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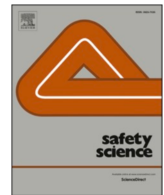

Review

Obesity as a risk factor for musculoskeletal injury during manual handling tasks: A systematic review and *meta*-analysis

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ABSTRACT

Obesity is a growing health concern worldwide and musculoskeletal disorders (MSD) are the leading cause of injury, disability, and work-related sickness absence globally. A systematic literature review and *meta*-analysis was undertaken to investigate the effects of increased body weight on the biomechanical, physiological, and psychophysical responses to manual handling.

Methods: A literature search was conducted on five electronic databases (EBSCO Health, SCOPUS, OVID (AMED), ProQuest, Google Scholar) that followed the PRISMA (Preferred Reporting Items for Systematic Review and Meta-Analysis) guidelines. Studies were included if they investigated a manual handling activity comparing responses of obese/overweight adults to those with a healthy body weight. Included studies had to report on at least one biomechanical, physiological, or psychophysical outcome measure. The Joanna Briggs Institute (JBI) Critical Appraisal Tool was used to assess risk of bias (RoB) and methodological quality. A narrative synthesis of the findings was conducted and where possible, a *meta*-analysis was performed using random-effects models.

Results: Eighteen cross-sectional studies met the inclusion criteria. Participants were predominately male (22% female) and were primarily classified into obese, overweight, or healthy body weight based on their body mass index (BMI). A task involving symmetrical box lifting was the most frequently performed activity. Pooled estimates of effect sizes suggest obesity increases the horizontal reach distance when lifting, and repetitive lifting leads to higher heart rates compared with healthy weight participants. There was moderate evidence of increased moments and compression forces in the lower spine. Factors unaffected by obesity were knee flexion and perceived estimates of the maximum acceptable weight of lift (MAWL).

Conclusions: Differences in the kinematics and kinetics of lifting between obese or overweight handlers and those of a healthier weight, suggest that approaches to preventing and managing work-related musculoskeletal conditions should consider a worker's body weight when designing workplaces, work practices, and training. To develop appropriate interventions, more high-quality studies are needed involving a range of industry and service sector handling tasks.

1. Introduction

Overweight and obesity is a growing health concern worldwide and is now considered an epidemic throughout Europe (World Health Organisation, 2022a). Defined as abnormal or excessive fat accumulation, obesity affects 60% of adults globally (World Health Organisation, 2022a). By 2030, it is estimated that one billion people worldwide will be classified as obese, affecting one in five women and one in seven men (World Health Organisation, 2022b).

Obese populations appear to have higher rates of work-related injury, work absenteeism, worker compensation claims, increased medical costs and reduced work productivity and work ability (Goetzel et al., 2010; Janssen et al., 2011; Lin et al., 2013; Schmier et al., 2006; Tonnon et al., 2019; Tsai et al., 2011; Virtanen et al., 2018). However, the role obesity plays in these associations is unclear. Obesity may act as a mediating or moderating variable in many instances. The risk of sustaining a workplace injury has been estimated to be between 25% and 45% higher for obese workers compared with those of a healthyweight (Gu et al., 2016; Lin et al., 2013).

Obese adults are at increased risk of musculoskeletal complaints,

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metabolic conditions (e.g. type 2 diabetes mellitus and cardiovascular disorders), and mental health issues (World Health Organisation, 2022a). Associations between obesity and an increased risk of musculoskeletal conditions has been linked to the higher mechanical and physiological loads on the body (World Health Organisation, 2022b). A number of risk factors linking obesity to causative mechanisms of musculoskeletal conditions have been proposed, including: greater internal and external joint forces due to the higher inertial characteristics of body segments, increased joint stiffness and reduced joint range of motion; higher cardiovascular demands from a reduced metabolic capacity; the earlier onset of fatigue from a lower percentage of fatigue resistant muscle fibres; and neuromuscular control deficiencies from impaired motor unit activity (Błaszczyk et al., 2009; Blimkie et al., 1990; Cavuoto & Nussbaum, 2014; Kern et al., 1999; Maltin, 2008; Mehta & Cavuoto, 2015; Newcomer et al., 2001; Park et al., 2010; Xu et al., 2008).

Despite technological developments and increased automation, manual handling remains a common activity in many workplaces and a leading cause of work-related musculoskeletal injury and disability (Dempsey, 1998, 2003; Coenen et al, 2014; da Costa and Vieira, 2010; Lotters et al, 2003). Whilst much is known about physical and psychosocial risk factors associated with these injuries, the role of individual factors is less clear. Individual factors, such as a high BMI, have been shown to influence lifting techniques, increasing horizontal reach, affecting trunk and pelvis inclination, and altering trunk acceleration when compared with those of a healthier body weight (Colim et al., 2020; Pryce & Kriellaars, 2018; Xu et al., 2008). Alterations in the kinematic and kinetics of lifting associated with obesity is believed to increase the risk of musculoskeletal injury (Cavuoto & Maikala, 2015; Lemus et al., 2022).

The ergonomic design of workplaces and work practices often cater to the average, “healthy” worker, with little consideration for those who fall outside these parameters (Akhavanfar et al., 2018; Capodaglio et al., 2010; Cavuoto & Nussbaum, 2014; Gordon & Bradtmiller, 2012; Lemus et al., 2022). The “one size fits all” approach, often used to delivery manual handling training, takes limited account of individual variability (Denis et al., 2020). Therefore, understanding the effects of obesity on biomechanical and physiological aspects of manual handling is needed if the risks of work-related musculoskeletal injuries are to be managed effectively (Cavuoto & Nussbaum, 2014).

Several studies have compared the physical and physiological differences between obese and healthy workers when performing manual handling tasks, but there is a lack of clarity and evidence to support risk reduction measures. A preliminary search of health-related databases (PROSPERO, MEDLINE, the Cochrane Database of Systematic Reviews, and JBI Evidence Synthesis) identified two previous reviews in the topic area, one restricted to one-handed carrying (Badawy et al., 2018b) and the other a narrative review published in 2014 (Cavuoto & Nussbaum, 2014). No other current or in-progress systematic reviews were identified. The aim of this systematic review and *meta*-analysis is to synthesise the scientific literature on the effects of obesity on biomechanical, physiological, and psychophysical responses to manual handling. Findings will provide information for employees, employers, health care providers and policymakers to inform future workplace design and risk reduction measures.

2. Methods

2.1. Protocol and registration

This systematic review was performed according to the recommendations of the PRISMA (Preferred Reporting Items for Systematic Review and Meta-Analysis) statement (Page et al., 2021) and the systematic review protocol was registered in the PROSPERO database (CRD42023371704).

2.2. Research question

This is a systematic review of observational and experimental studies to address the question: does being overweight/obese influence biomechanical, physiological, or psychophysical responses to manual materials handling, compared with those of a healthy BMI and if so, does this change the risk of musculoskeletal injury? The question was structured according to the PECOS framework, as detailed in Table 1.

2.3. Study design and eligibility criteria

To be included in the review, studies had to directly compare obese/overweight participants with those of a healthy weight (non-obese) performing a manual handling activity. Included studies were required to report on at least one measure associated with a biomechanical, physiological, or psychophysical response variable (Table 1). Such measures are used to provide estimates of the risk of musculoskeletal injury associated with occupational tasks. Studies were restricted to those published in English, with no constraints on the year of publication. Articles excluded from the review included literature reviews and congress abstracts. Although theses and dissertations were excluded based on the unknown peer-review status, a search of ProQuest (dissertations/thesis) identified relevant authors that were searched in each of the other electronic databases. A manual search was undertaken of the reference list of all articles meeting the inclusion criteria.

2.4. Sources of information and search

The literature search was conducted in five electronic databases (EBSCO Health (inclusive of Medline + CINAHL + SportsDiscus), SCOPUS, OVID (AMED), ProQuest, Google Scholar) using a search strategy that combined keywords associated with three domains: manual handling; obesity/overweight; and biomechanical, physiological, and psychophysical outcome measures. A list of keywords was developed from a preliminary search of relevant articles to identify listed keywords

Table 1
PECOS framework used to structure the research question and inclusion/exclusion criteria.

PECOS framework	Criteria	Comment
Population (P)	Adults of a working age (16–65 years) classified as obese or overweight.	Obesity defined according to recognised criteria, such as BMI, waist circumference to hip ratio, and/or % body fat.
Exposure (E)	Manual handling activities	Activities involving force exertions of more than 3 kg when lifting, lowering, pushing, pulling, carrying, climbing, and pivoting/twisting
Comparison (C)	Participants of an adult working age with a body weight considered normal and without health complaints	Healthy weight (non-obese) defined according to recognised criteria, such as BMI, waist circumference to hip ratio, and/or % body fat.
Outcome (O)	At least one biomechanical, physiological, or psychophysical outcome measure	Biomechanical outcome measures could include kinematic or kinetic measures. Physiological measures could include heart rate or oxygen consumption. Psychophysical measures could include MAWL or ratings of perceived exertion.
Studies included (S)	Observational or experimental studies	No restriction on study design

BMI – body mass index; kg – kilogram; MAWL – Maximum Acceptable Weight of Lift.

and was informed by subject headings from the selected databases. Combinations of the Boolean operators "AND" and "OR" enhanced the search strategy. An example of the search used with the EBSCO Health database is shown in Appendix A. This was modified to suit the search protocols of each database. The search was conducted in conjunction with a Senior Liaison Librarian who specialised in health and rehabilitation. Results from each database were exported to EndNote™ (Version 20; Clarivate, London, UK) and duplicates removed. The search was completed in January 2023.

2.5. Study selection

Prior to the selection of studies, two reviewers (MB and YN) discussed the eligibility criteria and applied them to a sample of searched articles (10 %) to determine inter-examiner agreement. Following discussions, the study selection process was performed independently by the two reviewers (MB and YN). Stage 1 involved selection of studies based on title and abstract; articles not related to the topic area were eliminated. Stage 2 involved reviewing the full text of selected studies against the inclusion criteria to ensure eligibility. When agreement between the two reviewers could not be reached, a third reviewer (GM) was consulted to adjudicate. The reviewers were not blinded to authors names or journal titles.

2.6. Risk of bias and individual quality of the studies

The risk of bias (RoB) and methodological quality of selected studies was assessed by two independent reviewers (MB and YN) using the Joanna Briggs Institute (JBI) Critical Appraisal Tools for use in JBI Systematic Reviews – checklist for analytical cross-sectional studies (JBI, 2023), as only cross-sectional studies met the inclusion criteria. A preliminary meeting of the reviewers established consensus on the interpretation of each checklist question. On completing the JBI checklist for each study, the two reviewers met to determine possible differences in assessments and agree on a consensus. Consultation took place with a third reviewer (GM) to resolve any outstanding disagreement.

The JBI checklist for cross-sectional studies consists of nine questions, each was answered and scored as follows: "yes", two points; "unclear", one point; "no" or "not applicable", zero points. Overall RoB for each study was calculated as a percentage of the maximum score achievable (16). Studies were classified as having a high RoB when they scored <50 %, moderate RoB when they scored ≥50 % and <70 %, and low RoB when the score ≥70 %.

2.7. Process of data collection and extraction

Two reviewers (MB and YN) independently extracted data from studies meeting all inclusion criteria, according to pre-agreed categories: study identification (author, year of publication); study design and purpose; participants demographics by group (e.g. overweight/obese/healthy – number of participants, sex, age, height, weight, BMI); manual handling task(s) performed; biomechanical, physiological and/or psychophysical method(s); dependent measures and statistical analysis; main findings; and conclusions. On completing data extraction, the reviewers met to agree on the appropriateness and completeness of the extracted data.

2.8. Synthesis of findings

A narrative synthesis of the findings was conducted for three broad categories of outcome: biomechanical, physiological, and psychophysical. Studies were initially grouped according to the manual handling task performed (lifting/lowering, carrying, holding) and the main outcome measures (e.g. trunk flexion, back moment). Comparable outcome measures were grouped, and statistical effects noted (population group differences and the direction of findings). The level of evidence considered the quality, quantity and consistency of findings using a modified version of the Institute of Work and Health synthesis approach (Institute for Work and Health, 2023) (Appendix B). Where possible, and using data from at least three studies, a *meta*-analysis was performed with random-effects models. Data incorporated into the *meta*-analysis were selected based on the largest differences in mean responses between population groups, or worst-case scenarios (e.g. heaviest load handled). Means, standard deviations (SD) and/or *p* values were used to determine the standardised mean difference (Hedge's g) and standard error (SE) for each study. These were used to calculate an overall mean effect size and 95 % confidence interval. The Z-value test provided an indication of the overall mean effect size. Q and I-squared (I^2) statistic, and Tau-squared (T^2) and Tau provided a measure of variance of the true effect. Meta analyses were performed using the Comprehensive Meta Analysis (CMA) software (Version 4, Biostat, Inc, USA).

3. Results

3.1. Study selection

Fig. 1 shows the PRISMA flow diagram of the identification of studies. A total of 4,595 articles were initial identified across the 5 electronic databases. Following removal of duplicates and miscellaneous records, the titles, and abstracts of 2,606 were retrieved. The abstracts of 95 articles were reviewed in detail, of which 50 were considered appropriate for full text review. Thirty were excluded, primarily because they failed to meet the criteria for a manual handling task (n = 15) or were master's or PhD theses (n = 10). Twenty studies met the inclusion criteria. The reference list of the included studies were checked to identify studies not retrieved in the main search and potential authors of interest. Following extraction of data, four studies (two per author) reported on the same participants and presented similar findings (Badawy et al., 2019a; Badawy et al., 2019b; Colim et al., 2016; Colim et al., 2021). Data from these studies were combined, resulting in 18 studies meeting the inclusion criteria, summaries of which are at Appendix C.

3.2. Study characteristics

All 18 studies were of a cross-sectional design and involved a total of 471 participants, grouped according to relative body adiposity, obese (n = 197), overweight (n = 56), and normal weight (n = 218). The median sample sizes of participants across studies were 10 (obese), 13 (overweight), and 10 (non-obese). Participants were predominately male, with only 25 % female in the obese, and 19 % in the normal weight groups. Obese participants were slightly older, with a mean age of 31.8 years compared with 26.7 years for those of a healthy weight.

The health status of most participants was classified according to the World Health Organisation (WHO) BMI indices of obesity (obese class I-III: BMI ≥ 30 kg/m^2), pre-obesity (29.9 kg/m^2 > BMI > 25.0 kg/m^2; referred hereafter as overweight) and healthy weight for adults (over 20 years old) (24.9 kg/m^2 > BMI > 8.5 kg/m^2) (World Health Organisation, 2010). One study selected participants based on lower and upper limits of BMI (40 kg/m^2 > BMI > 30 kg/m^2 (obese); 24.9 kg/m^2 ≥ BMI ≥ 18.5 kg/m^2 (normal)) (Cavuoto & Maikala, 2015), or used an additional grouping to classify participants (e.g., BMI 35 kg/m^2 < BMI < 39.9 kg/m^2–moderately obese; BMI > 40 kg/m^2–extremely obese) (Singh et al., 2009). Several studies reported on measures additional to BMI as an indication of body fat composition, which included: % body fat or body fat mass % (%BF/BFM%); body adiposity index (BAI); waist and hip circumference (WC and HC); and waist-to-hip (WtH) ratio. Only Pryce and Kriellaars (2018) selected participants based on cut-off values other than BMI, i.e. central adiposity (CA) defined as a WtH ratio ≥ 0.9 and waist circumference >102 cm. Colim et al. (2021) used BFM% as the criterion to classify participants, but cut-off values were not reported.

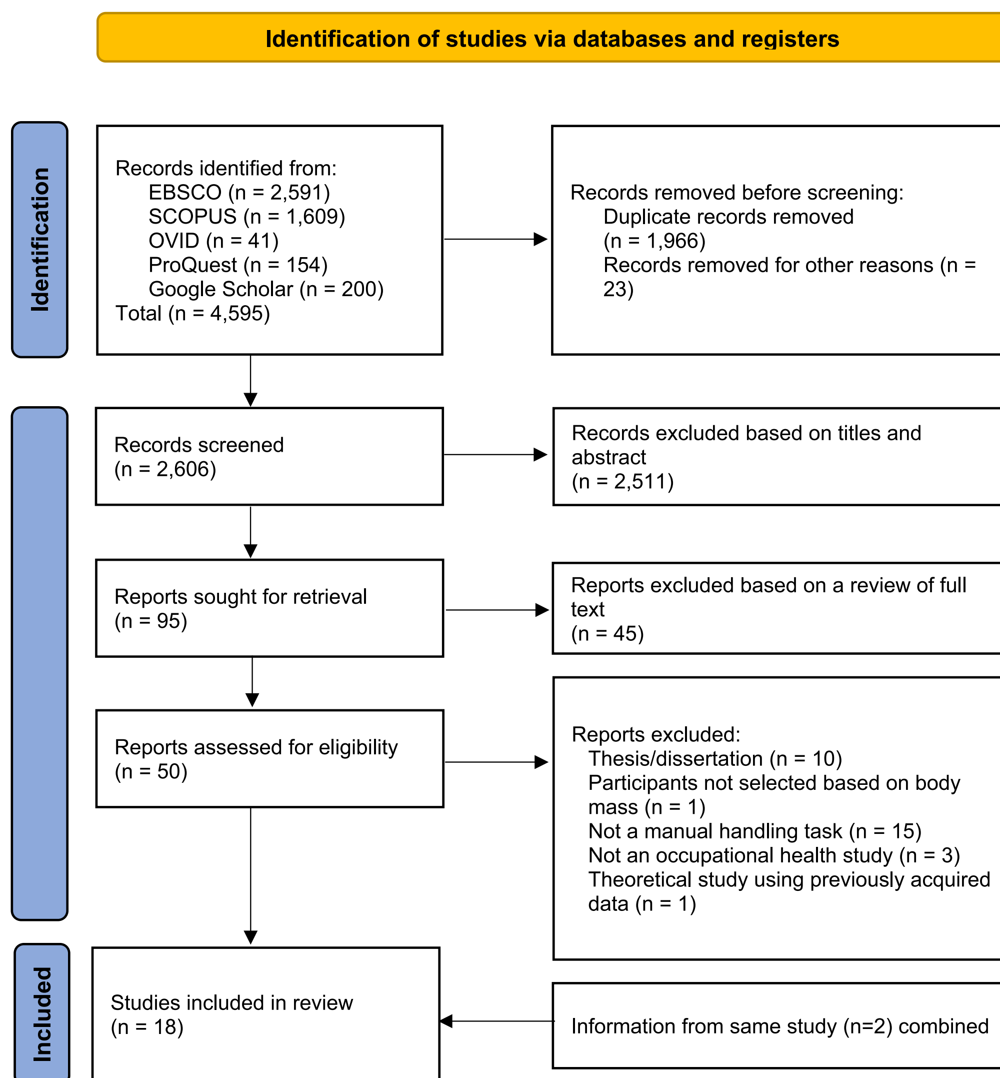


Fig. 1. Flow chart of the search strategy and identification of studies (Adapted from: Page et al. (2021)).

The study only reported that the groups conformed to a BMI < 25 kg/m^2 (normal), BMI ≥ 25 kg/m^2 (overweight), and BMI ≥ 30 kg/m^2 (obese).

Most studies (n = 12) required participants to symmetrically lift a box. Five of these studies involved repetitive lifting (defined here as: >1 min duration or >10 lifts) of the same task (Cavuoto & Maikala, 2015; Lemus et al., 2022; Marra et al., 2014; Pryce & Kriellaars, 2018; Sangachin & Cavuoto, 2016). Other tasks included asymmetrical box lifting (Singh et al., 2015; Xu et al., 2008), a simulated transfer of boxes from a conveyor belt to a trolley (Corbeil et al., 2019; Lussier et al., 2010), one-handed carrying of a dumbbell (Badawy et al., 2018a; Badawy et al., 2019a; Badawy et al., 2019b), and static box holding in 84 different postures (Park et al., 2009). One study (Tetteh et al., 2009) replicated lifting tasks observed in industry, where a small electric motor (6.9 kg) was moved between shelving. No studies were identified that involved the pushing or pulling of loads.

3.3. Risk of bias and individual quality of the studies

Of the 20 studies included in the review, six were considered to have a low RoB, ten a moderate RoB, and two a high RoB (Table 2). The two studies rated as high RoB adopted a repetitive lifting protocol that was likely to lead to different exposure between participants, adopted less stringent statistical significance, and/or failed to explain their statistical analysis (Lussier et al., 2010; Marra et al., 2014). Most studies (15) used objective criteria for the measurement of obesity (question 4, JBI checklist), with definitions comparable to the WHO BMI classifications (World Health Organisation, 2023). Reasons for downgrading question 4 to 'unclear' was ambiguity over the classification and grouping of participants into obese and overweight groups, although BMI was still an adopted measure. Most studies scored poorly on questions 5 and question 6 due to a lack of information about potential confounders (e.g. age differences between obese and healthy groups) or failure to considered confounders as part of the analysis.

3.4. Findings from studies

3.4.1. Obesity and kinematics

Seven studies investigated the effects of obesity/overweight on the kinematics of manual handling, six of which involved lifting and/or lowering tasks (infrequent and repetitive) (Colim et al., 2020; Corbeil et al., 2019; Marra et al., 2014; Pryce & Kriellaars, 2018; Sangachin & Cavuoto, 2016; Xu et al., 2008) and one, one-handed carrying (Badawy et al., 2019b). These studies used 3D motion tracking (3D optical electrical/video), 3D accelerometery and/or the Lumbar Motion Monitor (LMM, Chattanooga Group Inc, TN)) to derive kinematic measures. Outcome measures studied included: lifting duration, horizontal reach; three-dimensional (3D) body segment angles and ranges of motion (RoM) (shoulder, trunk (lower, mid, upper), hip/pelvis, knee, ankle);

Table 2
Risk of bias and study quality assessed using the Joanna Briggs Institute (JBI) checklist for analytical cross-sectional studies. Studies were classified as “high risk of bias (RoB)” when their overall score was <50 %, moderate RoB when they scored ≥50 % and <70 %, and low RoB when the score ≥70 %.

Authors	Q1[!]	Q2	Q3	Q4	Q5	Q6	Q7	Q8	%/RoB[#]
Badway et al., 2019a, 2019b	Y*	U	Y	Y	U	U	U	Y	75%/low
Badaway et al., 2018	Y	U	Y	Y	N	N	U	Y	63%/moderate
Cavuoto and Maikala, 2015	Y	Y	Y	Y	U	U	U	Y	81%/low
Colim et al., 2021Colim et al., 2016	Y	U	Y	Y	N	N	U	U	56%/moderate
Colim et al., 2020	Y	Y	Y	Y	U	N	U	U	69%/moderate
Colim et al., 2019	U	U	Y	U	U	U	N	U	50%/moderate
Corbeil et al., 2019	N	Y	N	U	Y	Y	Y	Y	69%/moderate
Lemus et al., 2022	Y	Y	Y	Y	N	U	Y	Y	81%/low
Lussier et al., 2010	N	U	Y	Y	N	N	Y	N	44%/high
Marra et al., 2014	Y	Y	N	Y	N	N	U	N	44%/high
Pajoutan et al., 2017	Y	Y	Y	Y	U	U	Y	Y	88%/low
Park et al., 2009	Y	Y	Y	Y	U	U	U	N	69%/moderate
Pryce and Kriellaars, 2018	Y	U	Y	U	U	U	Y	Y	75%/low
Sangachin and Cavuoto, 2016	Y	U	Y	Y	U	U	Y	N	69%/moderate
Singh et al., 2015	Y	Y	Y	Y	Y	U	N	Y	81%/low
Singh et al., 2009	Y	U	Y	Y	U	N	U	N	56%/moderate
Tetteh et al., 2009	U	Y	U	Y	N	N	N	Y	50%/moderate
Xu et al., 2008	Y	U	Y	Y	N	N	Y	Y	69%/moderate

*Y – Yes; U – Unclear; N – No.
[#] RoB (risk of bias) was calculated as a percentage of the maximum score achievable (16), where “yes” = 2 and “unclear” = 1.
[!]Q1. Were the criteria for inclusion in the sample clearly defined?; Q2. Were the study subjects and the setting described in detail?; Q3. Was the exposure measured in a valid and reliable way?; Q4. Were objective, standard criteria used for measurement of the condition?; Q5. Were confounding factors identified?; Q6. Were strategies to deal with confounding factors stated?; Q7. Were the outcomes measured in a valid and reliable way?; Q8. Was appropriate statistical analysis used?.

and 3D trunk velocities, acceleration, and jerk. Walking speed was a spatial–temporal measure reported for one-handed carrying (Badawy et al., 2019b).

The effects of obesity on lifting duration was investigated in three studies (Colim et al., 2020; Pryce & Kriellaars, 2018; Sangachin & Cavuoto, 2016), for which there was mixed evidence, one study (repetitive lifting, moderate RoB) reported longer lifting times for the obese handlers (Sangachin & Cavuoto, 2016), one study (repetitive lifting, low RoB) found shorter lifting duration for the obese handlers (Pryce & Kriellaars, 2018), and one study (infrequent lifting, moderate RoB) found no difference between populations (Colim et al., 2020). Studies included in the *meta*-analysis showed no overall difference in mean lifting duration between groups (p = 0.427) (Fig. 2).

Differences in horizontal reach distance was investigated in three lifting studies (Colim et al., 2020; Corbeil et al., 2019; Pryce & Kriellaars, 2018). Pryce and Kriellaars (2018) (low RoB) found that obese handlers adopted significantly longer reach distances, while two studies (Colim et al., 2020; Corbeil et al., 2019) (moderate RoB) found no significant difference between groups (mixed evidence). When combining data from each study, there was a significant overall effect size for reach distance suggesting that obese handlers adopt longer reach distances when lifting compared with healthy weight handlers (effect size = 0.838; p = 0.005) (Fig. 3).

Six studies investigated the effects of obesity on sagittal trunk flexion when lifting (Colim et al., 2020; Corbeil et al., 2019; Marra et al., 2014; Pryce & Kriellaars, 2018; Sangachin & Cavuoto, 2016; Xu et al., 2008). Measures of trunk angle differed between studies, with some reporting gross trunk angle, while others differentiated between lower (lumbar) and upper trunk angles. There was mixed evidence for the effects of obesity on peak trunk flexion when lifting, with two studies (low and moderate RoB) finding decreased flexion (Pryce & Kriellaars, 2018; Sangachin & Cavuoto, 2016), three studies (two moderate and one high RoB) finding no significant difference between groups (Corbeil et al., 2019; Marra et al., 2014; Xu et al., 2008) and Colim et al. (2020) (moderate RoB) finding increased flexion in the obese group. Whilst Pryce and Kriellaars (2018) reported decreased lumbar flexion in the obese group, they found that obese handlers adopted significantly greater mid-trunk flexion. The overall estimate of standardised mean difference was non-significant (p = 0.98) (Fig. 4).

Sagittal peak trunk acceleration was measured in four studies, with three (one high, one moderate and one low RoB) finding no-significant difference between groups (Marra et al., 2014; Pryce & Kriellaars, 2018;

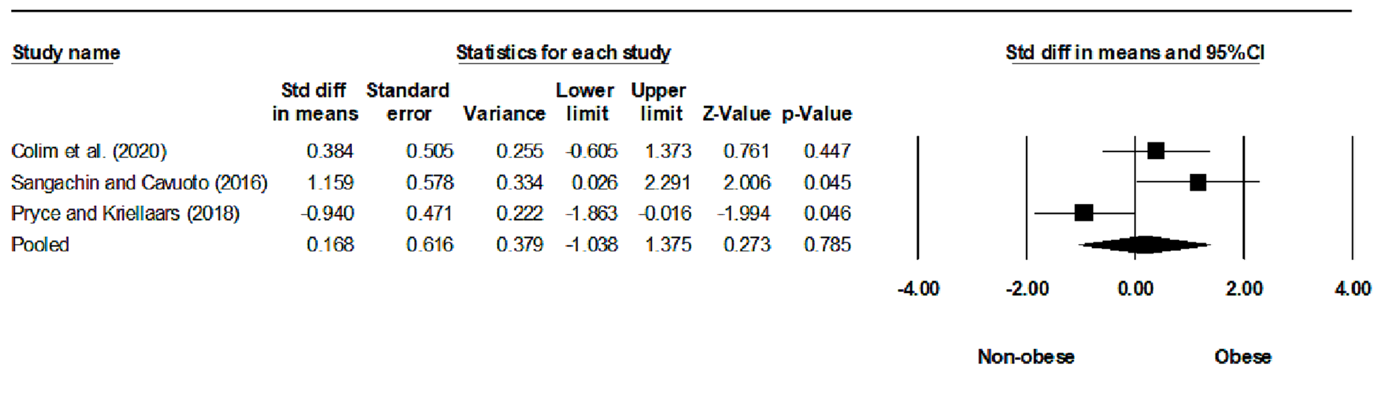


Fig. 2. Meta-analysis using a random-effects model of the standardised mean difference in lifting duration between obese and non-obese handlers. Heterogeneity: Q-value = 8.528, P-value = 0.0141; T^2 = 0.868; I^2 = 76.6 %.

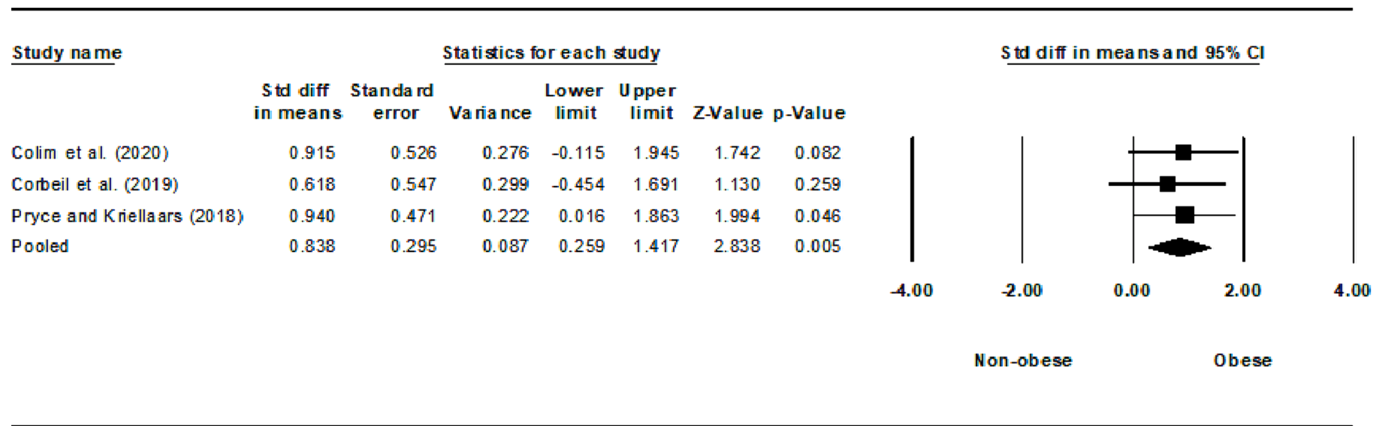


Fig. 3. Meta-analysis using a random-effects model of the standardised mean difference in horizontal load displacement between obese and non-obese handlers. Heterogeneity: Q-value = 0.229, P-value = 0.892; T^2 = 0.00; I^2 = 0.00 %.

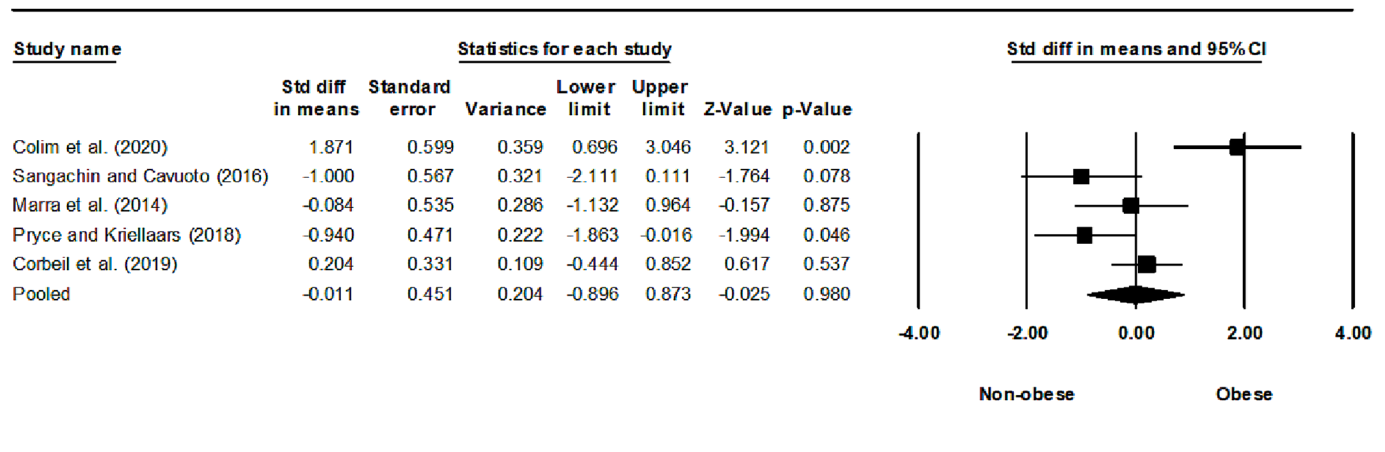


Fig. 4. Meta-analysis using a random-effects model of the standardised mean difference in trunk flexion between obese and non-obese handlers when lifting. Heterogeneity: Q-value = 17.2, P-value = 0.002; T^2 = 0.767; I^2 = 76.8 %. NB: Xu et al. (2008) found a non-significant difference between population groups for trunk measures and did not present data that could be incorporated in the *meta*-analysis.

Sangachin & Cavuoto, 2016), while Xu et al. (2008) (moderate RoB) found obese handlers had higher trunk accelerations when lifting (mixed evidence). Overall estimates of standardised mean differences for sagittal trunk acceleration were non-significant (p = 0.404) (Fig. 5).

Three studies (two moderate and one low RoB) (Colim et al., 2020; Corbeil et al., 2019; Pryce & Kriellaars, 2018) found no significant difference between population groups for measured peak knee flexion when lifting (moderate evidence).

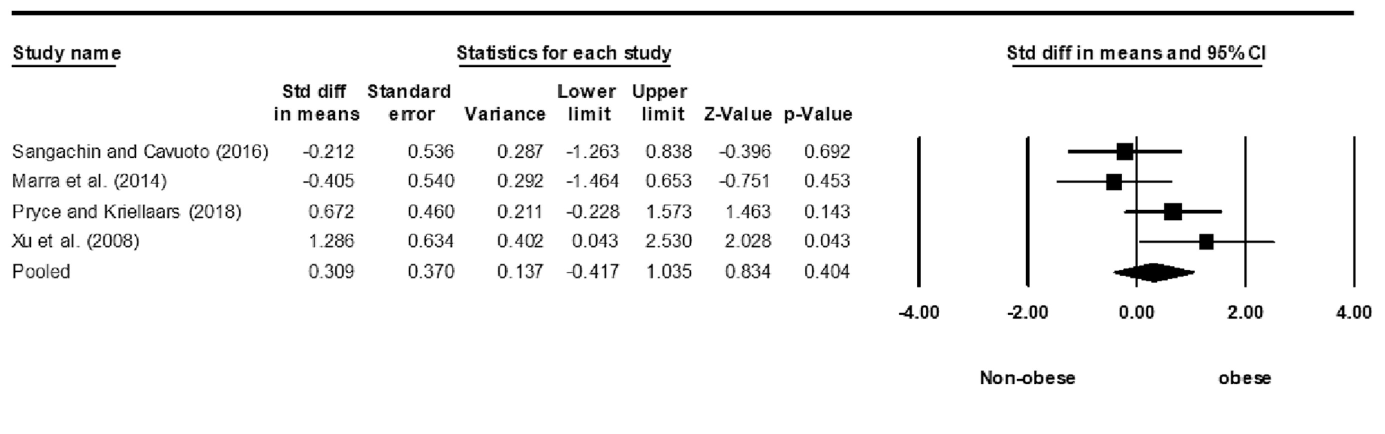


Fig. 5. Meta-analysis using a random-effects model of the standardised mean difference in peak sagittal trunk acceleration between obese and non-obese handlers when lifting. Heterogeneity: Q-value = 5.69, P-value = 0.127; T^2 = 0.259; I^2 = 47.3 %.

3.4.2. Obesity and kinetics

The effects of obesity/overweight on the kinetics of manual handling were investigated in seven studies (Badawy et al., 2019b; Corbeil et al., 2019; Lussier et al., 2010; Pajoutan et al., 2017; Pryce & Kriellaars, 2018; Singh et al., 2015; Xu et al., 2008). These studies used 3D force plates to measure external forces, in conjunction with kinematic measures and biomechanical models. Outcome measures included: 3D ground reaction forces and coefficient of friction (CoF); 3D static joint forces (compression, shear and lateral); 3D joint moments (absolute and normalised to body weight) about the lower trunk; postural stability (centre of pressure (CoP) displacement and destabilising force); and work and power performed during the task.

Measures of lower trunk moments were recorded in three studies, two for a lifting task (low and moderate RoB) (Corbeil et al., 2019; Pryce & Kriellaars, 2018) and one for one-handed carrying (low RoB) (Badawy et al., 2019b). All studies identified significantly higher moments for the lower back in the obese group compared with the non-obese group. There was moderate evidence of increased extensor moments when lifting in obese participants. No significant differences were found in the studies which normalised moments to body weight and/or height (Badawy et al., 2019b; Corbeil et al., 2019).

Estimates of lower back spinal compression were estimated in two lifting studies (low RoB) (Pryce & Kriellaars, 2018; Singh et al., 2015) and one study estimated shear forces (Pryce & Kriellaars, 2018) using static biomechanical models. Significantly higher compression (moderate evidence) and shear forces on the lower back were estimated in the obese compared with non-obese handlers when lifting.

Two studies (Lussier et al., 2010; Pajoutan et al., 2017) reported on improved balance in obese compared with healthy weight participants when lifting (insufficient evidence).

3.4.3. Obesity and psychophysical responses

Eight studies investigated the effects of obesity/overweight on psychophysical responses to manual handling. Ratings of perceived exertion (RPE) were measured in seven studies (Badawy et al., 2018a; Cavuoto & Maikala, 2015; Colim et al., 2019; Marra et al., 2014; Park et al., 2009; Pryce & Kriellaars, 2018; Sangachin & Cavuoto, 2016) and perceived maximum acceptable weight of lift (MAWL) in four studies (Marra et al., 2014; Pryce & Kriellaars, 2018; Sangachin & Cavuoto, 2016; Singh et al., 2009). RPE were assessed using Borg's scales (CR-10 and 6–20 scales) (Borg, 1998) and MAWL used the method proposed by Snook and Ciriello (1991).

For lifting tasks, four studies (two low, one moderate and one high RoB) reported no significant difference in whole body RPE when comparing obese and healthy weight participants, while Colim et al. (2019) (moderate RoB) found a negative correlation between BMI and RPE (Fig. 6) (limited evidence). Park et al. (2009) (moderate RoB) investigated the postural stress associated with holding 5 kg for 20 sec in 84 different postures and found obese handlers significantly rated whole body postural stress (RPE) more highly than the non-obese group. Two lifting studies (Cavuoto & Maikala, 2015; Pryce & Kriellaars, 2018) (low RoB) considered differences in RPE for different body regions (back and arms), both finding no difference between groups for RPE of the back and arms (moderate evidence).

No significant difference in the MAWL was found between obese and non-obese handlers in the four lifting studies (one low, two moderate and one high RoB) (Marra et al., 2014; Pryce & Kriellaars, 2018; Sangachin & Cavuoto, 2016; Singh et al., 2009) (Fig. 7) (moderate evidence).

3.4.4. Obesity and physiological responses

The effects of obesity on heart rate (HR) when manual handling was investigated in six studies (Badawy et al., 2018a; Cavuoto & Maikala, 2015; Lemus et al., 2022; Marra et al., 2014; Pryce & Kriellaars, 2018; Sangachin & Cavuoto, 2016). Two of these studies (Cavuoto & Maikala, 2015; Lemus et al., 2022) also considered metabolic, respiratory and/or blood measures (volume of oxygen uptake (VO_2), ventilation rate, volume of carbon dioxide production (VCO_2), respiratory exchange ratio, energy expenditure, O_2 pulse partial pressure of end-tidal CO_2, and cerebral haemodynamics (oxygenated and reduced states of haemoglobin, tissue blood volume and tissue oxygenation index)) in response to repetitive handling. Three studies used surface electromyography (EMG) to compare upper and lower back muscle activity in obese/overweight and non-obese participants, one when carrying (Badawy et al., 2019a) and two when lifting (Colim et al., 2016; Colim et al., 2021; Tetteh et al., 2009).

Of the six studies investigating heart rate responses, five involved repetitive lifting, of which two (Lemus et al., 2022; Pryce & Kriellaars, 2018) (low RoB) found significantly elevated HR (average value at steady state and % maximum, respectively) in obese/overweight compared with non-obese groups. Three studies (Cavuoto & Maikala, 2015; Marra et al., 2014; Sangachin & Cavuoto, 2016) (low, high and moderate RoB) found no difference in HR measures (peak, average and % change from baseline) between groups. Consequently, there was limited evidence for the effects of obesity on HR response to repetitive lifting. When effect sizes were pooled, there was an overall significant difference in standardised mean difference in HR responses between population groups (mean effect = 0.606; $p = 0.01$) (Fig. 8).

Based on two studies, there was limited evidence for the effects of obesity on VO_2 and VCO_2 when repetitive lifting. Lemus et al. (2022) (low RoB) found significant increase in steady state average VO_2 (ml/min) in obese/overweight compared with healthy weight handlers (p <

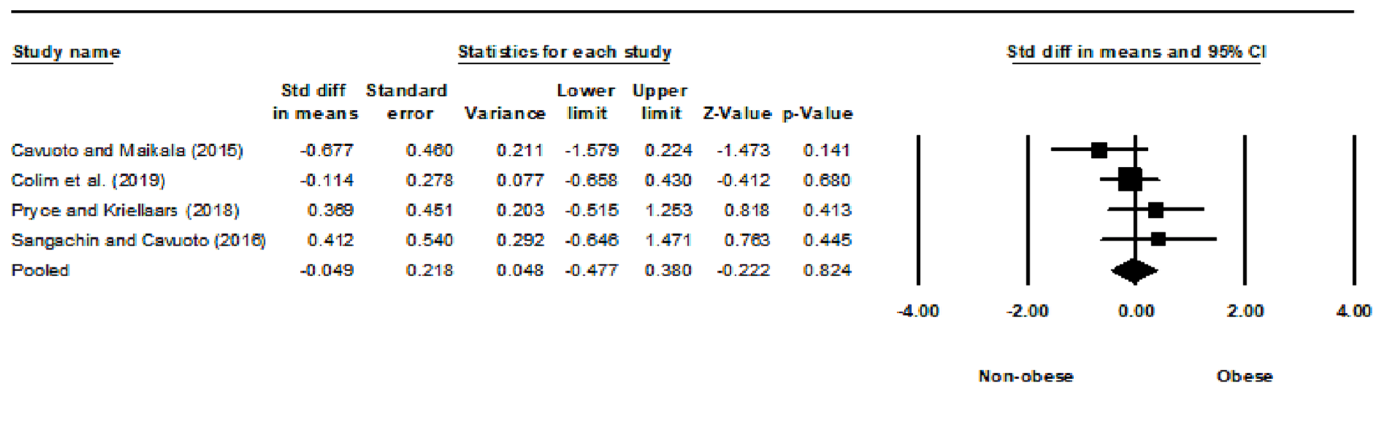
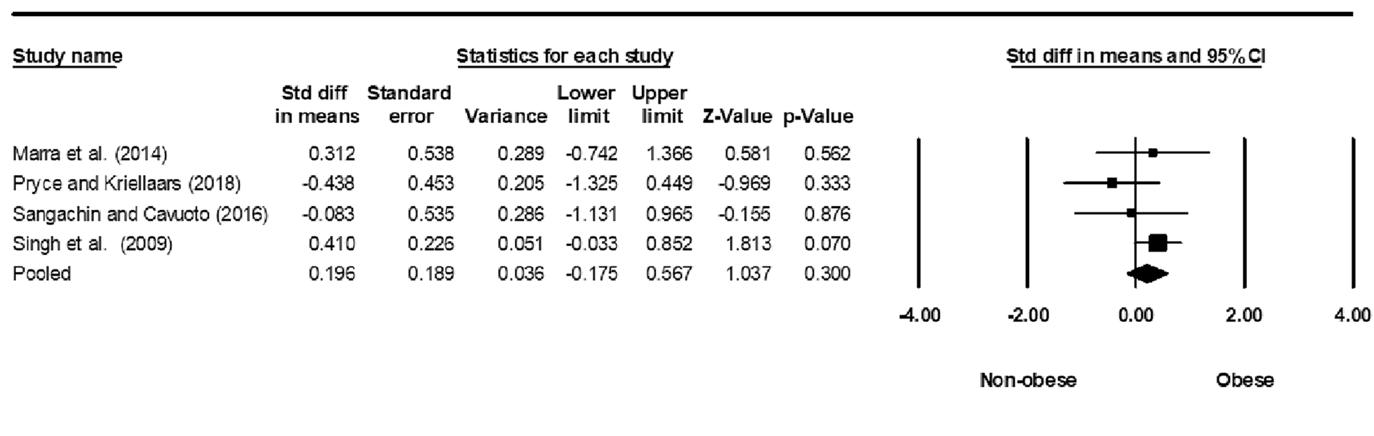
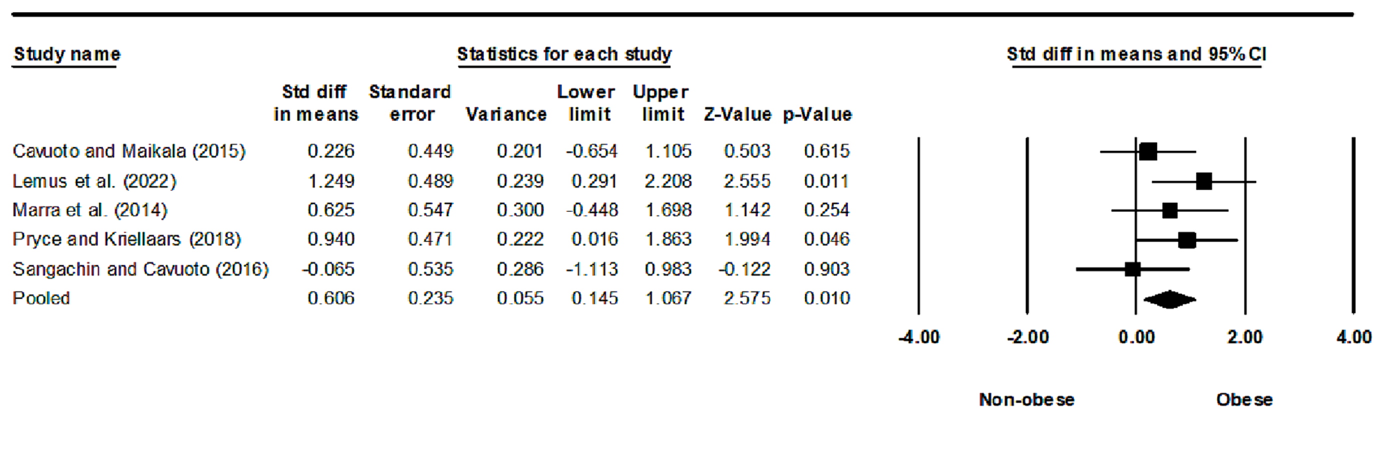


Fig. 6. Meta-analysis using a random-effects model of the standardised mean difference in whole body ratings of perceived exertion (RPE) between obese and non-obese handlers when lifting. Heterogeneity: Q-value = 3.511, P-value = 0.319; $T^2 = 0.029$; $I^2 = 14.5$ %.



Study name	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Marra et al. (2014)	0.312	0.538	0.289	-0.742	1.366	0.581	0.562
Pryce and Kriellaars (2018)	-0.438	0.453	0.205	-1.325	0.449	-0.969	0.333
Sangachin and Cavuoto (2016)	-0.083	0.535	0.286	-1.131	0.965	-0.155	0.876
Singh et al. (2009)	0.410	0.226	0.051	-0.033	0.852	1.813	0.070
Pooled	0.196	0.189	0.036	-0.175	0.567	1.037	0.300

Fig. 7. Meta-analysis using a random-effects model of the standardised mean difference in maximum acceptable weight of lift (MAWL) between obese and non-obese handlers. Heterogeneity: Q-value = 3.169, P-value = 0.366; T^2 = 0.01; I^2 = 5.3 %.



Study name	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Cavuoto and Maikala (2015)	0.226	0.449	0.201	-0.654	1.105	0.503	0.615
Lemus et al. (2022)	1.249	0.489	0.239	0.291	2.208	2.555	0.011
Marra et al. (2014)	0.625	0.547	0.300	-0.448	1.698	1.142	0.254
Pryce and Kriellaars (2018)	0.940	0.471	0.222	0.016	1.863	1.994	0.046
Sangachin and Cavuoto (2016)	-0.065	0.535	0.286	-1.113	0.983	-0.122	0.903
Pooled	0.606	0.235	0.055	0.145	1.067	2.575	0.010

Fig. 8. Meta-analysis using a random-effects model of the standardised mean difference in heart rate when repetitive lifting between obese and non-obese handlers. Heterogeneity: Q-value = 4.529, P-value = 0.892; T^2 = 0.339; I^2 = 11.7 %.

0.001), whereas Cavuoto and Maikala (2015) (low RoB) found no significant difference in peak absolute VO_2 (ml/min) and VCO_2 between obese and healthy weight lifters.

Back muscle activity measured in two lifting studies showed conflicting evidence, with one study (Colim et al., 2016; Colim et al., 2021) (moderate RoB) reporting significantly higher muscle activity (% of maximum voluntary contraction (MVC)) in obese compared with non-obese, while Tetteh et al. (2009) (moderate RoB) found decreased EMG activity (root-mean-square (RMS) of EMG signal) in the obese/overweight group compared with the non-obese group. For one-handed carrying (10 kg) over short distances, Badawy et al., (2019a) found no significant difference in muscle activity (peak and average %MVC during stance) between groups.

4. Discussion

The aim of this systematic review and *meta*-analysis was to synthesize and critically evaluate the available literature on the effects of obesity on manual handling tasks. The reported outcome measures (biomechanical, physiological, psychophysical) not only provide an evaluation of difference in response to a task but are often used to estimate the risk of musculoskeletal injury.

Whilst there was mixed evidence for the effects of obesity on increased horizontal reach when lifting, *meta*-analysis showed an overall significant effect. This is most likely explained by the larger anthropometric dimensions associated with increased BMI. Obesity is categorised by two main body types, abdominal (android) or peripherally-concentrated distributions (gynoid) of adipose (Cavuoto & Nussbaum, 2014; Stults-Kolehmainen et al., 2012). In those with an android body type, adipose accumulates around the abdomen, while those with peripheral body types, the adipose build up is predominately around the hips and thighs. Increases to these dimensions will likely lead to greater anterior reach during handling tasks, compared with those of a healthy weight.

Reach distance is an important independent variable incorporated into many manual handling risk assessment methods (e.g. National Institute for Occupational Safety and Health (NIOSH) lifting equation (Waters et al., 1993)). When lifting, increases to reach distance results in higher moments and compression forces on the lower spine. In a group of participants with high central adiposity (CA), Pryce and Kriellaars (2014) showed that between 30 % and 70 % of the compressive force on the spine was independent of body mass and a result of the task. The compressive forces were primarily due to the physical restriction created by the trunk and the increased moment arms of the external load and limb segments. Interestingly, Pinder and Frost (2011) investigated a number of manual handling tasks in industry and found a positive, linear associated between horizontal reach and work-related lost time injuries due to lower back pain, such that a 10 cm increase in reach distance resulted in a 25 % increase in lost time injuries (OR = 1.25, 95 % CI 1.04–1.49).

Evidence of altered sagittal trunk flexion, sagittal trunk acceleration and lifting duration between obese and healthy weight participants was equivocal. These findings may reflect the variation in lifting tasks and lifting strategies adopted between studies, particularly where repetition and fatigue may be an influencing factor. Galli et al. (2000) found that obese adults (BMI = 40 kg/m^2) with low back pain initially adopted reduced trunk flexion and increased ankle dorsiflexion for a sit-to-stand task in comparison to the healthy weight group. However, with repeated trials the obese participants resorted to a similar movement strategy to that of the healthy weight participants. The authors hypothesised that whilst the obese group may have initially wanted to protect their spine, protection became of secondary importance to fatigue.

Mixed findings for the effects of obesity on sagittal trunk flexion when lifting may arise from the different measurement methods, and definitions of trunk posture between studies. For example, trunk measures ranged between gross trunk angle (line joining L5/S1 and C7 spinous processes and relative to upright standing) (Colim et al., 2020) to specific regional changes in spine angle (e.g. relative angles of upper (C7-T7) and lower-trunk (T7-hip)) (Pryce & Kriellaars, 2018). Given the multi-segmental joint structure of the spine, these contradictory findings are not surprising. Interestingly, this review found no differences in knee flexion between obese and healthy participants when lifting, which suggests any variations in handling techniques are primarily hip, trunk and upper body-related. As Pryce and Kriellaars (2018) found, participants with high BMI (CA) adopted higher mid-trunk flexion, reduced lower-trunk flexion and increased shoulder flexion compared with those of a normal BMI.

There was moderate evidence for increased peak extension moments on the lower spine (L5/S1) in obese compared with healthy weight participants when lifting (Corbeil et al., 2019; Pryce & Kriellaars, 2018). Reflecting these higher moments, two studies (Pryce & Kriellaars, 2018; Singh et al., 2015) also found obese handlers experienced higher compression forces on the lower spine when lifting. As these compressive forces exceeded the NIOSH recommended 'action limit' (3400 N) (Waters et al., 1993), it was suggested that such forces significantly increased the risk of spinal injury.

The literature appears divided on whether prolonged exposure to increased body weight leads to beneficial adaptations in the material and mechanical properties of the spine (bone mineral density (BMD), bone mineral content (BMC) and end-plate area of the vertebral body), strengthening and protecting the spine against loading (Brinckmann et al., 1989; Hansson et al., 1980). In support of this notion, those studies which normalised back moments to body weight and/or height, showed that resulting differences between obese and healthy weight lifters was negated. However, some studies suggest that obesity lowers BMD/BMC and inhibits bone health (Greco et al., 2010; Pollock et al., 2007). Pollock et al. (2007) reported that excess fat mass potentially compromised the health of adolescent bone and Liuke et al. (2005) reported an association between obesity and disc degeneration. Consequently, the generalisability of the NIOSH guidelines to population groups other than those considered healthy, remains a matter of contention.

The two studies that estimated spinal compression forces used static biomechanical models. A limitation of static models when measuring compression forces is their failure to consider the inertial characteristics of body segments (Pryce & Kriellaars, 2014). During handling tasks, body weight has been shown to be the most significant factor influencing loads on the lower spine (Hajihosseinali et al., 2015; Pryce & Kriellaars, 2014). Obesity will likely lead to non-uniform distribution of body segment weights and alter the inertial characteristics during lifting, thereby influencing estimates of compressive forces.

Moderate evidence suggests that obesity/overweight does not alter the person's perception of MAWL. As MAWL reflects biomechanical and physiological stress, it might be expected that those with additional body weight would experience higher perceptions of stress due to increased workloads. Singh et al. (2009) suggested that the similarity in MAWL between obese and healthy weight handlers was due to the obese handlers' continued exposure to heavier loads, resulting in a desensitising of the physical stress and lowering of their perceptions of the external load. A similar explanation may also apply to whole body RPE when lifting and the lack of evidence for the effects of obesity. The one study that investigated static holding tasks (Park et al., 2009) found elevated RPE in obese compared with the healthy weight handlers. Whilst the amplification of perceived stress from the higher segmental weights and increased joint moments may provide explanation for these differences, the larger body dimensions associated with obesity may also have imposed restrictions on posture and created counteracting forces and discomfort. Singh et al. (2013) found that during seated forward reaching tasks, abdominal-thigh contact forces increased by approximately 10 % of body weight in obese participants (mean BMI = 39 kg/m^2).

The physiological responses to manual handling become increasingly important with repeated and prolonged exposure to a task (Pryce & Kriellaars, 2018). Although there was limited evidence for the effects of obesity on HR measures for repetitive lifting, *meta*-analysis showed a significantly higher HR in the obese handlers compared with those of a healthy weight when study findings were combined. Studies have shown elevated resting and submaximal HR at a given submaximal workload and lower cardiorespiratory fitness in obese compared with those of a healthy weight (Aneni et al., 2015; Hingorjo et al., 2017; Lemus et al., 2022; Yadav et al., 2017). With exercise, HR increases, and there has shown to be a negative, linear relationship between fitness level and BMI, depending on the exercise intensity (Hills et al., 1998; Lemus et al., 2022).

The two studies that measured VO_2 and VCO_2 as measures of physiological task demands found obese participants reached exhaustion faster than their healthier weight counterparts. Hingorjo et al. (2017) showed a strong inverse relationship between adiposity and maximal oxygen consumption (VO_2max), with those classified as obese having a lower VO_2max. The mechanisms leading to reduced cardiovascular fitness and early onset of fatigue in those with high adiposity have been linked to decreased capillary density and reduced blood flow to skeletal muscle (Kern et al., 1999), an increase in arterial stiffness and increased peripheral resistance to blood flow (Vasan, 2003), and a lower percentage of fatigue resistant muscle fibres (Maltin, 2008; Newcomer et al., 2001).

In synthesising the evidence of the effects of obesity on manual handling, this review is limited by the cross-sectional design of included studies. Experimental studies seeking to isolate the effects of obesity on task performance have not yet been undertaken, probably due to their complexity. Although 18 studies were included in the review, participant numbers were low across all studies and most studies lacked information on statistical power and necessary sample size estimates. The application and validity of many of the methods used with obese populations has been questioned, as high body fat may increase measurement errors. For example, skin marker-based systems to determine kinematics are susceptible to adipose tissue displacement and obscuration. Surface EMG is reliant on good electrical conductivity between the skin and underlying muscle and is affected by larger subcutaneous fat deposits.

To address these limitations, future studies need to be of a more robust design and incorporate work tasks and work practices which more closely replicate industry or service sectors. Further research is needed which include a female population to understand differences between the sexes. Studies investigating the effects of obesity on manual handling tasks should consider how body weight is classified; BMI may not be the most appropriate variable on which to differentiate individual characteristics when performing manual handling tasks. Biomechanical modelling approaches used with obese populations also need to adopt improved methods of measurement and analysis, including dynamic modelling of spinal loads and the use of more appropriate kinematic measurements and body segment inertial characteristics. To determine preventive and management approaches, experimental studies should

consider adaptations to training, workplaces, work practices and work organisation, which can better accommodate workers with high body weight. A "one size fits all approach" appears to be an inappropriate strategy.

5. Conclusions

Overall, there was mixed evidence for differences in the kinematics of lifting between obese/overweight handlers and those of a healthy weight. However, pooled estimates of effect sizes suggest obese handlers adopt increased horizontal reach compared with those of a healthy weight. When lifting, there was moderate evidence that obese handlers adopt similar knee postures to those of a healthy weight, and they experience higher moments and compression forces on the lower spine. Pooled estimates of effect sizes showed obese handlers experience higher HR and fatigue earlier than their healthier weight counterparts during repetitive lifting. There was moderate evidence that obese handlers do not perceive MAWL differently to those of a healthy weight. It is recommended that workplace design, work practices and training methods are cognisant of the effects of obesity on manual handling to better prevent and manage work-related musculoskeletal conditions.

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CRediT authorship contribution statement

Mark Boocock: Conceptualization, Data curation, Visualization, Writing – original draft, Writing – review & editing, Validation, Formal analysis, Investigation, Methodology, Project administration, Supervision. **Yanto Naudé:** Conceptualization, Investigation, Methodology, Validation, Visualization, Writing – review & editing. **Nicola Saywell:** Visualization, Writing – review & editing, Conceptualization, Methodology. **Grant Mawston:** Conceptualization, Investigation, Methodology, Validation, Writing – review & editing.

Declaration of competing interest

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

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Appendix A. Keywords and search strategy used with the EBSCO Health database

Database: EBSCO Health (Medline + CINAHL + SportsDiscus)
Search 1 (Overweight individuals)
(obese OR obesity OR overweight OR fat OR "Corpulence")
OR
(high OR elevated OR extreme OR severe) N3 (BMI OR "body mass index" OR "body weight" OR "Central adiposity" OR "adipose tissue")
Search 2 (Manual material handling)
("Manual hand*" OR "manual material* handl*" OR "Manual load*" OR "Load handl*" OR "material* handl*" OR lift* OR push* OR Pull*)
OR
(carry* OR carrying) N3 (load* OR weight* OR task* OR object*)
Search 3 (Biomechanics/physiology/psychophysics)
biomechanic* OR spine OR spinal OR lumbar OR trunk OR kinetic* OR kinematic* OR "disc compression" OR "low* back" OR "compression force*" OR "shear force*" OR "lumbar moment*" OR "L5/S1″ OR "back injur*" OR physiolog* OR psychophysic* OR Borg OR MAWL OR "maximum acceptable weight of lift" OR "perceived exertion" OR electromyography OR EMG OR "muscle activity" OR exertion OR "heart rate" OR fatigue OR "oxygen consumption"
Combined
Search 1 + 2 + 3.

Appendix B. Evidence synthesis (adapted from Institute for Work and Health, 2023)

Level of evidence	Minimum quality*	Minimum quantity	Consistency	Strength of message
Strong	High (H)	3	3H agree; If 3+ studies, ≥3/4 of the M & H agree	Recommendations
Moderate	Medium (M)	2H or 2 M & 1H	2H agree or 2 M & 1H agree; If 3+, ≥ 2/3 of the M & H agree	Practice considerations
Limited	Medium (M)	1H or 2 M or 1 M & 1H	2 (M and/or H) agree; If 2+, >1/2 of the M & H agree	Not enough evidence to make recommendations or practice considerations
Mixed	Medium (M)	2	Findings are contradictory	
Insufficient	Medium quality studies that do not meet the above criteria			

*High quality = low RoB when the score ≥ 70 % in quality assessment; Medium quality = moderate RoB score ≥ 50 % and < 70 %

Appendix C. A summary of extracted data from studies included in the review

Author	Participants	Body weight classification	Manual handling task	Methods	Dependent measures	Main findings (obese/ overweight vs healthy)	Conclusion
Badawy et al., (2019a) and Badawy et al., (2019b)	20 males, 4 groups: Young/Obese (YO) Young/Non-obese (YNO) Older/O (OO) Older/NO (ONO) Mean (±SD) YO age (yr) 29.1 (4.5) YNO age (yr) 25.4 (2.1) OO age (yr) 60.1 (0.8) ONO age (yr) 59.7 (3.5)	Groups stratified according to BMI: O BMI ≥ 30 kg/ m^2 NO BMI < 25 kg/m^2 Mean (±SD) YO BMI (kg/m^2) 35 (4.7) YNO BMI (kg/ m2) 23.7 (0.7) OO BMI (kg/m^2) 31.9 (1.4) ONO BMI (kg/ m^2) 22.9 (0.9)	One handed carrying, 6 m walking, 3 loads: 0, 5.67 & 10.21 kg	Electromyography (EMG) 3D motion capture and skin mounted markers 3D ground reaction forces 3D biomechanical model	6 bilateral muscles – peak and average % MVC during stance Walking speed 3D trunk angles 3D L4/L5 moments (absolute and normalized (% BW*Ht))	EMG – non-significant (NS) for 12 muscles Walking speed NS Peak trunk angles NS Absolute L4/L5 moments ↑ L4/L5 normalised moment NS	Obese handlers exhibit similar muscle activity as healthy weight handlers when carrying 10 kg for short distances Changes to trunk kinematics and kinetics are not dependent on age or obesity
Badawy et al. (2018)	12 adult males, two groups:Obese (O) (n = 6) Non-obese (NO) (n = 6) Mean (±SD) O age (yr) 28.8 (4.1) NO age (yr) 26 (2.4)	Groups stratified according to BMI: O BMI ≥ 30 kg/ m^2 NO BMI < 25 kg/m^2 Mean (±SD) O BMI: 34.2 (2.5) kg/m^2 NO BMI: 22.6 (1.5) kg/m^2	One handed carrying –0, 5.67 & 10.21 kg	Heart rate (HR) Ratings of perceived exertion (RPE): 15-point Borg Scale	Change in HR (ΔHR) = HR during load condition – resting HR RPE – whole body (WB), arm (A), back (BK)	ΔHR NS RPE (A) ↓ RPE (BK & WB) NS	10 kg can be considered a comfortable load to carry by young adult obese males
Cavuoto and Maikala (2015)	20 males from the local community, 2 groups: O (n = 10) NO (n = 10) Mean (±SD) O age: 29.7 (4.4) yr NO age: 27.2 (5.1) yr	Groups stratified according to BMI: O 30 < BMI < 40 kg/m^2 NO 18.5 < BMI < 25 kg/m^2 Mean (±SD) O BMI: 34.2 (2.5) kg/m^2 NO BMI: 22.6 (1.5) kg/m^2	Symmetrical lifting (only) 10 lifts/min,5 kg, 2 kg added/2 min	Metabolic analyzer HR monitor Cerebral hemodynamics – near-infrared spectroscopy (NIRS) RPE: Borg's 6 to 20 scale	*Peak responses* HR Oxygen uptake (VO2) Ventilation (VE) Carbon dioxide production (VCO_2) Respiratory equivalent ratio (RER) Oxygen pulse partial pressure of end-tidal carbon dioxide ($PetCO_2$) Cerebral hemodynamicsRPE: WB, BK, A	Load lifted (kg) ↓ Lifting duration (min) ↓ Ventilation rate (l/ min) NS Absolute oxygen uptake (l/min) NS Relative oxygen uptake (ml/min/ kg) ↓ Oxygen uptake by BMI (ml/m2/kg/ min) ↓ Oxygen uptake by BAI (ml/min/% adiposity) ↓ Oxygen uptake per load lifted (ml/ min/kg) NS Carbon dioxide production (l/min) NS Heart rate (beats/ min) NS Oxygen pulse (ml/ beat) NS Respiratory exchange ratio NS Breathing frequency (breaths/min) NS Ventilatory equivalent ratio for oxygen NS Partial pressure of end-tidal carbon dioxide (mm Hg) NS *Cerebral hemodynamics responses (peak O2)* O^2Hb NS HHb NS tBV NS	Acute exposure to repetitive lifting decreases cardiorespiratory responses and cerebral hemodynamics in obese handlers, which may contribute to their reduced lifting capacity

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Author	Participants	Body weight classification	Manual handling task	Methods	Dependent measures	Main findings (obese/ overweight vs healthy)	Conclusion
						TOI NS THI NS TOI per body mass (%/kg) ↓ THI per body mass (%/kg) NS RPE (WB) NS RPE (BK) NS RPE (A) NS	
Colim et al. (2021) and Colim et al. (2016)	14 university staff and students Very high O (n = 5) High O (n = 4) Normal (n = 5) Mean (±SD) Very high O (n = 5) age: 36.2 (±14.6) yr High O (n = 4) age: 26 (±6.9) yr Normal (n = 5) age: 24.8 (±3.1) yr	Bioelectrical impedance used to classify 3 groups: Very high O (n = 5) High O (n = 4) Normal (n = 5) Groups conformed to BMI: Very high O BMI ≥ 30 kg/m^2 High O BMI ≥ 25 kg/m^2 Normal BMI < 25 kg/m^2	Symmetrical lifting & lowering of a box (knee to shoulder height) 3 loads: 5, 10 and 15 kg 2 techniques: free and constrained (box behind a barrier 60 cm high)	Bilateral surface EMG muscle activity of right and left: • erector spinae (iliocostalis) at L2 (RI, LI); • erector spinae (longissimus) at L1 (RL, LL); • deltoideus anterior (RD, LD)	EMG normalized: % of mean amplitude/ peak value for each task (MCT%) Muscle Activation Times (AT)	BFM ↑ positively related to the ↑ in MCT% for all muscles Obesity*load interaction↑ between 5 and 10 kg ↓ between 10 and 15 kg, with higher values in obese Barrier constraint NS AT ↑ for: 10 kg constrained lifting LL 15 kg constrained lifting RI	Load affects muscle activity differently in obese and normal weight participants (higher values in obese) The different workstation configurations did not affect muscle activity in O and NO participants
Colim et al. (2020)	16 participants (8 males and 8 females) with no manual handling experience (students, researchers, and professors) Mean (±SD) O (4 M and 4F) age: 35.1 (4) yr NO (4 M and 4F) age: 29.4 (3.9) yr	Groups stratified according to BMI: O BMI ≥ 30 kg/ m^2 NO BMI < 25 kg/m^2 Mean (±SD) O BMI 33.7 (3.3) kg/m^2 NO BMI 22.7 (1.7) kg/m^2	Symmetrical lifting & lowering of a box (knee to shoulder height) 2 loads: 7 & 14 kg 2 techniques: free & constrained (box behind a barrier 60 cm high)	10 camera motion capture system 14 reflective markers attached to anatomical landmarks on the body	Duration of lift and lower Horizontal reach distance (force application – L5/S1 joint *Joint angles* Trunk flexion – C7 to L5/S1 (relative to upright standing) Knee flexion – greater trochanter to knee (relative to upright standing) Pelvis inclination – mid-points of greater trochanters and anterior superior iliacs (ASI) (relative to floor)	Lift/lower duration NS for most task conditions (except – lowering 14 kg free style) Load * group interaction O ↓ durations for higher loads Horizontal reach distance NS for most task conditions (except lowering 7 kg and 14 kg with constraint) Sagittal trunk flexion ↑ in O for most tasks (except lowering 14 kg with constraint) Knee flexion and pelvis inclination NS for all tasks	O handlers seem to be exposed to a ↑ risk for WMSD, as supported by the observed kinematic differences Results highlight the importance of designing workstations and evaluating tools that take into consideration O workers
Colim et al. (2019)	51 participants (26 M and 24F) of working age, and profession with similar physical requirements Mean (±SD) Age = 32.8 (9.6) yr	Groups stratified according to BMI: O & OW (n = 26) BMI ≥ 25 kg/m^2 NO (n = 24) BMI < 25 kg/m^2 % body fat mass (%BFM) measured by bioelectrical impedance	Symmetrical, infrequent (1 lift) box lifting and lowering between knee and shoulder height 3 loads: 5, 10 and 15 kg 2 techniques: free and constrained (box behind a barrier 60 cm high)	Ratings of Perceived Exertion (RPE) – Borg Category Ratio-10 (CR-10) scale, 0 to 10 with 10 defined as extremely high physical intensity	RPE score – median, minimum, and maximum RPE score for lifting and lowering	RPE scores (median) NS BMI negatively correlated with RPE scores for some conditions: Lifting, 10 kg without barrier & 15 kg with barrier Lowering, 10 kg without barrier, 15 kg without barrier,15 kg with barrier	Differing perceptions of physical overload may be related OW and O individuals being continually exposed to greater physical loads Special attention should be paid to OW and O workers, and the use of a psychophysical approach to assess risk in these workers does not seem the best risk assessment method
Corbeil et al. (2019)	37 male participants with manual handling experience Mean (±SD) O (n = 17)	Body weight classification not reported BMI of 2 groups (O and NO) statistically	Asymmetric box transfer between conveyor and trolley (90° and 1.5 m away)	3D motion capture and skin mounted markers 3D Ground reaction forces 3D linked segment biomechanical model	Lumbar flexion Lumbar lateral bending Lumbar torsion Horizontal distance of the hands from L5/S1 Knee flexion at the	Joint angles NS Horizontal distance of the hands from L5/S1 NS Body weight and	Excess weight of an obese worker has a deleterious effect on the external loading of the musculoskeletal structures of the back

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Author	Participants	Body weight classification	Manual handling task	Methods	Dependent measures	Main findings (obese/ overweight vs healthy)	Conclusion
	age: 34.0 (7.2) yr NO (n = 20) age: 25.3 (6.9) yr	different Mean (±SD) O BMI: 31.4 (1.5) kg/m^2 NO BMI: 21.9 (1.1) kg/m^2	4 box weight/ type: 15 kg, 23 kg, 15 kg weakened box, 15 kg (centre of gravity offset) 4 box heights (stacked) Freestyle technique		peak resultant moment L5/S1 net and normalised flexion/ extension, and asymmetric moment	external moments at L5/S1 – linear association Peak sagittal moment – box height × group ↑ differences for boxes closest to ground O handlers experienced ↑ moments when placing boxes Peak asymmetric resultant moments –O experienced ↑ moment for both box weights Normalized peak L5/S1 sagittal moment – NS for most conditions, except lifting the 23-kg box (O experienced ↓ moments)	The morphology of the obese handler also limits the possibility of bringing the load closer, which reduces their margin of manoeuvre Obese handlers are at greater risks of developing an MSD from manual materials handling than healthy-weight handlers
Lemus et al. (2022)	30 participants recruited from Miami-Dade metropolitan area and stratified into 3 groups of 10 Mean (±SD) O (5 M, 5F) age 30.4 (11.2) yr OW (5 M, 5F) age 37.5 (13.0) yr NO (5 M, 5F) age: 29.7 (11.1) yr	Groups stratified according to BMI: O BMI ≥ 30 kg/m^2 OW 25 ≤ BMI ≤ 29.9 kg/m^2 NO 18.5 ≤ BMI ≤ 24.9 kg/m^2 Mean (±SD) O BMI 36.1 (8.0) kg/m^2 OW BMI 26.9 (1.2) kg/m^2 NO BMI 22.5 (2.1) kg/m^2	Symmetrical, repetitive box lifting and lowering from floor to table Frequency = 6 lifts/min, 20 min duration Freestyle technique Box weight: 12.5 kg	Carbon dioxide production (VCO2) Oxygen consumption (VO2) Heart rate (HR)	VCO2 VO2 HR Respiratory exchange ratio (RER) = VCO2/ VO2 Energy expenditure rate (EER) kcal/min = 3.94*VO2 (ml/min) + 1.11*VCO2 (ml/min) Analysis conducted on final 5–10 mins of steady state measures	VCO2 ↑ VO2 ↑ HR ↑ EER ↑ RER NS Significant positive relationships between BMI and: • VCO2 (R^2 = 59.7 %, $p < 0.001$) • VO2 (R^2 = 45 %, $p < 0.001$) • HR (R^2 = 21.9 %, $p = 0.009$) • EER (R^2 = 50.8 %, $p < 0.001$)	Obese subjects (80 %) exceeded the NIOSH energy expenditure safety limit (4.7 kcal/ min), suggesting that these individuals would be at increased risk for workplace injury as compared to their overweight and normal counterparts
Lussier et al. (2010)	15 male experienced and 15 novice workers Mean (±SD) Experienced (n = 15) age 38.1 (9.8) yr Novices (n = 15) age 25.0 (5.9) yr	Groups stratified according to BMI:OW: BMI > 25 kg/m^2 (n = 10 experienced; n = 6 novice) NO: 20 ≤ BMI ≤ 25 kg/m^2 (n = 5 experienced; n = 9 novice)	Box transfer –96 cm height to hand trolley, 1.50 m away, frequency not specified Load 23 kg Freestyle technique	Large force plate and optoelectronic system	Destabilizing force (Fd): force applied to body's centre of gravity to bring the center of pressure outside the base of support A higher destabilizing force, more stable participant Fd measured during the lifting and deposit phase, and midpoint of task	Lifting phase – ↓ BMI ↓ Fd (less stable) No interaction between BMI and experience Deposit phase ↑ BMI ↑ Fd (more stable) A small interaction between BMI and experience	BMI is a contributing factor to stability among experienced workers who appear to be more stable when manual handling Experience and body mass distribution could influence the handling strategy adopted by workers and are important for ensuring postural stability
Marra et al. (2014)	14 male college students O (n = 7) age: 23.7 (4.3) yr NO (n = 7) age: 20.0 (1.7) yr	Groups stratified according to BMI: O BMI > 30 kg/m^2 NO BMI < 25 kg/m^2 Mean (±SD) O BMI 33.2 (3.2) kg/m^2 NO BMI 22.3 (1.9) kg/m^2	Symmetrical box lift (only) from floor to knuckle height Frequency: 4 lifts/min Duration: three 20 min periods 2 min rest after 20 mins of lifting	BioHarness 3 chest Strap (HR, trunk flexion and acceleration) Digital camera (skin mounted markers) Maximum acceptable weight of lift (MAWL) for each 20 min RPE scale (Borg CR-10)	Trunk kinematics – flexion, range of motion (RoM)and acceleration Average and peak trunk acceleration during each lift % change in acceleration over each 20 min period HR increase (baseline, start of 1 h period to end) MAWL: average weight for 2nd and 3rd lifting	Peak trunk flexion NS Trunk RoM NS Average and peak acceleration NS HR NS HR increase ↓ MAWL NS RPE NS	Obese and non-obese individuals adopted similar lifting strategies and these strategies remained consistent over an extended period (60 mins)

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Author	Participants	Body weight classification	Manual handling task	Methods	Dependent measures	Main findings (obese/ overweight vs healthy)	Conclusion
					segment RPE every 5 min		
Pajoutan et al. (2017)	Twelve young male university students (O n = 6; NO n = 6) Age not reported	Groups stratified according to BMI: O 30 < BMI < 40 kg/m^2 NO 18 < BMI < 25 kg/m^2 Mean (±SD) O BMI 33.3 (3.3) kg/m^2 NO BMI: 22.0 (2.1) kg/m^2	Symmetrical & asymmetrical (45°) box lift from floor to mid-chest Freestyle lifting Box weight: 10 % & 25 % of max back extension torque at 45° flexion 6 lifts in each trial for 1 min (1 lift/10 s) Fixed feet position	3D force plates	Centre of pressure (COP) Oscillation amplitudes in the medial–lateral (ML) & anterior-posterior (AP) directions (ML, AP) (mm) COP displacement divided by lifting time (SP, mm/s) Area swept by COP (SA, mm^2/s) divided by lifting time Frequency band in ML and AP directions (FB_ML, FB_AP) (Hz) Sample entropy (ML SampEn and AP SampEn) Last 4 lifts used to calculate each measureGround reaction forces normalized to subject's body weight	SP ↓ SA ↓ ML NS AP NS ML SampEn ↑ AP SampEn ↑ FB_ML NS FB_AP NS	Non-linear time series analysis of the COP trajectory indicated that the reduced postural sway reflects better balance control with obesity Lifting task orientation was a substantial factor for all dependent variables and interacted with obesity
Park et al. (2009)	40 participants from the Greater Cincinnati & Northern Kentucky area Mean (±SD) O (n = 20, M = 10, F = 10) age 31.2 (9.7) yr NO (n = 20, M = 10, F = 10) age 30.8 (9.1) yr	Groups stratified according to BMI: O BMI > 30 kg/m^2 NO 18.5 kg/m^2 < BMI < 24.9 kg/m^2 Mean (±SD) O BMI 46.3 (5.0) kg/m^2 NO BMI: 22.5 (1.8) kg/m^2	Static (20 s) box holding (5 kg) in 84 postures associated with Ovako Working Posture Analysing System (OWAS) 2 min or more between posture, postures randomized	RPE (Borg CR-10 scale)	RPE following each holding task	RPE ↑mean = 5.60 ('strong' and 'very strong') vs 2.52 ('weak' and'moderate') Strong linear relationship between O vs NO mean RPE pairs	Obesity significantly increased postural stress across all posturesErgonomic workplace/job designfor obese workers is challenging and requires a proactive approach
Pryce and Kriellaars (2018)	20 male participants Mean (±SD) Central adiposity (CA) (n = 10) age 41 (10.7) yr NO (n = 10) age 35.6 (10.1) yr	Groups stratified according to BMI: CA BMI > 29 kg/m^2 NO BMI < 25 kg/m^2 CA defined as waist-to-hip (W:H) ratio ≥ 0.9 and waist circumference (WC) > 102 cm Mean (±SD) CA BMI 33 (3.3) kg/m^2 WC: 111.8 (6.8) cm W:H: 0.98 (0.03) NO BMI: 23.3 (2.1) kg/m^2 WC: 80.5 (6.2) cm W:H: 0.84 (0.08) Grip: 50.3 (8.6) kg	Symmetrical box lifting (only) from floor to shelf (height: 76 cm; distance: 45 cm) Box weight: self-selected MAWL Duration: 3 sets of 20-min (5 min inter-set rest) Frequency: 4 lifts/min (1 lift every 15 s; 80 lifts/set) Freestyle lifting	2 digital cameras and video annotation tool to determine end points of each segment Wireless, tri-axial accelerometers Static biomechanical model Polar HR monitor MAWL RPE- modified Borg scale (6–20 scale)	Joint angles (hip. mid & lower trunk, knee, ankle, shoulders) Peak trunk acceleration Box distance from ankle and hip Lift duration (ascent) Resultant joint moment L5/S1 compressive and shear forces External mechanical work of box or head/ arms/trunk (HAT) centre of masses (CM) Average power HRmax – percent of age-adjusted maximum MAWL RPE WB, Low back (LB), Lower (LE) & upper extremity (UE)	Joint flexion Mean (±standard error (SE)) Hip ↓ Lower trunk ↓ Mid-trunk ↑ Shoulder ↑ Box position Ankle at origin ↑ Hip at destination ↑Lift duration Duration during sets 2 and 3 ↓ Peak trunk and box accelerations NS Vertical displacement of the HAT CM Displacement ↓ L5/S1 torque @ origin/destination ↑ L5/S1 compression @ origin/destination ↑ L5/S1 shear force @ origin/ destination ↑ Work (per session) – HAT + box NS Power (per rep)-	Individuals with CA and/or high BMI will be differentially exposed to mechanical load during long-duration lifting The mismatch between exertion and mechanical/ physiological loading is a disconcerting feature that may further increase injury risk. Observed CA-specific adaptations appeared to be aimed at minimizing mechanical and physiological loading, but are not part of current instructional approaches, which may not be effective for individuals with CA

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Author	Participants	Body weight classification	Manual handling task	Methods	Dependent measures	Main findings (obese/ overweight vs healthy)	Conclusion
						HAT + Box ↑ MAWL NS RPE WB, LB, LE & UE NS HRmax ↑	
Sangachin and Cavuoto (2016)	14 male university students Mean (±SD) O (n = 7) age 24 (4.1) yr NO (n = 7) age 19.7 (1.4) yr	Groups stratified according to BMI: O BMI > 30 kg/m^2 NO 18.5 < BMI < 25 kg/m^2 O BMI 33.2 (3.2) NO BMI 22.2 (1.5) Body fat percentage measured using a BC-568 InnerScan Segmental Body Composition Monitor	Symmetrical box lifting (only) from floor to a shelf at knuckle height Box weight: 20 % above MAWL O 21.2 (5.1) kg NO 21.2 (3.5) kg Duration: 3 sets of 20-mins (2 min inter-set rest) Frequency: 4 lifts/min; 80 lifts/set) Freestyle lifting	BioHarness 3 (HR, trunk flexion and acceleration)Wireless accelerometers (upper and lower body kinematics)	Sagittal trunk inclination – total and percentage time in neutral (<20°), mild (20° < and < 45°) and severe (45° <) flexion Lower back RoM Thigh RoM Movement coordination Lift duration Trunk acceleration and jerk (sagittal anterior and posterior, coronal, transverse, total) – root-mean-squared (RMS) amplitude of jerk HR (HRmax) HR changes from baseline (HR change) RPE (Borg CR-10) WB (every 5 mins)	Statistical significance level p = 0.1 Peak sagittal trunk flexion ↓ (p = 0.023) % time in neutral, mild and severe flexion NS Lower back RoM NS Thigh RoM NS Peak trunk acceleration (all) NS RMS jerk ↓ (p = 0.072) Lifting tasks duration ↑ (p = 0.051) Upper body and lower body midpoint (time at which half of the change in the angle had occurred) ↑ (p = 0.044) HR final ↓ (p = 0.031) HR change NS MAWL NS	Obese participants extended the lifting time and adopted a more stooped lifting strategy, possibly to benefit from a more biomechanically and energetically advantageous lifting pattern Although the majority of lifting variables were unaffected by BMI or its interaction with prolonged lifting, the differences, combined with a greater upper body mass, necessitate a more cautious use of existing psychophysical lifting limits for individuals who are obese, particularly when fatigued
Singh et al. (2015)	40 participants from the Greater Cincinnati and Northern Kentucky area Mean (±SD) O (n = 20; M = 10, F = 10) age: 31.6 (6.56) yr NO (n = 20; M = 10, F = 10) age 30.1 (7.68) yr	Groups stratified according to BMI: O (Severely obese) BMI > 35 kg/m^2 NO 18.5 < BMI < 24.9 kg/m^2 Mean (±SD) O BMI 45.96 (7.85) kg/m^2 NO BMI 22.4 (1.66) kg/m^2	16 symmetrical and asymmetrical lifting conditions: 4 initial locations: 2 vertical (25 cm and 35 cm), 2 angles (0° and 105°), horizontal distance 30 cm 4 final locations: 2 horizontal distances (48 cm and 60 cm), 2 vertical (93 cm and 144 cm), angle 0° Freestyle lifting Box weights – NIOSH recommend weight limit (RWL) for origin and destination 32 lifts randomized with rest in between	VICON motion capture system and optical markers on anatomical landmarks 3D static low back biomechanicalmodel	L5/S1 disc compression forces	*Lift origin*L5/S1 disc compression ↑ *Destination*L5/S1 disc compression ↑	99.5 % of L5/S1 compression forces for severely obese participants ranged from 3000 N to 8500 N and many exceeded the 3400 NNIOSH action limit by large margins Severely obese individuals are likely to be at an increased risk of lifting-related low back pain compared with normal weight individuals
Singh et al. (2009)	60 participants (students, office workers and 3 yr manual handling experience) from	Groups stratified according to BMI: EO BMI > 40 kg/m^2	Symmetrical box lifting to/ from moveable shelf 18 different	Self-selected MAWL suitable for 8 h/day MAWL adjustment period approximately 25 min per trial	MAWL (average of 2 lifts and within 15 %) for each condition	MAWL NS Obesity (interaction), p = 0.0069 Mean MAWL of	Obesity does not influence MAWL Since MAWL of obese individuals were similar or even slightly

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Author	Participants	Body weight classification	Manual handling task	Methods	Dependent measures	Main findings (obese/ overweight vs healthy)	Conclusion
	Greater Cincinnati and Northern Kentucky Mean (±SD) Extreme obese (EO) (M, n = 10; F, n = 10) age (M) 32.6 (9.56) yr; (F) 32.5 (10.4) yr Moderately obese (MO) (M, n = 10; F, n = 10) age (M) 34.5 (11.6) yr; (F) 31 (11.9) yr NO (M, n = 10; F, n = 10) age (M) 30 (8.7) yr; (F) 32.2 (10) yr	MO (n = 20; M = 10, F = 10): 35 kg/m^2 < BMI < 39.9 kg/m^2 NO 18.5 < BMI < 24.9 kg/m^2 Mean (±SD) EO BMI (M) 47.8 (9.9) kg/m^2; (F) 43.7 kg/m^2 MO BMI (M) 37.1 (1.6) kg/m^2; (F) 37.2 (1.4) kg/m^2 NO BMI (M) 22.6 kg/m^2; (F) 22.2 (2) kg/m^2	lifting conditions, two repetitions for each condition: 3 lifting heights Floor-to-knuckle (F–K), Knuckle-to-shoulder (K–S), Shoulder-to-arm reach (S–A) 6 lifting frequencies: one lift every 5, 9, 14 s, 1 min, 30 min and 8 h Freestyle lifting	36 trials randomised with 6 trials/day		the moderately obese and extremely obese groups were similar @ high frequency, as were MAWL for moderate and non-obese at low frequencies	higher than those of non-obese across various lifting conditions, it may not be necessary to develop new psychophysical lifting limits to protect obese workers
Tetteh et al. (2009)	30 male participants from a truck-manufacturing company in Dallas–Fort Worth metro area, Texas Mean (±SD) O (n = 15) age 36.6 (10.7) yr NO (n = 15) age 33.5 (8.6) yr	Groups stratified according to BMI: O BMI ≥ 25 kg/m^2 NO BMI < 25 kg/m^2 Mean (±SD) O BMI 29.6 (4.4) kg/m^2 NO BMI 22.2 (1.6) kg/m^2	Symmetrical lifting and lowering a small electric motor (6.89 kg) between 3 shelves, as observed at a factory Shelf heights: 13 cm, 53 cm and 143 cm *Basic task:* lifting from lowest shelf to highest and back *Advanced task*: lifting from lowest shelf to highest, to middle, and back to lowest 3 postures: 0 (sagittal), 30° and 60° to right side of the body Repeated 10x	Bilateral EMG of 4 upper back muscles: • Trapezius p. descendens, • Deltoideus p. scapularis • Infraspinatus • Latissimus dorsi	RMS of the raw EMG value Task completion time	Trapezius p. descendens ↓ Deltoideus p. scapularis ↓ Infraspinatus NS Latissimus dorsi NS Completion time ↓ BMI and mean completion time negatively correlated (r = 0.469; p = 0.009)	The effects of BMI are relative to the extent of the involvement of the muscles in conducting the task The variation in BMI does not have a significant influence on fatigue
Xu et al. (2008)	12 male participants from the North Carolina State University student body and surrounding community Mean (±SD) O (n = 6) age:? yr NO (n = 6) age:? yr	Groups stratified according to BMI: O BMI > 30 kg/m^2 NO BMI < 25 kg/m^2 Mean (±SD) O BMI 33.3 (3.3) kg/m^2 NO BMI 22 (2.1) kg/m^2 O Max trunk extension torque: 191.8 (24.9) Nm NO Max trunk extension torque: 171.6 (20) Nm	Symmetrical and asymmetrical box lifting from floor to mid chest height Start positions: directly in front and 45° to right of the mid-sagittal plane Box weight: 10 % and 25 % max trunk extension torque 6 lifts per trial in 1 min (one lift every 10 s) Randomised and repeated 3x Box handles 19 cm above ground, 51 cm from mid-ankles Freestyle lifting (feet position	Lumbar Motion Monitor (LMM): trunk kinematics 2 force plates: ground reaction force:	Trunk angles – peak sagittal flexion and rotational (transverse) positions Trunk velocity –peak sagittal and rotational extension velocity Trunk acceleration – peak sagittal extension and rotational acceleration Ground reaction forces (right) normalised to body weight – peak lateral and anterior shear, coefficient of friction Last 4 lifts of each trial analysed	Transverse trunk velocity ↑ Transverse trunk acceleration ↑ Sagittal trunk velocity ↑ Sagittal trunk acceleration ↑ Peak trunk transverse position NS Peak trunk sagittal flexion angle NS Ground reaction forces NS	The dynamics of lifting were greater for the obese group than the normal weight group and bring into question the utility of BMI as a measure of obesity and may explain why there has been only limited evidence of a positive relationship between BMI and the incidence ofLBP in the epidemiological literature

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Author	Participants	Body weight classification	Manual handling task	Methods	Dependent measures	Main findings (obese/ overweight vs healthy)	Conclusion
			fixed) 1 min rest between trials				

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