by Wright and Mital (1999) and Bampouras and Dewhurst (2016). Although these results may seem unexpected, small and self-selected loads were considered in these studies that may explain the lack of statistically significant differences. In addition, although a few studies included elderly people while studying biomechanical responses to different load carrying methods including one-handed carrying (Bergmann et al. 1997; Neumann 1996; Rohlmann et al. 2014; Webb and Bratsch 2017), the effect of age was not considered as an independent variable. Moreover, to the best of our knowledge, the effect of obesity during one-handed carrying has not been studied in the literature. In many ways, any research on the effects of age and obesity during one-handed carrying may be considered novel and warrants further exploration. Resources should be focused on addressing this critical gap as the proportion of aging and obese people in the general and working populations continues to increase.

Results of this review provide some general conclusions regarding one-handed carrying that is relevant to young adults and middle-aged people:

- The physiological effects of carrying a load in one hand are approximately the same as carrying twice the load equally distributed between two hands. Potential explanations for this phenomenon are one-handed carrying may require greater muscle recruitment and local muscle fatigue than other methods of load carrying (Legg 1985), the change in center of gravity of the participant's body due to load location (Neumann and Cook 1985), and the increased lever arm created while carrying off-balance (Bergmann et al. 1997).
- Load location is a significant factor in determining the MALC for different load carrying methods. The average MALC (kg) in one hand was 51–83% of the two-hand MALC.
- Given the same frequency and load magnitude, one-handed carrying had the largest RPE(A), whereas, for two-handed carrying, RPE of the back RPE(BK) was the largest.
- RPE(A) has been observed to be equivalent to approximately one-eighth of the observed HR during one-handed carrying.
- Muscle activity and forces at the hip and low back joints were larger during one-handed carrying (contralateral side) than during two-handed carrying (anteriorly or bilaterally) and posterior carrying.

- To avoid fatigue or injury, loads carried in one hand have been recommended to not exceed 9–10 kg for males and 6–7 kg for females.

Although results of the reviewed articles suggested that the carrying capacity is higher and potential injury risk is lower, while carrying a load in two hands than when carrying the same load in one hand, there is no evidence that these suggestions remain true for elderly and obese individuals. Also, although RPE may be used to estimate HR during one-handed carrying of self-selected loads by young adult males and females, it is unknown if RPE represents accurate estimates of physiological responses in elderly and obese individuals during one-handed carrying. In addition, it is unknown if the one-handed loads recommended in the literature are safe for the elderly and/or obese people to carry. More research on the effects of age and obesity during one-handed carrying is needed. Studies with larger sample sizes that consider different variables that may affect health and performance (e.g. working temperature, characteristics of the load to be carried, characteristics of the walking surface, history of load carrying tasks, etc.) are also warranted. Although different physiological and biomechanical aspects were investigated, both even in one study, no study discussed the effects of muscle fatigue on the change of the biomechanics of carrying. The effect of muscle fatigue on the change of muscle recruitment and hence load distribution (if existing) remains unknown.

Several limitations of this systematic review should be discussed. One limitation was that articles on one-handed carrying were only included if they were written in English and published in peer-reviewed journals. Accordingly, results published on the topic in other publications (conference proceedings, book chapters, thesis or dissertations), or in non-English publications, were not reviewed. Another limitation is that for articles involving more than one study, the review focused only on the study/studies that included one-handed carrying experiment/s. Other topics in some of the reviewed articles were not discussed in the review. Despite these limitations, many research gaps were identified that once addressed, have the potential to have a positive impact on the health and safety of working people that perform MMH tasks.

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