Relationship Between BMI and Fatigability Is Task Dependent

Ranjana K. Mehta, Texas A&M University, College Station, and **Lora Anne Cavuoto**, University at Buffalo, New York

Objective: The objective of the current study was to determine the effect of body mass index (BMI) on fatigability of three different muscle groups at four different work intensities.

Methods: Forty-nine normal-weight, 50 overweight, and 43 obese adults (32.1 ± 9.2 years; 50% males) performed fatiguing handgrip, shoulder flexion, and trunk extension exertions at 20%, 40%, 60%, and 80% of the associated maximum voluntary contractions.

Results: Obese adults demonstrated 22% to 30% shorter endurance times than normal-weight adults, but this was only observed at lower intensities and with larger and more postural muscles of the shoulder and low back. Strength and fatigue-related strength loss remained comparable across BMI groups in both males and females in these task-specific conditions. Obesity was associated with faster progression in perception of effort at low-intensity shoulder and trunk exertions. While males were stronger than females across all muscle groups, females exhibited greater shoulder fatigue resistance than males at lower intensity levels.

Conclusion: Findings indicate that the relationship between obesity and fatigability is task dependent.

Application: These findings provide initial evidence on the impact of obesity on worker capacity. Future work that extends the current investigation to include more occupationally relevant scenarios are needed to facilitate occupational task (re)design and assessment practices, such that altered work capacities of two-thirds of the working population are accommodated.

Keywords: obesity, endurance, strength loss, overexertion, exhaustion

Address correspondence to Ranjana K. Mehta, Environmental and Occupational Health, 1266 TAMU, Texas A&M University, College Station, TX 77843, USA; e-mail: rmehta@tamu.edu.

HUMAN FACTORS
Vol. 59, No. 5, August 2017, pp. 722–733
DOI: 10.1177/0018720817695194

INTRODUCTION

Work-related musculoskeletal disorders (WMSDs), particularly overexertion injuries, represent a significant economic burden and involve substantial adverse personal outcomes. Approximately one-third of all workplace injuries and illnesses requiring days away from work are WMSDs, and workers' compensation claims for overexertion injuries exceed $13 billion each year (Bureau of Labor Statistics, 2012; Liberty Mutual Research Institute for Safety, 2013). In particular, injuries to the shoulder, wrist, and back account for some of the most severe injuries (~61% of all WMSDs), with a median of 21, 17, and 7 days away from work for each incident, respectively (Bureau of Labor Statistics, 2012). It is necessary to evaluate personal risk factors that may contribute to the current and future incidence and severity levels of these injuries. One demographic change over the past 30 years that is expected to continue over the next 20 years is a dramatic increase in the prevalence of overweight and obesity, defined as having a body mass index (BMI) $\geq$25 kg/m^2 and $\geq$30 kg/m^2, respectively (Flegal, Carroll, Ogden, & Johnson, 2002; Levy et al., 2013). Higher levels of obesity have been correlated to higher rates of injury risk (Finkelstein, Chen, Prabhu, Trogdon, & Corso, 2007; Finkelstein, Fiebelkorn, & Wang, 2005; Werner, Albers, Franzblau, & Armstrong, 1994; Withrow & Alter, 2011); therefore, an increasing obesity prevalence may increase the future incidence of WMSDs.

Obesity is linked to increased absolute quadriceps and trunk muscle strengths (Hulens et al., 2001; Maffiuletti et al., 2007; Rolland et al., 2004), but relative muscle strengths (scaled to body mass) are about ~10% lower in the obese (Hulens et al., 2001). Studies have examined obesity-related changes in muscle strength; however, little is known on its effect on endurance and fatigue.

While a causal relationship between fatigue and injury is yet to be determined, muscle fatigue and incomplete recovery can lead to decreased muscle capacity that can potentially result in an increased risk of injury and decline in work efficiency (de Looze, Bosch, & van Dieen, 2009; Kumar, 2001; Visser & van Dieën, 2006).

Alterations in muscle fiber type composition may influence fatigue resistance capacity in individuals who are obese. With obesity, greater proportions have been observed for fast twitch fibers that are more fatigable, compared to slow twitch or fatigue-resistant fibers (Hickey et al., 1995; Kriketos et al., 1997; Krotkiewski, Grimby, Holm, & Szczepanik, 1990; Tanner et al., 2002). Thus, obesity-related differences in endurance may depend on muscles that have distinct functions (executive vs. postural) or different fiber type compositions (fast vs. slow twitch). However, similar obesity-related decrements in fatigue resistance were reported during sustained isometric grip contractions at 30% of maximum strength (Eksioglu, 2011) and modified Sørensen back endurance test (Fogelholm et al., 2006; Kankaanp et al., 1998). It should be noted that these studies were limited to a single intensity level. A recent study by Mehta and Cavuoto (2015) reported that obese adults exhibited ~32% shorter endurance across multiple submaximal hand grip fatigue exercises, ranging from 20% to 80% of maximal voluntary contractions (MVCs), when compared to non-obese adults. It is unclear to what extent fatigue resistance of the different upper extremity muscles and trunk musculature (muscle groups that are associated with high injury rates) is impaired in overweight and obese individuals and whether this relationship is task (i.e., intensity and muscle) dependent.

The aim of the current study was to determine the effects of BMI on fatigability of multiple upper extremity and trunk muscle groups at different work intensities. Establishing these obesity effects on functional work capacity will facilitate a better understanding of the capabilities of individuals who are overweight or obese when performing tasks that require extensive use of the upper body and the low back. The muscle groups tested in this study are commonly afflicted by work-related injuries (accounting for >60% of all nonfatal injuries in the workplace). It was hypothesized that adults with higher BMIs will exhibit greater fatigability and that this relationship will be task dependent (i.e., muscle group employed and intensity level).

METHODS

Participants

One hundred and forty-two participants were recruited from the university and local communities in Texas and New York. A convenience stratified sampling, by gender and BMI, was adopted to obtain around 33% of participants (balanced by gender) in three BMI groups: normal weight ($18.5 \leq \text{BMI} < 25$ kg/m^2), overweight ($25 \leq \text{BMI} < 30$ kg/m^2), and obese (BMI ≥ 30 kg/m^2). All three groups of BMI class were assessed since each one currently represents approximately one-third of the U.S. population. Group assignment was first based on BMI collected by self-report during participant recruitment and confirmed through anthropometric measurements in the laboratories during the first experimental session, described later. Participants were recruited using emails, posted fliers, newspaper announcements, and visits to local organizations. Efforts were made to recruit equal numbers of males and females in each obesity group to control for the differences in body composition and body fat distribution (Nedungadi & Clegg, 2009; Taylor, Grant, Williams, & Goulding, 2010). Participants who were involved in regular aerobic or resistance training (more than 3 sessions of 30 minutes each per week) were excluded from the study. Participants were also excluded if they reported musculoskeletal disorders, current or in the past one year, that interfered with upper extremity and low back exercises. Individuals who were hypertensive (>160/90 mm Hg) or diabetic, based on self-report, were also excluded from the study. This research complied with the tenets of the Declaration of Helsinki and was approved by the Institutional Review Boards at Texas A&M University and University at Buffalo. Informed consent was obtained from each participant prior to testing.

Experimental Procedures

The study sites in College Station, Texas, and Buffalo, New York, utilized the same experimental protocols and equipment to avoid

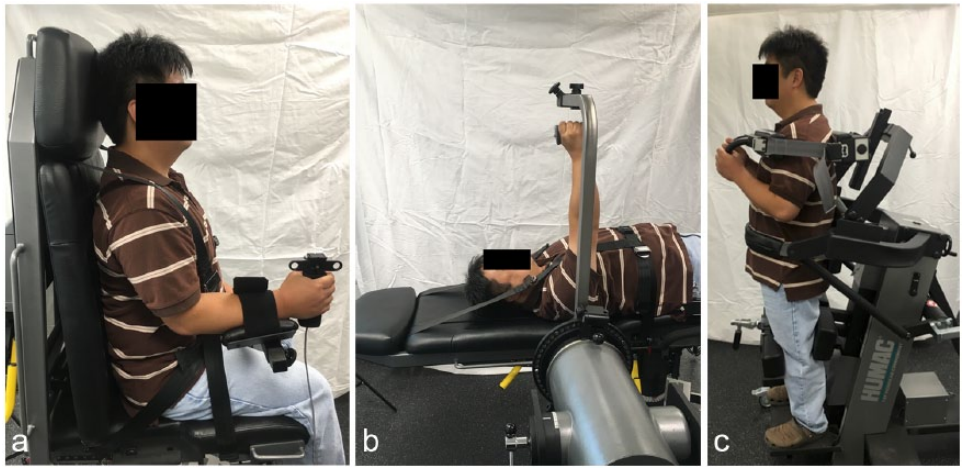

Figure 1. Postures employed during (a) handgrip, (b) shoulder flexion, (c) and trunk extension testing.

methodological and equipment-related discrepancies. Participants at each site completed four experimental sessions, and each session included a series of MVC testing and an isometric fatiguing exertion of each muscle group at a specified relative intensity level. The sessions (i.e., the presentation of work intensity) for each participant were counterbalanced and separated by at least 48 hours each to reduce any residual effects of fatigue or soreness. The order of muscle group presentation in each session was also counterbalanced to minimize learning and fatigue effects.

Upon consent, demographic information, health history, and anthropometric and body composition assessments were obtained at the first session. Participants' heights and weights (without shoes) were measured to the nearest 0.1 cm and 0.1 kg using a standard stadiometer and a digital metric scale, respectively. A standard flexible, inelastic measuring tape was used to measure waist and hip circumference to the nearest 0.1 cm at the level of the iliac crest and the maximum extension at the buttocks level, respectively. BMI was calculated as weight (kg) divided per squared height (meters). Bioelectric impedance analyses were carried out using the Tanita BC 418 MA Segmental Body Composition Analyzer (Tanita, Japan) according to the manufacturer's manual to obtain body fat percentage.

At each session, depending on the muscle group order within the session, participants performed testing on each muscle group with a 15-minute break between testing of the subsequent muscle groups. The testing included warm-up exercises, MVC testing, and fatiguing exertions for each muscle group.

Hand grip testing. Participants performed a 2-minute intermittent gripping warm-up exercise using a stress ball. For hand grip MVC testing, participants were seated upright with their upper arm at their side. A digital grip dynamometer (BIOPAC Systems, Inc., Goleta, CA, USA) was held in the dominant hand, and the participant maintained the standardized grip testing posture depicted in Figure 1a (Innes, 1999; Mital & Kumar, 1998; Nicolay & Walker, 2005; Roman-Liu, Tokarski, & Kowalewski, 2005). To minimize the possible effects of fatigue in the surrounding muscles due to the support of body segment mass (Price, 1990; Rohmert, Wangenheim, Mainzer, Zipp, & Lesser, 1986), the weight of the arm and dynamometer were supported. A series of three handgrip MVC trials were collected, with 2 minutes between each MVC trial. During each MVC trial, participants were instructed to maximally grip the hand dynamometer for 4 seconds based on standard strength testing procedures (Caldwell et al., 1974). For each participant, the maximum of the three repeated MVCs determined the maximum

handgrip MVC. Real-time visual feedback and verbal encouragement were provided during the MVC trials. While the MVC values obtained during the first session were used to determine the intensity level for each participant's fatiguing tasks for all four sessions, MVC values obtained during each of the four sessions were employed to compute strength loss for that session.

After sufficient rest from the MVC testing, participants began the submaximal handgrip fatiguing task at 20%, 40%, 60%, or 80% (depending on the order of presentation for that session) of their MVC. The targeted intensity level was presented as a red line on a computer screen at eye height, and participants were instructed to track their generated force against the target level as closely as possible for as long as they could. Verbal encouragement was provided during the fatiguing task. The fatiguing task ended when either the participant indicated he or she could no longer continue or his or her exerted force/moment dropped >10% below the required effort level for more than 5 seconds. Participants provided ratings of perceived exertion (RPEs) using a 10-point scale (Borg, 1990) for the relevant body part(s) every 30 seconds during the 20% and 40% MVC tasks and every 10 seconds for the 60% and 80% MVC tasks (Garg, Hegmann, Schwoerer, & Kapellusch, 2002). The scale ranged from 0 = *nothing at all* to 10 = *extremely strong, almost maximum*. Different collection rates were used since shorter endurance times were expected at higher percent MVC. Immediately after an endurance time was assessed, a post-MVC was measured to quantify strength loss based on the MVC value obtained at the start of that session. The RPE scores generated from the fatiguing task were plotted against time using linear regressions to obtain the slope coefficient, namely, RPE rate, that examined differences in fatigue progression.

Shoulder flexion testing. For the shoulder muscle group, participants performed a series of intermittent shoulder flexion/extension and abduction/adduction exercises for a 2-minute warm-up period, following which shoulder MVC testing was conducted. Participants were situated in a supine position in a commercial dynamometer (Humac NORM, Computer Sports Medicine, Stoughton, MA, USA), with their dominant shoulder flexed at 90° (Figure 1b). The dynamometer's center of rotation was aligned with the arm and the glenohumeral joint. During each MVC trial, participants were instructed to maximally flex their shoulder by gripping the dynamometer handle using similar MVC testing procedures described earlier. For each participant, the maximum of the three repeated MVCs was used as the maximum shoulder flexion strength, which determined the intensity level for each participant's fatiguing task. After sufficient rest from the MVC testing, participants began the submaximal shoulder fatiguing task at 20%, 40%, 60%, or 80% (depending on the order of presentation for that session) of their shoulder MVC. At the end of the fatiguing task, which was similar to that described earlier, shoulder endurance times, strength loss, and RPE rates were obtained.

Trunk extension testing. For the trunk muscle group, participants performed a series of intermittent trunk flexion/extension and rotational exercises for a 2-minute warm-up period, following which trunk extension MVC testing was conducted. Participants stood upright on the dynamometer footplate with slightly flexed (< 5°) trunk against the sacral pad. Participants' feet were positioned against the footplate heel cups separated at about shoulder width (Figure 1c). The thigh pad, tibial pad, and pelvic belt were used to firmly secure the lower body and minimize the contributions of other muscles during trunk extension. The dynamometer's axis of rotation was aligned based on participants' iliac crest and L5/S1 location. During each MVC trial, participants were instructed to maximally extend their torso by pushing back against the dynamometer pad using similar MVC testing procedures described earlier. For each participant, the maximum of the three repeated MVCs determined the maximum trunk extension strength, which determined the intensity level for each participant's fatiguing tasks. After sufficient rest from the MVC testing, participants began the submaximal trunk fatiguing task at 20%, 40%, 60%, or 80% (depending on the order of presentation for that session) of their trunk MVC. At the end of the fatiguing task, which was similar to that described earlier, trunk endurance times, strength loss, and RPE rates were obtained.

Statistical Analyses

First, parametric model assumptions were assessed across all demographic (age, height, weight, BMI, percentage body fat, waist and hip circumference, and muscle strength) and fatigue (endurance time, strength loss, and RPE rate) measures. Except for endurance times and RPE rates, all study measures were normally distributed. Log transformations of endurance times and RPE rates were used to achieve homoscedasticity. Separate two-way analyses of variance (ANOVAs) were used to assess the main and interactive effects of gender (male or female) and BMI (normal weight, overweight, or obese) on demographic measures. Separate mixed-factor ANOVAs were used to assess the main and interactive effects of gender (male or female), BMI (normal weight, overweight, or obese), and intensity level (20%, 40%, 60%, or 80% MVC) on endurance times, strength loss, and RPE rates during handgrip, shoulder, and trunk fatiguing tasks. The level of statistical significance was set at $p < .05$ for all analyses. Significant interaction effects were examined using Bonferroni corrections as needed.

RESULTS

Detailed demographic information of the study participants, pooled across both sites, is presented in Table 1. Significant group-level differences, across male and female participant pools, in percentage body fat and waist circumference support that BMI differences were due to obesity rather than other confounding factors such as high muscularity. Handgrip, shoulder flexion, and trunk extension strength were found comparable across all BMI groups. Males demonstrated greater muscle strength than females across all muscle groups. Mean and standard deviation values for endurance times, strength loss, and RPE rates are listed in Table 2.

Handgrip Fatigability

A significant main effect of intensity was found on endurance time, $F(3, 399) = 603.31$, $p < .0001$; strength loss, $F(3, 408) = 100.21$, $p < .0001$; and RPE rate, $F(3, 399) = 953.13$, $p < .0001$, during handgrip exertions. In general, intensity showed a negative relationship with endurance time and strength loss and a positive relationship with RPE rate. BMI and gender or their interactions with intensity did not impact handgrip endurance times, strength loss, or RPE rates (all $p > .25$).

Shoulder Fatigability

A significant main effect of intensity was found on endurance time, $F(3, 390) = 322.21$, $p < .0001$; strength loss, $F(3, 408) = 67.89$, $p < .0001$; and RPE rate, $F(3, 390) = 875.53$, $p < .0001$, during shoulder exertions. Additionally, females exhibited 22.4% longer endurance times than males, $F(1, 130) = 8.01$, $p = .005$, and normal-weight adults demonstrated 21.7% longer endurance times than obese adults, $F(2, 130) = 2.54$, $p = .08$. A significant Intensity × Gender interaction, $F(3, 390) = 7.46$, $p < .0001$, was found; post hoc analyses revealed that the females demonstrated 21% to 25% longer endurance times than males during 20% and 40% MVC intensity levels. Similarly, a significant Intensity × BMI interaction, $F(6, 390) = 3.20$, $p = .004$, indicated that decrements in endurance times in obese adults were found statistically significant at 20% MVC intensity level. A significant Intensity × Gender × BMI interaction, $F(6, 390) = 2.23$, $p = .039$, revealed that during the 20% MVC exercise, while both normal-weight and overweight males demonstrated 32% to 34% longer endurance times than obese males, normal-weight females exhibited 24% to 30% longer endurance times than overweight and obese females. Strength loss remained comparable across gender and BMI groups across all intensity levels (all $p > .32$). RPE rates were significantly faster for males than females, $F(1,130) = 8.43$, $p = .004$. Additionally, a significant Intensity × Gender × BMI interaction on RPE rates was found, $F(6, 390) = 2.36$, $p = .03$. During the 20% MVC exertion, RPE rates were significantly faster in obese females than normal-weight females; these differences were not observed in males or during other intensity levels.

Trunk fatigability

Increasing levels of work intensity was found to significantly decrease trunk endurance times, $F(3, 366) = 161.93$, $p < .0001$, and strength loss, $F(3, 363) = 27.45$, $p < .0001$, and increase

TABLE 1: Participant Demographics

	Males						Females					
	Normal Weight (*N* = 24)		Overweight (*N* = 25)		Obese (*N* = 22)		Normal Weight (*N* = 25)		Overweight (*N* = 25)		Obese (*N* = 21)	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Age (years)	28.88	5.24	30.96	8.09	30.91	8.33	33.76	10.30	35.84	10.84	31.95	10.69
Height (cm)	175.38	6.69	174.22	6.58	173.73	5.52	163.47	5.15	162.11	5.01	165.62	7.03
Weight (kg)	70.41	5.60	82.13	6.37	106.24	15.60	59.43	7.09	71.15	5.64	95.18	15.04
BMI (kg/m^2)[a]	22.88	1.92	27.04	1.31	35.11	3.93	22.16	2.20	27.12	1.52	34.56	3.79
BF (%)[a,b]	14.47	4.50	23.37	4.85	30.31	4.01	28.64	5.59	36.39	2.85	43.08	3.72
WC (cm)[a,b]	84.06	6.18	92.98	6.93	113.05	12.58	75.74	12.39	88.55	8.08	103.11	8.68
HC (cm)[a]	97.54	6.31	103.91	6.98	120.99	14.83	93.12	16.20	102.53	7.93	116.82	12.06
Handgrip MVC (Nm)[b]	399.10	109.60	395.30	91.90	399.20	82.30	268.70	57.60	253.60	70.00	274.40	69.80
Shoulder MVC (Nm)[b]	56.40	15.10	59.10	13.10	61.40	13.50	33.60	8.70	33.80	7.70	35.80	8.30
Trunk MVC (Nm)[b]	133.50	51.10	142.40	61.20	140.10	60.20	86.20	36.20	83.90	39.40	77.90	34.10

Note. BMI = body mass index; BF = body fat; WC = waist circumference; HC = hip circumference; MVC = maximal voluntary contractions; Nm = Newton meter.
[a]Significant BMI group difference ($p < .0001$).
[b]Significant gender difference ($p < .0001$).

RPE rates, $F(3, 354) = 327.06$, $p < .0001$. All three trunk fatigue measures, namely, endurance times, strength loss, and RPE rates, were found to be comparable across both gender and BMI groups (all $p > .60$). However, significant Intensity × BMI interaction was found on endurance times, $F(6, 366) = 3.36$, $p = .003$, and RPE rates, $F(6, 354) = 3.99$, $p = .001$. Post hoc analysis revealed that during the 20% MVC exertion, normal-weight adults demonstrated 30% longer endurance times and 46.2% slower RPE rates than obese adults.

DISCUSSION

The present study aimed to quantify the effects of BMI on fatigue measures during sustained submaximal fatiguing tasks across three different muscle groups (handgrip, shoulder, and trunk). The major findings suggest that obese adults exhibit greater fatigability than normal-weight adults at the lower work intensity levels, particularly during shoulder and trunk exertions.

Consistent with existing literature on the nonlinear relationship between intensity and fatigue (Garg et al., 2002; Rohmert et al., 1986), increasing work intensities were associated with shorter endurance times, greater decreases in force generating capacity, and faster progression in perception of effort. This was evident across all the three muscle groups and across the entire study sample.

Females were found to be weaker but more fatigue resistant than males, particularly during shoulder exertions. This finding is consistent with existing evidence of gender differences on fatigability during isometric contractions at similar contraction intensities (Clark, Manini, Thé, Doldo, & Ploutz-Snyder, 2003; Hunter & Enoka, 2001). Additionally, the magnitude of gender differences in skeletal muscle fatigability decreased as contraction intensity increased; namely, males and females exhibited comparable endurance times at 60% to 80% MVC levels. During low-force sustained isometric contractions, females have shown greater muscle perfusion than males for some

TABLE 2: Mean (*SD*) of Endurance Times, Strength Loss, and RPE Rates Across Gender and BMI Groups During Handgrip, Shoulder, and Trunk Fatiguing Exertions at 20%, 40%, 60%, and 80% MVC Levels

			Males						Females					
			Normal Weight		Overweight		Obese		Normal Weight		Overweight		Obese	
			M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Endurance time (seconds)	Handgrip	20%	250.94	97.31	239.01	73.04	205.19	92.86	268.82	132.75	218.80	80.96	230.96	93.10
		40%	95.17	31.57	99.49	37.57	89.91	37.37	116.41	54.01	93.25	35.24	101.75	46.56
		60%	50.72	21.76	52.30	22.86	43.36	18.15	50.16	23.87	49.97	21.19	53.46	27.44
		80%	27.34	11.99	30.82	20.26	24.46	14.82	27.21	15.28	28.49	17.03	29.43	20.52
	Shoulder	20%	262.88	143.77	258.98	122.52	204.65	142.17	429.62	261.20	279.26	164.36	297.15	130.81
		40%	82.75	42.91	87.04	41.69	72.31	38.98	114.67	54.11	106.32	78.68	105.21	57.28
		60%	45.57	21.15	43.37	22.84	39.42	25.26	55.35	29.30	48.51	30.93	53.36	30.89
		80%	24.44	14.56	19.96	16.80	18.89	13.83	22.95	15.79	23.07	18.22	27.19	19.45
	Trunk	20%	986.85	759.81	796.82	645.93	709.25	673.24	1138.47	751.48	908.80	626.44	716.02	441.64
		40%	390.71	344.77	382.94	298.78	402.17	277.16	513.80	481.79	444.08	439.68	315.62	169.06
		60%	145.44	139.33	180.63	173.02	197.73	171.31	226.00	229.49	221.74	232.04	192.74	126.36
		80%	70.55	65.02	94.25	103.74	108.82	94.04	76.44	86.98	92.16	101.00	111.69	100.81
Strength loss (%)	Handgrip	20%	41.74	12.09	43.67	14.64	40.19	16.17	44.03	14.75	41.88	13.44	42.10	16.96
		40%	34.96	11.39	40.12	14.66	32.28	14.88	33.41	8.73	34.72	12.43	32.00	12.69
		60%	30.93	11.90	31.41	12.93	29.66	10.90	31.15	10.00	26.52	9.59	26.79	10.99
		80%	23.25	15.07	17.33	23.17	21.89	15.42	16.30	10.78	16.35	8.22	16.35	8.89
	Shoulder	20%	30.36	16.86	32.35	18.93	25.71	12.84	29.59	15.98	37.69	14.48	31.68	17.79
		40%	22.70	15.16	24.92	12.41	23.66	13.72	15.67	15.45	22.29	12.32	22.55	12.61
		60%	17.98	18.91	14.48	11.78	13.57	14.99	15.28	12.72	18.26	19.24	16.04	16.77
		80%	10.98	14.34	11.59	12.94	8.94	18.30	7.26	22.70	4.73	14.02	10.44	16.76
	Trunk	20%	14.86	29.97	24.77	26.41	15.55	19.19	29.52	22.43	14.26	25.36	26.14	22.32
		40%	11.72	13.85	18.92	18.15	11.41	17.58	16.20	18.17	14.02	15.31	19.00	18.99
		60%	7.38	22.21	6.87	19.65	4.58	18.49	8.92	17.90	12.18	19.42	9.21	19.60
		80%	1.25	23.50	0.68	28.22	–3.15	20.27	–2.45	17.13	4.05	17.39	1.41	28.79

(continued)

TABLE 2: (continued)

			Males						Females					
			Normal Weight		Overweight		Obese		Normal Weight		Overweight		Obese	
			M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
RPE rate (/min)	Handgrip	20%	2.36	0.87	2.75	0.97	3.15	2.06	2.46	1.17	2.88	1.30	2.96	1.54
		40%	6.63	2.27	5.82	2.58	7.64	3.94	5.48	2.55	6.98	3.66	7.19	4.74
		60%	12.13	4.61	12.21	5.75	14.74	8.38	13.16	7.58	12.72	6.07	14.71	13.26
		80%	25.59	13.44	26.90	19.16	29.45	17.49	30.03	18.95	27.85	16.84	25.59	16.16
	Shoulder	20%	2.66	1.73	2.59	1.12	3.94	2.78	1.67	0.99	2.74	1.72	2.07	1.33
		40%	7.76	4.07	6.73	3.00	8.50	4.38	5.58	2.64	7.25	4.99	6.08	3.80
		60%	15.46	9.40	17.82	14.40	18.83	13.95	13.24	12.70	18.14	15.18	11.42	6.60
		80%	25.44	15.61	35.01	19.63	31.72	15.51	32.30	19.46	29.54	17.55	22.74	16.85
	Trunk	20%	0.87	0.82	1.00	0.62	1.34	1.43	0.65	0.76	0.67	0.52	0.90	0.56
		40%	2.22	2.07	2.60	2.75	1.88	1.58	1.85	2.23	1.94	1.70	2.00	1.71
		60%	5.39	5.24	5.05	4.15	6.01	7.38	5.69	8.40	5.25	6.60	6.59	14.57
		80%	12.65	11.24	14.11	15.80	11.93	15.25	18.73	19.56	11.24	10.72	7.00	5.76

Note. RPE = ratings of perceived exertion; BMI = body mass index; MVC = maximal voluntary contractions.

muscle groups due to the lower levels of intramuscular pressure placed onto the feed arteries, which may have contributed to longer endurance times (Hicks, Kent-Braun, & Ditor, 2001; Hunter, 2009; Hunter et al., 2006; Maughan, Harmon, Leiper, Sale, & Delman, 1986).

In general, BMI was found to adversely affect muscle fatigability; however, this relationship was task dependent. Adverse effects of BMI were found on endurance times and RPE rates during shoulder and trunk exertions but not during handgrip exertions. The findings obtained here are generally consistent with existing evidence on the negative impact of obesity on endurance (Cavuoto & Nussbaum, 2013; Maffiuletti et al., 2007; Mehta & Cavuoto, 2015). While the present study found large obesity effects in the postural muscles, similar to that reported by Maffiuletti et al. (2007), these effects were not markedly different during handgrip exertions. The obesity-related increases in postural muscle fatigability were mostly observed at lower work intensities (i.e., at 20% MVC). At higher intensity levels during shoulder and trunk exertions and across all intensity levels during handgrip exertions, endurance times were similar across the three BMI groups. It is possible that the added body segment mass in obese adults during shoulder and trunk exertions may have contributed to increased fatigability when compared to handgrip exertions (Garg et al., 2002), particularly at the lower intensity levels when endurance times were longer.

Overweight males and females demonstrated similar magnitudes of fatigability as their normal-weight and obese counterparts across all intensity levels during handgrip and trunk exertions. During shoulder exertions, normal-weight and overweight males demonstrated longer endurance times than obese males; however, overweight and obese females exhibited shorter endurance times than normal-weight females. However, this was only observed during 20% MVC intensity level.

The underlying physiological mechanisms causing obesity difference in muscle fatigability are not completely understood. The explanation for the observed obesity differences in this study likely involves a combination of muscular mechanisms that include potential obesity differences in muscle fiber type composition and skeletal muscle capillarity. The postural muscles of the back and shoulder are made of greater proportions of slow twitch muscle fibers (Jørgensen, 1997; Manta, Kalfakis, Kararizou, Vassilopoulos, & Papageorgiou, 1996) when compared to hand/arm muscles that have greater proportion of fast twitch muscle fibers (Sadamoto, Mutoh, & Miyashita, 1992). It is possible that obesity-related increases in fatigability are related to the reductions in the proportion of slow twitch, namely, fatigue-resistant fibers (Lillioja et al., 1987; Tanner et al., 2002) in the postural musculature. Increased adiposity has also been linked to lower capillary densities in postural skeletal muscles (Lillioja et al., 1987). As such, it is possible that muscle perfusion in obese adults was affected during the low intensity exertions, resulting in greater imbalance between blood supply and task demand (Kagaya & Homma, 1997; Sadamoto et al., 1992). While obesity-related changes in muscle physiology are documented, changes in muscle function and structure in overweight adults, namely, those with BMI ranging between 25 and 30 kg/m^2, are relatively understudied. As such, the mechanisms for greater fatigability in overweight females during low-force shoulder exertions remains unclear.

Because shoulder and trunk endurance times were generally longer than handgrip endurance times, particularly at the lower intensities, early onset of central fatigue may have also played a large role in modulating exercise cessation time with obesity. Previous studies have attributed obesity-related changes in central drive, such as central activation failure (Maffiuletti et al., 2007; Pajoutan, Mehta, & Cavuoto, 2016), corticomuscular changes (Mehta, 2015, 2016; Mehta & Shortz, 2014), and changes in effort perception and/or motivation (Cavuoto & Nussbaum, 2013; Mehta, 2015), as the limiting factor for intermittent upper extremity endurance exercises. Because strength loss was comparable across all muscle groups within each BMI group, it is unlikely that differences in motivation between groups would have impacted the endurance times observed. Moreover, perceived effort rates remained comparable across the BMI groups at the lower intensities. Thus, it is possible that previously reported

obesity-related impairments in central drive (Pajoutan et al., 2016; Zory, Boerio, Jubeau, & Maffiuletti, 2005) may have contributed toward the shorter endurance times seen here.

An alternative, or supplementary, explanation of fatigue effects with obesity at lower work intensities may relate to varying cognitive processes associated with target-matching tasks, such as those employed in the present study. Obesity has previously shown to impair motor performance requiring precision force control (Gentier et al., 2013; Mehta & Shortz, 2014), and recent evidence has demonstrated that neural processes in motor function–related cortical regions, which are responsible for sending downstream muscle activation commands, are compromised with obesity (Mehta, 2016). Thus, longer exposure to the cognitive demands associated with maintaining target force/moment levels during the 20% MVC fatiguing task may have affected neuromuscular outcomes in obese adults.

There are several limitations in the present study. First, the study findings are limited to sustained voluntary fatiguing tasks rather than the more occupationally relevant intermittent static/dynamic tasks. Little was known regarding the impact of different task parameters on obesity-related differences in fatigability. As such, we first aimed to understand voluntary fatigue differences during sustained tasks. Second, while the four intensity levels, ranging from 20% to 80% MVC, are likely not representative of the ranges of workplace demand levels, it provided valuable insights regarding the nature and extent to which obesity, categorized based on BMI ranges, impacted muscle fatigability across different force production levels. Third, while the handgrip and trunk postures were representative of commonly observed work postures, the shoulder posture was selected to minimize gravitational impact of added body mass in the overweight and obese groups; however, shoulder testing lacked occupational relevance. Fourth, several mechanisms are presented that could potentially explain the obesity-related differences reported in this study; however, the investigation was largely descriptive in its approach. Fifth, the influence of chronic comorbidities with obesity, such as hypertension or diabetes, on muscle fatigability was not investigated in this study. Finally, while efforts were made to recruit workers, the study participants were largely university students and residents from local communities. Thus, the study inferences should be approached with caution when translating the present findings to workforce practices.

CONCLUSION

Over two-thirds of the U.S. working population is now overweight or obese; thus, it is critical that the influence of personal risk factors on fatigue and the subsequent likelihood of injury are determined to account for the changing workforce. The present study examined BMI-related differences on localized muscle fatigue that takes into account task parameters, such as work intensity levels and muscle groups employed. Obese adults demonstrated 22% to 30% shorter endurance times than normal-weight adults, but this was observed only at lower intensities and with larger and more postural muscles of the shoulder and low back. Obesity differences in worker capacites at low-force contraction levels are more critical from an ergonomics perspective since it's more likely that work tasks fall in this range rather than at higher (and near maximal) intensities. These findings provide initial evidence on the impact of obesity worker capacity. Future work is warranted to extend this investigation to include more occupationally relevant scenarios and testing of workers who have varying years of work experience and varied health statuses. Mechanistic investigations that provide better understanding of the nature and extent to which obesity impacts muscular capacities are also needed to inform effective strategies to minimize worker fatigue.

ACKNOWLEDGMENT

This publication was supported by the Grant No. 1 R03 OH 010547-01, funded by the Centers for Disease Control and Prevention–National Institute for Occupational Safety and Health. Its contents are solely the responsibility of the authors and do not necessarily represent the official views of the Centers for Disease Control and Prevention or the Department of Health and Human Services.

KEY POINTS

- Most existing ergonomic guidelines are derived from data with normal-weight participants, yet nearly two-thirds of the U.S. working population is overweight or obese.
- This study involved testing worker capacities across 12 different task conditions (3 muscle groups and 4 intensities) matched by gender and BMI ranges.
- Obese adults demonstrated 22% to 30% shorter endurance times than non-obese adults, but this was observed only at lower intensities and with larger and more postural muscles of the shoulder and low back.
- Females demonstrated 21% to 25% longer endurance times than males during shoulder exertions at lower intensities but not during handgrip or trunk exertions.

REFERENCES

Borg, G. (1990). Psychophysical scaling with applications in physical work and the perception of exertion. *Scandinavian Journal of Work, Environment & Health*, *16*, 55–58.

Bureau of Labor Statistics. (2012). *Nonfatal occupational injuries and illnesses requiring days away from work, 2011*. Retrieved from https://www.bls.gov/news.release/archives/osh2_11082012.pdf

Caldwell, L. S., Chaffin, D. B., Dukes-Dobos, F. N., Kroemer, K. H., Laubach, L. L., Snook, S. H., & Wasserman, D. E. (1974). A proposed standard procedure for static muscle strength testing. *American Industrial Hygiene Association Journal*, *35*(4), 201–206. doi:10.1080/0002889748507023

Cavuoto, L. A., & Nussbaum, M. A. (2013). Obesity-related differences in muscular capacity during sustained isometric exertions. *Applied Ergonomics*, *44*(2), 254–260.

Clark, B. C., Manini, T. M., Thé, D. J., Doldo, N. A., & Ploutz-Snyder, L. L. (2003). Gender differences in skeletal muscle fatigability are related to contraction type and EMG spectral compression. *Journal of Applied Physiology*, *94*(6), 2263–2272. doi:10.1152/japplphysiol.00926.2002

de Looze, M., Bosch, T., & van Dieen, J. (2009). Manifestations of shoulder fatigue in prolonged activities involving low-force contractions. *Ergonomics*, *52*(4), 428.

Eksioglu, M. (2011). Endurance time of grip-force as a function of grip-span, posture and anthropometric variables. *International Journal of Industrial Ergonomics*, *41*(5), 401–409.

Finkelstein, E., Chen, H., Prabhu, M., Trogdon, J. G., & Corso, P. S. (2007). The relationship between obesity and injuries among U.S. adults. *American Journal of Health Promotion: AJHP*, *21*(5), 460. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/17515011

Finkelstein, E., Fiebelkorn, L. C., & Wang, G. (2005). The costs of obesity among full-time employees. *American Journal of Health Promotion: AJHP*, *20*(1), 45. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/16171161

Flegal, K. M., Carroll, M. D., Ogden, C. L., & Johnson, C. L. (2002). Prevalence and trends in obesity among US adults, 1999-2000. *JAMA*, *288*(14), 1723–1727.

Fogelholm, M., Malmberg, J., Suni, J., Santtila, M., Kyrlinen, H., & Mntysaari, M. (2006). Waist circumference and BMI are independently associated with the variation of cardio-respiratory and neuromuscular fitness in young adult men. *International Journal of Obesity*, *30*(6), 962–969.

Garg, A., Hegmann, K. T., Schwoerer, B. J., & Kapellusch, J. M. (2002). The effect of maximum voluntary contraction on endurance times for the shoulder girdle. *International Journal of Industrial Ergonomics*, *30*(2), 103–113. doi:10.1016/S0169-8141(02)00078-1

Gentier, I., D'Hondt, E., Shultz, S., Deforche, B., Augustijn, M., Hoorne, S., . . . Lenoir, M. (2013). Fine and gross motor skills differ between healthy-weight and obese children. *Research in Developmental Disabilities*, *34*(11), 4043–4051.

Hickey, M. S., Carey, J. O., Azevedo, J. L., Houmard, J. A., Pories, W. J., Israel, R. G., & Dohm, G. L. (1995). Skeletal muscle fiber composition is related to adiposity and in vitro glucose transport rate in humans. *American Journal of Physiology-Endocrinology and Metabolism*, *268*(3), E457.

Hicks, A. L., Kent-Braun, J., & Ditor, D. S. (2001). Sex differences in human skeletal muscle fatigue. *Exercise and Sport Sciences Reviews*, *29*(3), 109–112.

Hulens, M., Vansant, G., Lysens, R., Claessens, A. L., Muls, E., & Brumagne, S. (2001). Study of differences in peripheral muscle strength of lean versus obese women: An allometric approach. *International Journal of Obesity & Related Metabolic Disorders*, *25*(5), 676–681.

Hunter, S. K. (2009). Sex differences and mechanisms of task-specific muscle fatigue. *Exercise and Sport Sciences Reviews*, *37*(3), 113. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/19550202

Hunter, S. K., & Enoka, R. M. (2001). Sex differences in the fatigability of arm muscles depends on absolute force during isometric contractions. *Journal of Applied Physiology*, *91*(6), 2686–2694.

Hunter, S. K., Schletty, J. M., Schlachter, K. M., Griffith, E. E., Polichnowski, A. J., & Ng, A. V. (2006). Active hyperemia and vascular conductance differ between men and women for an isometric fatiguing contraction. *Journal of Applied Physiology*, *101*(1), 140–150. doi:10.1152/japplphysiol.01567.2005

Innes, E. V. (1999). Handgrip strength testing: A review of the literature. *Australian Occupational Therapy Journal*, *46*(3), 120–140.

Jørgensen, K. (1997). Human trunk extensor muscles physiology and ergonomics. *Acta Physiologica Scandinavica Supplementum*, *637*, 1. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/9246395

Kagaya, A., & Homma, S. (1997). Brachial arterial blood flow during static handgrip exercise of short duration at varying intensities studied by a Doppler ultrasound method. *Acta Physiologica Scandinavica*, *160*(3), 257–265.

Kankaanp, M., Laaksonen, D., Taimela, S., Kokko, S., Airaksinen, O., & Hnninen, O. (1998). Age, sex, and body mass index as determinants of back and hip extensor fatigue in the isometric Sørensen back endurance test. *Archives of Physical Medicine and Rehabilitation*, *79*(9), 1069–1075.

Kriketos, A. D., Baur, L. A., O'Connor, J., Carey, D., King, S., Caterson, I. D., & Storlien, L. H. (1997). Muscle fibre type composition in infant and adult populations and relationships

with obesity. *International Journal of Obesity & Related Metabolic Disorders*, *21*(9), 796–801.

Krotkiewski, M., Grimby, G., Holm, G., & Szczepanik, J. (1990). Increased muscle dynamic endurance associated with weight reduction on a very-low-calorie diet. *The American Journal of Clinical Nutrition*, *51*(3), 321–330.

Kumar, S. (2001). Theories of musculoskeletal injury causation. *Ergonomics*, *44*(1), 17–47. doi:10.1080/00140130120716

Levy, J., Segal, L. M., Thomas, K., Laurent, R. S., Lang, A., & Rayburn, J. (2013). *F as in fat: How obesity threatens America's future 2013*. Princeton, NJ: The Robert Wood Johnson Foundation.

Liberty Mutual Research Institute for Safety. (2013). 2*012 Liberty Mutual Workplace Safety Index*. Retrieved from http://www.mhi.org/downloads/industrygroups/ease/technicalpapers/Libery-Mutual-Safety-Index-2012-WSI.pdf

Lillioja, S., Young, A. A., Culter, C. L., Ivy, J. L., Abbott, W. G., Zawadzki, J. K., . . . Bogardus, C. (1987). Skeletal muscle capillary density and fiber type are possible determinants of in vivo insulin resistance in man. *The Journal of Clinical Investigation*, *80*(2), 415–424. doi:10.1172/JCI113088

Maffiuletti, N. A., Jubeau, M., Munzinger, U., Bizzini, M., Agosti, F., De Col, A., . . . Sartorio, A. (2007). Differences in quadriceps muscle strength and fatigue between lean and obese subjects. *European Journal of Applied Physiology*, *101*(1), 51–59.

Manta, P., Kalfakis, N., Kararizou, E., Vassilopoulos, D., & Papageorgiou, C. (1996). Size and proportion of fiber types in human muscle fascicles. *Clinical Neuropathology*, *15*(2), 116. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/8925596

Maughan, R. J., Harmon, M., Leiper, J. B., Sale, D., & Delman, A. (1986). Endurance capacity of untrained males and females in isometric and dynamic muscular contractions. *European Journal of Applied Physiology and Occupational Physiology*, *55*(4), 395–400. doi:10.1007/BF00422739

Mehta, R. K. (2015). Impacts of obesity and stress on neuromuscular fatigue development and associated heart rate variability. *International Journal of Obesity*, *39*(2), 208–213.

Mehta, R. K. (2016). Stunted PFC activity during neuromuscular control under stress with obesity. *European Journal of Applied Physiology*, *116*(2), 319–326.

Mehta, R. K., & Cavuoto, L. A. (2015). The effects of obesity, age, and relative workload levels on handgrip endurance. *Applied Ergonomics*, *46*, 91–95.

Mehta, R. K., & Shortz, A. E. (2014). Obesity-related differences in neural correlates of force control. *European Journal of Applied Physiology*, *114*(1), 197–204.

Mital, A., & Kumar, S. (1998). Human muscle strength definitions, measurement, and usage: Part I—Guidelines for the practitioner. *International Journal of Industrial Ergonomics*, *22*(1), 101–121.

Nedungadi, T. P., & Clegg, D. J. (2009). Sexual dimorphism in body fat distribution and risk for cardiovascular diseases. *Journal of Cardiovascular Translational Research*, *2*(3), 321–327. doi:10.1007/s12265-009-9101-1

Nicolay, C. W., & Walker, A. L. (2005). Grip strength and endurance: Influences of anthropometric variation, hand dominance, and gender. *International Journal of Industrial Ergonomics*, *35*(7), 605–618.

Pajoutan, M., Mehta, R. K., & Cavuoto, L. A. (2016). The effect of obesity on central activation failure during ankle fatigue: A pilot investigation. *Fatigue: Biomedicine, Health & Behavior*, *4*(2), 115–126.

Price, A. D. (1990). Calculating relaxation allowances for construction operatives—Part 2: Local muscle fatigue. *Applied Ergonomics*, *21*(4), 318–324.

Rohmert, W., Wangenheim, M., Mainzer, J., Zipp, P., & Lesser, W. (1986). A study stressing the need for a static postural force model for work analysis. *Ergonomics*, *29*(10), 1235–1249.

Rolland, Y., Lauwers-Cances, V., Pahor, M., Fillaux, J., Grandjean, H., & Vellas, B. (2004). Muscle strength in obese elderly women: Effect of recreational physical activity in a cross-sectional study. *The American Journal of Clinical Nutrition*, *79*(4), 552–557.

Roman-Liu, D., Tokarski, T., & Kowalewski, R. (2005). Decrease of force capabilities as an index of upper limb fatigue. *Ergonomics*, *48*(8), 930–948.

Sadamoto, T., Mutoh, Y., & Miyashita, M. (1992). Cardiovascular reflexes during sustained handgrip exercise: Role of muscle fibre composition, potassium and lactate. *European Journal of Applied Physiology and Occupational Physiology*, *65*(4), 324–330.

Tanner, C. J., Barakat, H. A., Dohm, G. L., Pories, W. J., MacDonald, K. G., Cunningham, P. R., . . . Houmard, J. A. (2002). Muscle fiber type is associated with obesity and weight loss. *American Journal of Physiology-Endocrinology and Metabolism*, *282*(6), E1196.

Taylor, R. W., Grant, A. M., Williams, S. M., & Goulding, A. (2010). Sex differences in regional body fat distribution from pre- to postpuberty. *Obesity*, *18*(7), 1410–1416. doi:10.1038/oby.2009.399

Visser, B., & van Dieën, J. H. (2006). Pathophysiology of upper extremity muscle disorders. *Journal of Electromyography and Kinesiology*, *16*(1), 1–16. doi:10.1016/j.jelekin.2005.06.005

Werner, R. A., Albers, J. W., Franzblau, A., & Armstrong, T. J. (1994). The relationship between body mass index and the diagnosis of carpal tunnel syndrome. *Muscle & Nerve*, *17*(6), 632–636. doi:10.1002/mus.880170610

Withrow, D., & Alter, D. A. (2011). The economic burden of obesity worldwide: A systematic review of the direct costs of obesity. *Obesity Reviews*, *12*(2), 131–141.

Zory, R., Boerio, D., Jubeau, M., & Maffiuletti, N. A. (2005). Central and peripheral fatigue of the knee extensor muscles induced by electromyostimulation. *International Journal of Sports Medicine*, *26*(10), 847–853.

Ranjana K. Mehta is an assistant professor in the Department of Environmental and Occupational Health at the Texas A&M University and graduate faculty in the Texas A&M Institute for Neuroscience. Her research examines multifactorial causes and injury mechanisms of work-related musculoskeletal disorders, particularly with obesity and aging.

Lora Anne Cavuoto, is an assistant professor in the Department of Industrial and Systems Engineering at the University at Buffalo and director of the Ergonomics and Biomechanics Laboratory. Her research focuses on quantifying physical exposures and physiological responses in the workplace to identify indicators of fatigue development.

Date received: August 6, 2016
Date accepted: January 3, 2017