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The psychophysical and physiological responses of individuals with varying body fat percentages and physical fitness levels during one-handed carrying on an inclined surface

Duha Ali [a,*], Mark Schall [b], Sean Gallagher [b], Richard Sesek [b], Mashnur Rashid [c], L. Bruce Gladden [b]

[a] California Polytechnic State University, San Luis Obispo, United States
[b] Auburn University, United States
[c] Ohio State University, United States

A B S T R A C T

One-handed carrying is a demanding and understudied form of manual material handling (MMH). Existing studies have not adequately considered the roles of body fat and physical fitness on the psychophysical and physiological responses of individuals performing one-handed carrying. A laboratory treadmill study involving 16 male and 16 female participants was completed to characterize the physiological and psychophysical responses incurred by one-handed MMH on a flat and inclined surface. Participants walked at a speed of 3.2 km/h for a distance of 96.5 m over four experimental conditions: No-load and flat surface [NF], no-load and inclined surface [NI], load and flat surface [LF], load and inclined surface [LI]). The results indicated generally consistent main effects of body fat, physical fitness, load, and incline on psychophysical and physiological responses, highlighting the inadequacy of current MMH guidance in addressing the impact of body fat percentage and physical fitness on one-handed carrying task performance.

1. Introduction

Musculoskeletal disorders (MSDs) are among the most prevalent and burdensome adverse medical conditions affecting workers worldwide (Blyth et al., 2019). In the United States, 502,380 reported workplace MSDs resulted in at least one day away from work from 2021 to 2022, an annualized incidence rate of 25.3 MSDs per 10,000 full-time equivalent workers (USBLS 2023b). Work-related MSDs accounted for 55.4% of emergency room visits in 2019 (USBLS 2023a). The United States Institute of Medicine estimates that the economic burden of work-related MSDs, as measured by compensation costs, lost wages, and lost productivity, is between $45 and $54 billion annually (CDC, 2021).

In 2018, work-related MSDs represented 40–50% of all days away from work cases in professions specifically involving manual material handling (MMH) activities such as lifting, pushing, pulling, and carrying (USBLS 2023a). According to Liberty Mutual, the largest workers' compensation insurance provider in the United States, overexertion injuries associated with lifting, pushing, pulling, holding, carrying, or throwing objects cost employers $13.4 billion annually (National Academies Press (US), 2001). Carrying is a common MMH task that is not easily analyzed, leading to inadequate data in ergonomic assessment (Ciriello et al., 1999). Carrying a load with one hand is more physically demanding than two-handed carrying and other carrying methods (e.g., loading on the back) and can contribute to overexertion and MSDs (Cook and Neumann, 1987; Ganguli and Datta, 1977; Lind and McNicol, 1968; Rohlmann et al., 2014). Higher spinal compression has been reported when a load (e.g., 30 kg) is carried in one hand than when the same load is carried in each hand (i.e., 60 kg total) (McGill et al., 2013). One-handed carrying tasks have also been reported to incur more perceived arm exertion than two-handed carrying tasks (Yoon and Smith, 1999). Although carrying an object using one hand is common and can be observed in many tasks, it has not been adequately studied (Badawy et al., 2018a,b). The lack of research on one-handed carrying has contributed to limited guidance regarding suggested action limits that may contribute to an increased risk of MSDs, particularly for individuals who are overweight or obese.

The number of obese individuals (BMI $\geq$30 kg/m^2) in the United States has steadily increased over the past 30 years (Ogden, 2010). In particular, the prevalence of severe obesity (BMI $\geq$35 kg/m^2) increased from 4.7% to 9.2% (CDC, 2021). Even though the prevalence of obesity among workers in the United States is lower than the prevalence among the United States general population, the rise of obesity among workers

* Corresponding author.
E-mail address: duali@calpoly.edu (D. Ali).

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has shown a similar pattern to that of the general population (Caban et al., 2005; Hertz et al., 2004). Obesity among workers may have adverse occupation-related consequences (Pollack et al., 2007; Rodbard et al., 2009). Obese workers experienced a higher overall risk of occupational injury than those with a recommended healthy weight, with a multivariable-adjusted hazard ratio of 1.21 (Kouvonen et al., 2013). Additionally, obese employees' MMH abilities may be compromised (Gates et al., 2008), contributing to a higher frequency of work-related injuries (Viester et al., 2013). As the general and working population is increasingly obese, and because these workers may be particularly susceptible to work-related MSDs, a more comprehensive understanding of the performance of workers with varying body fat percentages during MMH activities, such as one-handed carrying, is needed.

Although obesity has been associated with a higher risk of chronic disease, physical fitness is determined by factors such as muscular strength, endurance, flexibility, and cardiovascular fitness, which are not directly related to body weight. Physical fitness is important in reducing the risk of injury and disease, as cardiorespiratory fitness is directly related to integrating the musculoskeletal system with other systems in the human body. VO_2 max, the maximum amount of oxygen a person can intake, is often used as a marker of physical fitness and considered the best indicator of cardiorespiratory fitness (Verma et al., 1977). VO_2 max does not change despite an increase in workload over some time. Badawy et al., 2018a,b indicated that total VO_2 was statistically significantly higher among obese individuals than among participants with a healthy BMI during a one-handed carrying task. However, the physical fitness level of these participants was not considered. Additional work is needed to understand the physiological and psychophysical responses of individuals with varying body fat percentages and physical fitness levels during one-handed carrying.

Many work environments require workers to perform MMH, including one-handed carrying, on surfaces that are not flat (e.g., agriculture, construction, maritime, military, and aviation). In the maritime industry, for example, dock workers and sailors handle ropes, tools, and cargo on the sloped and often slippery surfaces of docks and ship decks (Cezar-Vaz et al., 2014; Ross, 2017). Delivery workers and movers often handle loads with one hand on sloped surfaces such as loading ramps (Keyserling et al., 1999; Rim and Jung, 2022; Lavender et al., 2023). Baggage handlers in the aviation industry have been reported to be exposed to more hazardous trunk and arm postures when working on ramps than when working in sorting areas (Wahlström et al., 2016). Similarly, soldiers and military personnel may carry weapons, supplies, and equipment across varied terrains, including hills, trenches, and other sloped terrain (Stevenson et al., 2004).

Working on inclined surfaces may increase physiological loading and affect MMH techniques employed by workers, which may alter the biomechanical loads imposed on the spine, shoulders, and other body segments. According to earlier studies, walking on inclined surfaces necessitates specific sensory-motor control techniques that may affect lifting kinematics and kinetics (Earhart and Bastian, 2000; Gregor et al., 2006; Van de Crommert et al., 1998). According to Shin and Mirka (2004), ground slope angle affects the kinematics and kinetics of MMH and should be considered when assessing the risk of MSDs. Choi and Fredericks (2008) indicated that workers performing a task on a steep surface showed postural instability sooner than on flat surfaces and that workers should be given adequate time to recover after completing an activity on an inclined surface (such as a roofing task on a pitched roof) before switching to heavy MMH.

Liu (2007) explored the roles of carried load distribution, walking speed, and surface grade on the physiological responses of infantry soldiers. The results indicated that the distribution of a load plays a critical role in the body's physiological reaction to load carriage, and the best position to distribute objects in a backpack may depend on the grade of the inclined surface. In contrast, (Nelson-Wong and Callaghan, 2010) investigated the biomechanical effects of 2 h of prolonged standing on a sloped surface of $\pm$ 16° and reported significant biomechanical effects. Extended standing on a sloped surface reduced college-aged participants' reported low back pain, with 87.5% reporting that they would utilize the sloped surface if their job required them to stand for long periods.

Despite these studies, little information is available characterizing the physiological and psychophysical responses of working-age individuals of varying body fat percentages and physical fitness levels during one-handed carrying on inclined slopes. We aimed to characterize the physiological and psychophysical responses of individuals with varying body fat percentages and physical fitness levels during one-handed carrying on an inclined and flat surface. Specifically, we hypothesized that carrying a load in the dominant hand on an inclined surface would increase perceived exertion and objective measurements of oxygen uptake (VO_2) and heart rate (HR). We also hypothesized that participants with a higher body fat percentage would perceive the tasks as more demanding and have higher physiological responses than participants with lower body fat percentages.

2. Experimental protocol and procedures

A treadmill study was conducted to evaluate the physiological and psychophysical responses of individuals with varying body fat percentages and physical fitness levels during one-handed carrying on inclined and flat surfaces. All experiments were performed on a NordicTrack Commercial X11i Treadmill (NordicTrack, Chaska, Logan, Utah, USA). All experiments were conducted in the Human Factors Laboratory at Auburn University. Participants who met the inclusion criteria were asked to keep their living habits constant for the course of the study.

2.1. Participants

Participants were recruited from the Auburn University campus. The eligibility criteria for participants in this study included: 1) reporting no history of physician-diagnosed MSD or cardiovascular disease; 2) reporting no chronic pain in the neck, shoulder, or lower back in the six months preceding the data collection; 3) not being pregnant, 4) not receiving radiation therapy at the time of the study, and 5) reporting no history of smoking. Participants who weighed more than 160 kg were excluded due to the weight limit of the treadmill used in the study.

An equal number of male and female participants were recruited for this study. Different experimental protocols based on biological sex at birth were followed. Female participants were asked not to perform the experiment during their menstruation phase to avoid any potential effects on psychological and physiological stressors. As cardiorespiratory fitness decreases by approximately 8–10% per decade beyond the age of 30 years (Norton et al., 2010), all recruited participants were 19–30 years old. The Auburn University Institutional Review Board approved the study protocol.

2.2. Physiological and psychophysical measures

Percent body fat was obtained from a body composition scale (Health-o-meter BCS-G6-ADULT; Mccook, Illinois, USA). Cardiorespiratory fitness was assessed as maximal oxygen uptake (VO_2Max). VO_2Max of the participants was estimated using the Balke and Ware treadmill protocol on a different day during the same week. A COSMED K5 (COSMED, Rome, Italy) metabolic cart was used to measure repertory gas exchange during the experimental tasks (Figs. 1 and 2). The COSMED K5 features a face mask that seals around the mouth and nose to measure oxygen uptake and carbon dioxide emissions during respiration. A Garmin heart rate sensor (GARMIN, Olathe, Kansas, USA) was secured to the participant's chest via a strap around the torso. Heart rate and oxygen uptake data were stored on OMNIA (COSMED, Rome, Italy). To ensure accurate measurements, the COSMED K5 device was calibrated with the manufacturer's four recommended calibrations: flowmeter, scrubber, reference gas, and delay calibrations, prior to each data

Fig. 1. COSMED K5 device.

Fig. 2. Experimental setup.

collection.

Psychophysical assessments included using Borg's rating of perceived exertion (RPE) for the whole body (WB) and arm, and a rating of perceived dyspnea (RPD) (Borg, 1982). The multi-dimensional NASA-TLX scale was used to rate the perceived workload associated with the experimental tasks (Williams, 2017) (Table 1).

Table 1
Variables of interest.

Independent Variables	Dependent Variables
Load (kg)	**Pyschophysical**
Categorical (no-load and load)	RPE (WB)
Incline (degrees)	RPE (Arm)
Categorical (flat and incline)	RPD
Fitness (VO2Max)	NASA TLX
Continous	**Physiological**
Obesity (body fat %)	VO2/kg
Continous	HR

2.3. Data collection

Participants completed 3 min of warm-up by walking on the treadmill at a speed of 1.7 km/h. The participants were asked to walk four randomized trials on a treadmill at a 3.2 km/h walking speed for a distance of 96.5 m, the same distance used by (Badawy et al., 2018a,b). The speed was identical to that used by (Kilbom et al., 1992). The selected speed was maintained in all trials to minimize the effect of speed on performance measurements. The trials were randomized using the counterbalancing restricted randomization method. The trials were randomized to control for potential sequence effects.

The experiment included two variables with two levels: load (9 kg and 5.5 kg, for males and females, respectively) and no-load, inclined surface (11.21° equivalent to 20% grade) and flat surface. Therefore, the four experimental tasks were: No-load and flat surface [NF], no-load and inclined surface [NI], load and flat surface [LF], load and inclined surface [LI]). All participants carried the same load size with dimensions of (22.4 cm L x 17.8 cm W x 31.8 cm H).

The incline was selected based on a previous study that examined the effect of trunk kinematics during lifting (Shin and Mirka, 2004), as well as OSHA's provisions concerning maximum allowable slopes that any ramp with an angle greater than 20° from the horizontal must be provided with handrails. VO_2 was recorded with every breath. RPE (WB), RPE (Arm), and RPD were measured before and after the experiment was terminated for each subject. NASA-TLX measurements were documented after each experimental trial. The participants were given 10 min to rest between the trials. The participants were allowed to drink water between the trials to ensure good hydration, and food was not allowed between the four trials.

2.4. Statistical analysis

Four independent variables were investigated: Load (no-load vs. load), incline (flat vs. incline), fitness (VO_2Max), and obesity (body fat percentage). The dependent psychophysical variables included the RPE (WB), RPE (Arm), RPD, and the six subscales of the NASATLX. The dependent physiological variables included VO_2/kg and HR. VO_2/kg represented the average oxygen uptake over the duration of each experimental trial. HR was the highest HR achieved during each experimental trial, typically observed at the end of each trial.

The data were visually inspected for outliers, and histograms, normality, and residual plots were examined to confirm that the normality assumptions for using a generalized linear model regression analysis were met. The statistical significance of the main effect of each of the four independent variables (load, incline, body fat percentage, and physical fitness) and the interactions of these variables on the dependent variables were considered. The interactions were ultimately removed from the final analyses because no statistically significant interactions between the variables were identified. All statistical analyses were performed using statistical analysis software (R Studio, version 4.1.3, R Core Team and the R Foundation for Statistical Computing and Minitab, version 21.1.1, Minitab, LLC, State College, Pennsylvania). An alpha value of 0.05 was used in all analyses. R-squared is reported as a measure of effect size for statistically significant differences.

3. Results

3.1. Physical characteristics

Thirty-two participants were recruited (16 male and 16 female). Descriptive statistics (mean and standard deviation) for age, height, weight, BMI, percent body fat, and VO_2Max by sex and collectively as a group are presented in Table 2.

3.2. Psychophysical responses

Tables 3 and 4 present the mean and standard deviation of the reported psychophysical responses for the four experimental trials. Generally, trials performed on an incline led to higher RPE (WB) for both sexes. RPE (WB) was statistically significant for load ($F_{(1, 59)} = 4.34$, $p < 0.05$, R-squared = 0.38) for males, while incline was statistically significant for males ($F_{(1, 59)} = 29.36$, $p < 0.001$, R-squared = 0.38), and females ($F_{(1, 59)} = 83.77$, $p < 0.001$, R-squared = 0.6). The RPE (Arm) means were statistically significantly higher for the trials that involved the load for males ($F_{(1, 59)} = 23.69$, $p < 0.001$, R-squared = 0.4) and females ($F_{(1, 59)} = 29.51$, $p < 0.001$, R-squared = 0.4). Incline was only statistically significant for females ($F_{(1, 59)} = 6.98$, $p < 0.05$, R-squared = 0.4). Additionally, the fitness level of the male participants was statistically significant for RPE (Arm) ($F_{(1, 59)} = 7.90$, $p < 0.01$, R-squared = 0.4). Higher means of RPD were reported for the trials performed on an incline. Load was statistically significant ($F_{(1, 59)} = 5.18$, $p < 0.05$, R-squared = 0.51) only for female participants, while the incline was statistically significant ($F_{(1, 59)} = 27.59$, $p < 0.001$, R-squared = 0.39) only for male participants. The fitness level of both sexes was statistically significant for RPD (Male: $F_{(1, 59)} = 5.33$, $p < 0.05$, R-squared = 0.39; Female: $F_{(1, 59)} = 6.92$, $p < 0.05$, R-squared = 0.51).

Tables 5 and 6 present the mean and standard deviation of the reported psychophysical responses of the six NASA-TLX sub-scales for the four trials. In general, carrying the load on the inclined surface had the highest reported means among the four trials for both sexes for the NASA-TLX sub-scales. Load had a statistically significant effect on mental effort for male participants ($F_{(1, 59)} = 6.04$, $p < 0.05$, R-squared = 0.4). Incline was statistically significant for males ($F_{(1, 59)} = 21.47$, $p < 0.001$, R-squared = 0.4) and females ($F_{(1, 59)} = 12.81$, $p < 0.001$, R-squared = 0.43). Body fat percentage was statistically significant in males ($F_{(1, 59)} = 4.52$, $p < 0.05$, R-squared = 0.4) and females ($F_{(1, 59)} = 7.71$, $p < 0.05$, R-squared = 0.43). The physical fitness of female participants had a statistically significant effect on perceived mental effort ($F_{(1, 59)} = 25.94$, $p < 0.001$, R-squared = 0.43). Load ($F_{(1, 59)} = 13.90$, $p < 0.001$, R-squared = 0.67), incline ($F_{(1, 59)} = 71.94$, $p < 0.001$, R-squared = 0.67), and physical fitness ($F_{(1, 59)} = 18.12$, $p < 0.001$, R-squared = 0.67) had a statistically significant effect on physical effort for male participants. Similarly, load ($F_{(1, 59)} = 6.97$, $p < 0.05$, R-squared = 0.61), incline ($F_{(1, 59)} = 54.04$, $p < 0.001$, R-squared = 0.61), and physical fitness ($F_{(1, 59)} = 8.15$, $p < 0.01$, R-squared = 0.61) was statistically significant for female participants. Body fat percentage ($F_{(1, 59)} = 28.45$, $p < 0.001$, R-squared = 0.61) had a statistically significant effect on physical effort for females.

Experimental trials that involved the load or the incline led to a perceived increase in the temporal perception of participants despite the treadmill speed being fixed and consistent for all trials. Incline for males ($F_{(1, 59)} = 51.33$, $p < 0.001$, R-squared = 0.58) and females ($F_{(1, 59)} =$

Table 2
Physical characteristics of participants.

	Female (N = 16)	Male (N = 16)	Overall (N = 32)
Age (years)			
Mean (SD)	27.4 (1.93)	28.1 (2.19)	27.8 (2.06)
Median [Min, Max]	27.0 [24.0, 30.0]	29.0 [21.0, 30.0]	28.0 [21.0, 30.0]
Height (cm)			
Mean (SD)	164 (6.30)	178 (6.99)	171 (9.53)
Median [Min, Max]	161 [158, 179]	179 [167, 191]	171 [158, 191]
Weight (kg)			
Mean (SD)	66.7 (17.3)	84.7 (15.0)	75.7 (18.4)
Median [Min, Max]	64.05 [42.5, 115]	85.7 [59.2, 111]	74.4 [42.5, 115]
Body Mass Index (kg/m^2)			
Mean (SD)	24.4 (5.84)	26.5 (4.33)	25.4 (5.17)
Median [Min, Max]	23.1 [16.2, 35.54]	25.9 [20.9, 33.2]	24.6 [16.2, 35.5]
Body Fat (%)			
Mean (SD)	24.3 (9.36)	17.3 (7.87)	20.8 (9.22)
Median [Min, Max]	23.5 [10.5, 40.3]	15.8 [7.50, 28.4]	20.8 [7.50, 40.3]
VO_2Max			
Mean (SD)	37.2 (10.6)	39.3 (8.2)	38.25 (9.51)
Median [Min, Max]	40.45 [13.1, 52.6]	39.275 [29.0, 58.3]	39.75 [13.1, 58.4]

Table 3
Rating of perceived exertion for the whole body (RPE-WB), rating of perceived exertion for the dominant arm (RPE-Arm), and rating of perceived dyspnea (RPD) as reported by male participants. No-load and inclined surface [NI], load and inclined surface [LI], No-load and flat surface [NF], load and flat surface [LF].

	LF (N = 16)	LI (N = 16)	NF (N = 16)	NI (N = 16)	Overall (N = 64)
RPE-WB					
Mean (SD)	2.75 (3.40)	7.13 (2.83)	1.50 (2.97)	5.25 (2.98)	4.16 (3.70)
Median [Min, Max]	2.00 [0, 11.0]	7.00 [1.00, 13.0]	0.500 [0, 9.00]	5.00 [0, 12.0]	3.50 [0, 13.0]
RPE-Arm					
Mean (SD)	4.06 (2.24)	5.19 (2.83)	0.938 (2.57)	2.06 (3.40)	3.06 (3.20)
Median [Min, Max]	4.00 [1.00, 10.0]	5.50 [0, 12.0]	0 [0, 8.00]	0 [0, 12.0]	2.50 [0, 12.0]
RPD					
Mean (SD)	1.22 (1.52)	3.41 (1.94)	0.594 (1.47)	2.59 (1.68)	1.95 (1.97)
Median [Min, Max]	0.500 [0, 6.00]	3.00 [0.500, 8.00]	0 [0, 6.00]	2.25 [0.500, 7.00]	1.50 [0, 8.00]

Table 4
Rating of perceived exertion for the whole body (RPE-WB), rating of perceived exertion for the dominant arm (RPE-Arm), and rating of perceived dyspnea (RPD) as reported by female participants. No-load and inclined surface [NI], load and inclined surface [LI], No-load and flat surface [NF], load and flat surface [LF].

	LF (N = 16)	LI (N = 16)	NF (N = 16)	NI (N = 16)	Overall (N = 64)
RPE-WB					
Mean (SD)	1.13 (1.59)	5.63 (2.42)	0.500 (0.730)	4.50 (2.16)	2.94 (2.83)
Median [Min, Max]	0.500 [0, 5.00]	7.00 [2.00, 9.00]	0 [0, 2.00]	4.50 [0, 8.00]	2.00 [0, 9.00]
RPE-Arm					
Mean (SD)	2.06 (2.02)	3.69 (2.41)	0.250 (0.577)	0.875 (1.20)	1.72 (2.13)
Median [Min, Max]	1.00 [0, 7.00]	3.00 [0, 9.00]	0 [0, 2.00]	0 [0, 4.00]	1.00 [0, 9.00]
RPD					
Mean (SD)	0.656 (1.09)	3.22 (0.999)	0.594 (0.935)	1.97 (1.61)	1.61 (1.59)
Median [Min, Max]	0 [0, 4.00]	3.00 [1.00, 5.00]	0 [0, 3.00]	1.75 [0, 6.00]	1.00 [0, 6.00]

Table 5
NASA Task Load Index as reported by male participants after each trial. No-load and inclined surface [NI], load and inclined surface [LI], No-load and flat surface [NF], load and flat surface [LF].

	LF	LI	NF	NI	Overall
	(N = 16)	(N = 16)	(N = 16)	(N = 16)	(N = 64)
Mental					
Mean (SD)	3.06 (2.14)	6.44 (4.03)	1.75 (1.48)	4.50 (3.18)	3.94 (3.31)
Median [Min, Max]	3.00 [1.00, 10.0]	5.00 [1.00, 15.0]	1.00 [1.00, 7.00]	4.00 [1.00, 12.0]	3.00 [1.00, 15.0]
Physical					
Mean (SD)	4.69 (2.52)	10.3 (4.78)	2.13 (2.03)	7.88 (3.28)	6.25 (4.51)
Median [Min, Max]	4.00 [2.00, 10.0]	11.0 [2.00, 17.0]	1.00 [1.00, 8.00]	8.00 [2.00, 14.0]	5.50 [1.00, 17.0]
Temporal					
Mean (SD)	3.63 (2.53)	8.38 (4.66)	2.13 (1.26)	6.63 (2.73)	5.19 (3.87)
Median [Min, Max]	3.00 [1.00, 10.0]	6.00 [2.00, 17.0]	2.00 [1.00, 5.00]	6.50 [2.00, 10.0]	4.00 [1.00, 17.0]
Performance					
Mean (SD)	20.1 (1.95)	19.4 (2.03)	20.4 (1.50)	19.6 (1.78)	19.9 (1.82)
Median [Min, Max]	10.5 [13.0, 21.0]	20.0 [14.0, 21.0]	21.0 [15.0, 21.0]	20.0 [15.0, 21.0]	20.5 [13.0, 21.0]
Effort					
Mean (SD)	5.44 (3.48)	10.8 (4.57)	2.38 (1.93)	8.44 (3.42)	6.75 (4.65)
Median [Min, Max]	4.50 [2.00, 13.0]	10.5 [4.00, 18.0]	2.00 [1.00, 7.00]	9.00 [3.00, 15.0]	6.00 [1.00, 18.0]
Frustration					
Mean (SD)	1.81 (1.11)	4.50 (4.10)	1.50 (1.03)	3.06 (2.52)	2.72 (2.73)
Median [Min, Max]	1.50 [1.00, 5.00]	3.00 [1.00, 15.0]	1.00 [1.00, 5.00]	2.00 [1.00, 9.00]	2.00 [1.00, 15.0]

Table 6
NASA Task Load Index as reported by female participants after each trial. No-load and inclined surface [NI], load and inclined surface [LI], No-load and flat surface [NF], load and flat surface [LF].

	LF	LI	NF	NI	Overall
	(N = 16)	(N = 16)	(N = 16)	(N = 16)	(N = 64)
Mental					
Mean (SD)	3.81 (3.82)	7.94 (5.72)	2.94 (6.60)	5.75 (5.23)	5.11 (4.96)
Median [Min, Max]	2.00 [1.00, 13.0]	7.50 [1.00, 17.0]	1.00 [1.00, 12.0]	3.50 [1.00, 17.0]	2.00 [1.00, 17.0]
Physical					
Mean (SD)	4.88 (4.47)	12.1 (4.49)	3.31 (3.34)	9.00 (4.70)	7.31 (5.43)
Median [Min, Max]	3.00 [1.00, 16.0]	13.0 [6.00, 19.0]	2.00 [1.00, 10.0]	8.00 [8.00, 17.0]	6.00 [1.00, 19.0]
Temporal					
Mean (SD)	4.25 (4.30)	11.6 (6.25)	3.13 (3.44)	9.13 (5.90)	7.02 (6.08)
Median [Min, Max]	2.00 [1.00, 13.0]	11.0 [2.00, 21.0]	2.00 [1.00, 10.0]	9.00 [1.00, 20.0]	4.50 [1.00, 21.0]
Performance					
Mean (SD)	19.4 (2.03)	17.5 (5.09)	19.8 (1.76)	17.9 (3.94)	18.7 (3.54)
Median [Min, Max]	20.0 [16.0, 21.0]	20.0 [6.00, 21.0]	20.5 [15.0, 21.0]	20.0 [10.0, 21.0]	20.0 [1.00, 20.0]
Effort					
Mean (SD)	5.44 (5.06)	12.6 (4.69)	3.06 (2.93)	10.5 (5.19)	7.91 (5.89)
Median [Min, Max]	4.00 [1.00, 19.0]	12.5 [6.00, 20.0]	2.00 [1.00, 10.0]	11.5 [4.00, 20.0]	7.00 [1.00, 20.0]
Frustration					
Mean (SD)	3.56 (3.90)	5.63 (5.63)	2.19 (2.14)	5.44 (5.10)	4.20 (4.53)
Median [Min, Max]	1.00 [1.00, 12.0]	3.00 [1.00, 19.0]	1.00 [1.00, 7.00]	3.50 [1.00, 18.0]	2.00 [1.00, 19.0]

37.24, $p < 0.001$, R-squared = 0.52) and physical fitness for males ($F_{(1, 59)} = 18.05$, $p < 0.001$, R-squared = 0.58) and females ($F_{(1, 59)} = 21.61$, $p < 0.001$, R-squared = 0.52) had statistically significant effects on how participants perceived the temporal aspects of the trials. The participants reported that their performance was the worst during the trials involving a load and incline compared to the other trials. Physical fitness had a statistically significant effect on how the participants perceived their performance for males ($F_{(1, 59)} = 7.08$, $p < 0.05$, R-squared = 0.35) and females ($F_{(1, 59)} = 10.17$, $p < 0.01$, R-squared = 0.23). The reported effort for the tasks was significantly affected by load ($F_{(1, 59)} = 18.85$, $p < 0.001$, R-squared = 0.73), incline ($F_{(1, 59)} = 84.41$, $p < 0.001$, R-squared = 0.73), and physical fitness ($F_{(1, 59)} = 28.37$, $p < 0.001$, R-squared = 0.73) for males and females (load $F_{(1, 59)} = 6.60$, $p < 0.05$, R-squared = 0.67, incline $F_{(1, 59)} = 69.68$, $p < 0.001$, R-squared = 0.67, and physical fitness $F_{(1, 59)} = 42.55$, $p < 0.001$, R-squared = 0.67). Body fat percentage was only statistically significant for males ($F_{(1, 59)} = 4.88$, $p < 0.05$, R-squared = 0.73). Frustration and stress during the task were statistically significantly driven by the incline (Male: $F_{(1, 59)} = 15.39$, $p < 0.001$, R-squared = 0.41; Female $F_{(1, 59)} = 7.43$, $p < 0.01$, R-squared = 0.31), body fat percentage (male $F_{(1, 59)} = 9.07$, $p < 0.01$, R-squared = 0.41; Female: $F_{(1, 59)} = 5.48$, $p < 0.05$, R-squared = 0.31), and physical fitness variables (Male: $F_{(1, 59)} = 3.14$, $p < 0.05$, R-squared = 0.41; Female $F_{(1, 59)} = 15.46$, $p < 0.001$, R-squared = 0.31).

Equations (1)–(9) present the regression equations of the statistically significant variables for male participants:

$$\text{RPE (Male)} = 4.156 + 0.781\ \text{Load} + 2.031\ \text{Incline} \quad (1)$$

$$\text{RPEA (Male)} = 6.81 + 3.13\ \text{Load} - 0.1351\ VO_2\text{Max} \quad (2)$$

$$\text{RPD (Male)} = 3.30 + 2.1\ \text{Incline} - 0.0609\ VO_2\text{Max} \quad (3)$$

$$\text{Mental (Male)} = -0.842 + 1.625\ \text{Load} + 3.062\ \text{Incline} + 0.1408\ \text{Fat} \quad (4)$$

$$\text{Physical (Male)} = 11.26 + 2.5\ \text{Load} + 5.69\ \text{Incline} - 0.2313\ VO_2\text{Max} \quad (5)$$

$$\text{Temporal (Male)} = 10.60 + 4.63\ \text{Incline} - 0.1965\ VO_2\text{Max} \quad (6)$$

$$\text{Performance (Male)} = 15.655 + 0.1073\ VO_2\text{Max} \quad (7)$$

$$\text{Effort (Male)} = 9.96 + 2.69\ \text{Load} + 5.69\ \text{Incline} + 0.1035\ \text{Fat} - 0.2336\ VO_2\text{Max} \quad (8)$$

$$\text{Frustration (Male)} = 2.20 + 2.12\ \text{Incline} + 0.1234\ \text{Fat} - 0.0680\ VO_2\text{Max} \quad (9)$$

Equations 10–18 present the regression equations of the statistically significant variables for female participants:

$$\text{RPE (Female)} = 2.938 + 2.125\ \text{Incline} \quad (10)$$

$$\text{RPEA (Female)} = 1.719 + 1.156\ \text{Load} + 0.563\ \text{Incline} \quad (11)$$

$$\text{RPD (Female)} = 2.744 + 0.656\ \text{Load} - 0.0394\ VO_2\text{Max} \quad (12)$$

$$\text{Mental (Female)} = 15.99 + 3.47\text{Incline} - 0.1519\ \text{Fat} - 0.2402\ VO_2\text{Max} \quad (13)$$

$$\text{Physical (Female)} = 14.81 + 2.31\ \text{Load} + 6.44\ \text{Incline} - 0.1411\ \text{Fat} - 0.2272\ VO_2\text{Max} \quad (14)$$

$$\text{Temporal (Female)} = 11.89 + 6.66\ \text{Incline} - 0.2207\ VO_2\text{Max} \quad (15)$$

Performance (Female) = 13.88 + 0.1286 VO_2Max (16)

Effort (Female) = 12.98 + 2.25 Load + 7.31 Incline - 0.2651 VO_2Max (17)

Frustration (Female) = 12.93 + 2.66 Incline - 0.1288 Fat - 0.1864 VO_2Max (18)

3.3. Physiological responses

Tables 7 and 8 present the mean and standard deviation of the measured physiological responses for the four trials. VO_2 and HR during the trials involving a load and incline recorded the highest values, indicating that the participants required more oxygen and worked harder to perform this task compared to the rest of the tasks. Load ($F_{(1, 59)} = 5.08$, $p < 0.05$, R-squared = 0.8), incline ($F_{(1, 59)} = 226.38$, $p < 0.001$, R-squared = 0.8), and physical fitness ($F_{(1, 59)} = 13.80$, $p < 0.001$, R-squared = 0.8) had a statistically significant effect on the measured VO_2 for male participants. The same variables were found to be significant for female participants: Load ($F_{(1, 59)} = 4.23$, $p < 0.05$, R-squared = 0.8), incline ($F_{(1, 59)} = 107.47$, $p < 0.001$, R-squared = 0.8), and physical fitness ($F_{(1, 59)} = 7.90$, $p < 0.01$, R-squared = 0.8). Concerning the recorded HR, the load was statistically significant for males ($F_{(1, 59)} = 6.60$, $p < 0.05$, R-squared = 0.8) and trended towards significance for females ($F_{(1, 59)} = 160.07$, $p < 0.001$, R-squared = 0.8). Moreover, incline was statistically significant for males ($F_{(1, 59)} = 4.23$, $p < 0.05$, R-squared = 0.8), and females ($F_{(1, 59)} = 171.00$, $p < 0.001$, R-squared = 0.8). Physical fitness was statistically significant for males ($F_{(1, 59)} = 9.86$, $p < 0.01$, R-squared = 0.8) and females ($F_{(1, 59)} = 11.50$, $p < 0.001$, R-squared = 0.8). Body fat percentage was only statistically significant for female participants ($F_{(1, 59)} = 7.25$, $p < 0.01$, R-squared = 0.8).

Equations 19–22 present the regression equations of the VO_2/kg and HR for both males and females.

VO_2/kg (Male) = −1.25 + 0.2907 VO_2Max + 18.14 Incline + 2.72 Load (19)

HR (Male) = 134.2–0.006 Fat - 0.809 VO_2Max + 46 Incline + 9.3 Load (20)

VO_2/kg (Female) = 5.05 + 0.204 VO_2Max + 14.35 Incline + 2.85 Load (21)

HR (Female) = 138.14–0.65 VO_2Max + 44.06 Incline (22)

Table 7
Physiological values for the four tasks: load and flat surface [LF], load and inclined surface [LI], no-load and flat surface [NF], and no-load and inclined surface [NI] that 16 male participants performed.

	LF (N = 16)	LI (N = 16)	NF (N = 16)	NI (N = 16)	Overall (N = 64)
VO_2 (ml/kg.min-1)					
Mean (SD)	13.2 (3.22)	30.8 (7.57)	9.93 (3.03)	28.6 (6.31)	20.6 (10.6)
Median [Min, Max]	13.1 [7.90, 19.2]	30.0 [18.1, 44.8]	10.7 [4.80, 16.3]	28.1 [17.1, 38.1]	17.8 [4.80, 44.8]
HR (beats/min)					
Mean (SD)	110 (13.5)	159 (15.2)	104 (14.6)	146 (19.4)	130 (28.3)
Median [Min, Max]	108 [92.0, 140]	166 [133, 181]	103 [80.0, 139]	150 [99.0, 173]	130 [80.0, 181]

Table 8
Physiological values for the four tasks: load and flat surface [LF], load and inclined surface [LI], no-load and flat surface [NF], and no-load and inclined surface [NI] that 16 female participants performed.

	LF (N = 16)	LI (N = 16)	NF (N = 16)	NI (N = 16)	Overall (N = 64)
VO_2 (ml/kg.min-1)					
Mean (SD)	15.1 (3.11)	30.2 (6.89)	13.0 (3.28)	26.6 (8.60)	21.2 (9.39)
Median [Min, Max]	15.3 [9.90, 23.1]	30.1 [16.6, 43.3]	12.7 [8.00, 18.3]	26.2 [11.5, 41.5]	17.8 [8.00, 43.3]
HR (beats/min)					
Mean (SD)	116 (17.8)	162 (12.0)	112 (17.1)	154 (15.7)	136 (27.2)
Median [Min, Max]	114 [85.0, 150]	157 [147, 184]	110 [83.0, 144]	151 [127, 177]	144 [83.0, 184]

4. Discussion

This study aimed to evaluate the physiological and psychophysical responses of individuals with varying body fat percentages and physical fitness levels during one-handed carrying on an inclined and flat surface. Previous research has investigated the effects of one-handed carrying on various psychophysical and physiological outcomes, and our results are generally consistent with these findings (Badawy et al., 2018a,b; Kilbom et al., 1992). However, our main contributions addressed incline effects, body fat percentage, and fitness level, which have not been extensively studied in one-handed carrying.

4.1. Incline

While few studies have examined the effects of inclined walking surfaces on balance or gait (Jansen, 1988; Wade and Davis, 2005), there is a notable lack of research investigating the effects of inclined surface angle on psychophysical and physiological responses. Choi and Fredericks (2007) reported that participants experienced no significant difference in psychological or physiological response variables such as HR, VO_2, and perceived exertion when walking on an incline relative to a level surface. In contrast, a study by Philippe et al. (2016) reported that inclined walking contains a higher percentage of eccentric muscle activity than level walking, indicating greater physiological strain.

The inclined walking surface in this study significantly affected psychophysical and physiological responses in both males and females. In males, the inclined walking surface statistically significantly affected RPE (WB), RPD, mental, physical, temporal, effort, frustration, VO_2, and HR. The findings suggest that walking on an incline can increase physiological stress and a greater sense of perceived exertion in males. Furthermore, the incline affected the RPEarm for females, and a significant difference was observed for the RPD for males. These findings suggest that walking on an inclined surface may result in greater cardiovascular and muscular demands, leading to increased levels of perceived exertion and reduced performance. Prior research has shown differences between males and females in stress-related physiological parameters (Kirschbaum et al., 1999; Philippe et al., 2016). However, the present study did not intend to compare sex differences on inclined surfaces, given the known physiological differences between males and females.

As the incline variable had a much larger coefficient than the other variables in the physiological regression model, the inclined working surface angle appears critically important during one-handed carrying. These findings suggest that the incline of a walking surface should be considered when designing workplace programs and interventions to optimize the psychophysical and physiological responses in both males and females.

4.2. Body fat percentage

In general, the results of this study suggest that individuals with a greater percentage of body fat often perceive one-handed carrying tasks as harder and have higher physiological reactions, such as increased VO_2 and HR, compared to leaner individuals. In males, body fat percentage was found to affect all mental, effort, and frustration responses during the task as measured by the NASA TLX subscale. Similarly, in females, body fat percentage significantly affected mental, frustration, and physical NASA TLX responses. However, for physiological responses, body fat percentage only affected HR in female participants.

Park et al. (2009) reported that body fat percentage significantly increases postural stress and amplifies the effects of postural changes on postural stress. Salvadori et al. (1999) reported that obese individuals had higher VO_2 and HR during exercise, indicating a higher physiological cost of physical activity. This increase in the physiological responses is thought to be due to increased body weight and fat mass, which can lead to higher energy expenditure during physical activity. Hall et al. (2012) reported that when obese individuals were asked to walk at a moderate intensity, they tended to select a lower workload than healthy-weight individuals, which suggests that they perceive the same task as more difficult than normal-weight individuals. Similarly, Maffels et al. (1993) indicated that walking and running are energetically more expensive for obese individuals than their leaner counterparts, indicating greater physiological strain. These findings suggest that individuals with a greater percentage of body fat may experience greater physical and psychological barriers to engaging in "safe" one-handed carrying activities and may require additional support and resources (e.g., training and assistive devices) to overcome these challenges.

4.3. Physical fitness

The current study suggests that physical fitness influences how one-handed carrying tasks are perceived physiologically and psychophysically, regardless of body fat percentage level. In this study, physical fitness has been shown to positively affect psychophysical and physiological responses, regardless of body fat percentage. In particular, physical fitness impacted all physiological and psychophysical measures except for RPE (WB). The results suggest that individuals with higher levels of physical fitness tend to have lower HRs, lower VO_2, and lower frustration levels while performing one-handed carrying. Additionally, individuals with higher levels of physical fitness tend to have better mental and physical responses during the task, indicating that they can handle the demands of physical activity. The results are consistent with existing work. For example, a study by Sharma et al. (2006) indicated that physical fitness was associated with lower levels of stress and depression and improved cognitive function and mood in individuals of all weight statuses. According to a study by Hamer and Chida (2009), regular physical exercise can improve cognitive function, reduce the risk of neurodegenerative diseases, and is inversely associated with the risk of dementia. A meta-analysis conducted by Rebar et al. (2015) found that physical fitness is associated with better mental health outcomes, including reduced symptoms of anxiety and depression. In terms of physiological responses, a study by An et al. (2019) found that increasing physical activity could be a helpful strategy for improving cardiometabolic health for individuals regardless of their body fat percentage. Ultimately, the findings suggest that physical fitness can benefit mental and physical health outcomes, irrespective of an individual's body weight, when performing one-handed carrying tasks.

4.4. Limitations

This study had several limitations that must be acknowledged. Our findings revealed no evidence of significant interaction between the dependent variables. This finding may be attributed to the relatively small sample size and number of loads and inclines considered. A larger sample size could increase the generalizability of the findings. Secondly, fat percentage was measured using a body impedance analysis device instead of the gold standard dual-energy X-ray absorptiometry (DEXA) scan, which could have led to measurement errors. Finally, different loads and inclines and a wider range of fitness levels could have been included to provide a more comprehensive analysis.

5. Conclusion

The incline of the walking surface should be carefully considered when designing work programs for individuals with varying fitness and body fat percentage levels. It may be necessary to adjust the incline and intensity of the task according to individual capabilities to ensure safety. Current guidance for MMH does not adequately consider the potential impact of high body fat percentage and low physical fitness levels on workers' ability to perform some tasks. This lack of consideration has important implications for workers' safety and health, as obese workers may face an increased risk of MSDs and other health complications. Therefore, more studies should be conducted to explore the impact of body fat percentage and physical fitness levels on workers' ability to perform MMH tasks and to inform the development of new standards and regulations that better reflect the current workforce. The characterizations from this study provide valuable information for designing work tasks involving one-handed carrying.

CRediT authorship contribution statement

Duha Ali: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Mark Schall:** Writing – review & editing, Validation, Supervision, Investigation, Funding acquisition, Conceptualization. **Sean Gallagher:** Supervision. **Richard Sesek:** Supervision. **Mashnur Rashid:** Data curation. **L. Bruce Gladden:** Writing – review & editing, Supervision.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Duha Ali reports This study was partially supported by the Deep South Center for Occupational Safety and Health at the University of Alabama-Birmingham (UAB) and Auburn University (Grant # 2T42OH008436). The findings and conclusions are those of the authors and do not necessarily represent the views of the CDC or NIOSH.

Data availability

The data that has been used is confidential.

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Further reading

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