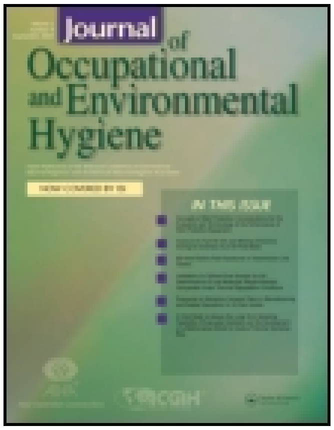
This article was downloaded by: [2.225.205.158]
On: 06 August 2014, At: 23:20
Publisher: Taylor & Francis
Informa Ltd Registered in England and Wales Registered Number: 1072954 Registered office: Mortimer House, 37-41 Mortimer Street, London W1T 3JH, UK



Journal of Occupational and Environmental Hygiene
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/uoeh20

The Influences of Obesity and Age on Functional Performance During Intermittent Upper Extremity Tasks

Lora A. Cavuoto[a] & Maury A. Nussbaum[b]

[a] Department of Industrial and Systems Engineering, University at Buffalo, SUNY, Buffalo, New York

[b] Department of Industrial and Systems Engineering, Virginia Tech, Blacksburg, Virginia

Accepted author version posted online: 31 Jan 2014.Published online: 21 Jul 2014.

To cite this article: Lora A. Cavuoto & Maury A. Nussbaum (2014) The Influences of Obesity and Age on Functional Performance During Intermittent Upper Extremity Tasks, Journal of Occupational and Environmental Hygiene, 11:9, 583-590, DOI: 10.1080/15459624.2014.887848

To link to this article: http://dx.doi.org/10.1080/15459624.2014.887848

PLEASE SCROLL DOWN FOR ARTICLE

Taylor & Francis makes every effort to ensure the accuracy of all the information (the “Content”) contained in the publications on our platform. However, Taylor & Francis, our agents, and our licensors make no representations or warranties whatsoever as to the accuracy, completeness, or suitability for any purpose of the Content. Any opinions and views expressed in this publication are the opinions and views of the authors, and are not the views of or endorsed by Taylor & Francis. The accuracy of the Content should not be relied upon and should be independently verified with primary sources of information. Taylor and Francis shall not be liable for any losses, actions, claims, proceedings, demands, costs, expenses, damages, and other liabilities whatsoever or howsoever caused arising directly or indirectly in connection with, in relation to or arising out of the use of the Content.

This article may be used for research, teaching, and private study purposes. Any substantial or systematic reproduction, redistribution, reselling, loan, sub-licensing, systematic supply, or distribution in any form to anyone is expressly forbidden. Terms & Conditions of access and use can be found at http://www.tandfonline.com/page/terms-and-conditions

Journal of Occupational and Environmental Hygiene, 11: 583–590
ISSN: 1545-9624 print / 1545-9632 online

DOI: 10.1080/15459624.2014.887848

The Influences of Obesity and Age on Functional Performance During Intermittent Upper Extremity Tasks

Lora A. Cavuoto[1] and Maury A. Nussbaum[2]

[1]Department of Industrial and Systems Engineering, University at Buffalo, SUNY, Buffalo, New York
[2]Department of Industrial and Systems Engineering, Virginia Tech, Blacksburg, Virginia

In this study, the main and interactive effects of obesity and age on functional performance were assessed during intermittent exertions involving the upper extremity. The prevalence of obesity has doubled over the past 30 years and this increase is associated with higher health care costs, rates of workplace injury, and lost workdays. Obesity and aging can modify job demands and affect worker capacity in terms of muscular and psychomotor function. However, there is a lack of empirical studies quantifying the work-relevant (or ergonomic) impacts related to task demands, capacities, and their potential imbalance. Eight obese and eight non-obese participants from each of two age groups (18–25 and 50–65 years) completed three endurance tasks involving fixed levels of task demands: hand grip, shoulder flexion, and a simulated assembly task using the upper extremity. Measures of functional performance including endurance, discomfort, motor control, and task performance were recorded for each of the task conditions. Endurance times were ∼60% longer for the non-obese group, and older participants had longer endurance times; however there was no evidence of interactive effects of obesity and age. Obesity also impaired functional performance, as indicated by higher rates of strength loss, increases in discomfort, and declines in task performance. These observed impairments may reflect underlying physiological differences among individuals who are obese, but that are independent of age. Obesity-related impairments may have implications for the design of work duration and demand level to prevent fatigue development for workers who are obese.

Keywords aging, endurance, intermittent exertions, motor control, obesity, shoulder fatigue

Address correspondence to: Lora A. Cavuoto, Department of Industrial and Systems Engineering, University at Buffalo, SUNY, 324 Bell Hall, Buffalo, NY 14260; e-mail: loracavu@buffalo.edu

INTRODUCTION

Work-related injuries can result in decreased productivity, lost workdays, lower work quality, and worker dissatisfaction.(1–3) Recent demographic changes, leading to an older and more obese workforce, can be expected to continue if not increase the incidence and costs of these injuries. Worldwide, there are over 1.5 billion adults with a body mass index (BMI) > 25 kg/m^2, who are classified as overweight.(4) Over the past 30 years, the prevalence of obesity (defined as a BMI $>$ 30 kg/m^2) has more than doubled.(4) Workers who are obese have up to 13 times as many lost workdays per workplace incident,(5) in addition to higher rates of injury,(6) direct medical costs,(7,8) and workers' compensation claims.(9) Similarly, the past 30 years have seen a doubling of workers over 65 years old.(10) Occupational injuries and illnesses become more severe as age increases, with workers over 55 missing a median of 12 days of work per injury.(1)

Obesity is associated with physiological changes at the muscle level, including a decrease in capillary density(11) and blood flow,(12) thereby limiting the supply of oxygen and energy sources. Typical interventions for obesity such as training and weight loss appear insufficient for returning capillary density to normal levels.(11,13,14) Combined with limited blood flow, muscle cells in individuals who are obese have a decrease in the relative amount and size of the mitochondria necessary to provide energy.(12,15)

When performing sustained contractions, these physiological changes reduce recovery efficiency and may thereby lead to a faster onset of muscle fatigue.(12) In support of this, Eksioglu(16) reported an inverse relationship between BMI and endurance time during sustained isometric contractions at 30% of maximum. An earlier study on obesity-related endurance differences for young adults found contrary results, with comparable endurance times observed among individuals in obese and non-obese groups, for hand grip, shoulder flexion, and torso extension at fixed exertion levels.(17) However, in another study, which included both young and older adults, shorter shoulder flexion endurance times were found with obesity.(18)

Fatigue-induced reductions in muscle capacity can lead to increased risk of injury, as well as decreased work performance.(19) Recently, Tetteh et al.(20) investigated fatigue of the upper back muscles during two manual handling tasks, concluding that a higher BMI leads to a longer time to complete self-paced tasks and decreased performance. Movement time increases have also been observed for upper extremity tasks requiring controlled aiming.(21) For seated tasks that remove the mechanical demands of additional inertial load from body mass support, children who are obese have been shown to have poorer performance in a fine motor control task (peg placing) compared to those who are non-obese or overweight.(22)

With respect to aging, there is a selective reduction of fatigable muscle fibers,(23,24) leading to slower fatigue development and longer endurance with age when tasks are performed at fixed levels relative to individual strength.(25,26) Previous examinations of activities of daily living have indicated that both age and obesity lead to an increased risk of mobility limitation, particularly for walking and lower extremity tasks.(27–30) The tasks tested have primarily involved the lower extremity under light-loading conditions, and previous studies have rarely considered the impact of loading demands for upper extremity tasks. In addition, most of these noted studies have focused on women over 60 years old, which provides only a limited understanding of capabilities/limitations of the broader segment of the obese and aging workforce. In one of our earlier studies, we had inconclusive findings regarding a potential interactive effect of obesity and age on endurance time for sustained isometric exertions.(18) For the older obese population, no studies to the authors' knowledge have examined tasks with direct relevance to workplace demands, capacity, or performance.

Given the ongoing changes in workforce demographics, and some limitations of previous research as noted, new data are needed to guide the design of manual work for persons of all body types. Therefore, and as an initial step toward this goal, the purpose of the current work was to assess the main and interactive effects of age and obesity on functional performance during intermittent exertions. Functional performance here includes endurance, discomfort, motor control, and task performance, and was measured in three distinct task conditions that involved a range of upper extremity demands. Use of intermittent tasks was intended to move toward a closer replication of workplace conditions, which often involve short rest periods. It was hypothesized that: 1) individuals who are obese would have decreased functional performance; 2) a more substantial effect of obesity would be observed among older participants; and 3) the effect of obesity would be larger when a task requires support and movement of arm mass.

METHODS

Participants

Thirty-two participants from the local community were recruited to form four groups of eight each (four males, four females), based on obesity level and age: non-obese young ($18.5 < \text{BMI} < 25$ kg/m^2, 18–25 years), obese young ($30 < \text{BMI} < 40$ kg/m^2), non-obese older (50–65 years), and obese older. BMI was restricted to < 40 kg/m^2 to avoid the likely comorbidities present at higher BMIs. Participants completed an informed consent procedure approved by the Virginia Tech Institutional Review Board. All participants reported their regular physical activity using the Global Physical Activity Questionnaire.(31) Each of the four groups had comparable statures and levels of physical activity (summary data on the four groups provided in Table I). The mean physical activity levels are approximately equivalent to walking for 1 hr per day. Significant group-level differences in waist and hip circumferences support that BMI differences were due to obesity rather than factors such as high muscularity.(32,33)

Procedures

The study involved two experimental sessions, separated by at least two days to minimize any effects from residual muscle fatigue or soreness. In one session, participants completed intermittent endurance tasks involving unilateral hand grip and shoulder flexion, and in the other they completed a simulated functional upper extremity endurance task using a Purdue pegboard (Model 32020, Lafayette Instrument, Lafayette, Ind.). The presentation order of the two sessions was counterbalanced, as was the presentation order of the hand grip and shoulder flexion tasks within a session. Participants were provided with sufficient rest (∼5 min) between the hand grip and shoulder flexion tasks such that their discomfort returned to baseline levels before starting the second task.

Prior to each endurance task, warm-up exercises and task familiarization were completed and involved intermittent static and dynamic submaximal exertions of the specific task. Subsequently, participants performed a series of isometric maximum voluntary contractions (MVCs), involving hand grip, shoulder flexion, or shoulder abduction depending on the task being tested, and with shoulder abduction used as a representative strength measure for the pegboard task. All tasks were performed with the right arm/hand, and all participants reported being right-hand dominant. Grip strength was measured using a digital grip dynamometer (microFET 4, Hoggan Health Industries Inc., West Jordan, Utah). For shoulder flexion, participants sat in a commercial dynamometer (Biodex System 3 Pro, Biodex Medical Systems, Shirley, N.Y.). Postures for the hand grip and shoulder flexion tasks were standardized as described in previous work.(17) For shoulder abduction, participants sat upright in the Biodex with their shoulder abducted so that their arm was parallel to the ground (Figure 1). During both shoulder exertions, the dynamometer center-of-rotation was aligned with that of the glenohumeral joint. For each MVC, participants were asked to build to a maximum exertion over 2 sec, hold it for 3 sec, and then ramp down to rest, while maintaining the test posture.

Participants were given verbal encouragement and visual feedback of their force/moment output. At least three MVC trials were completed, each separated by 2 min of rest, until peak moments were non-increasing. The maximum force or moment across MVC trials was recorded as the participant's MVC, with subsequent corrections, as relevant, for gravitational effects on dynamometer fixtures and body segments.

Following the MVCs and at least 2 min of rest, participants completed an endurance task for one of the three exertions. The hand grip and shoulder flexion endurance tasks involved

TABLE I. Summary Data from the Four Participant Groups (mean (SD))^A

Measure	Group					
	Non-obese Young	Obese Young	Non-obese Older	Obese Older	Obesity *p*-value	Age *p*-value
Age (yr)	20.6(2.1)	22.0(2.1)	56.6(4.3)	55.0(3.6)	0.91	$< 0.001^*$
Body Mass (kg)	70.0(7.3)	100.6(14.6)	76.4(5.3)	104.2(14.9)	$< 0.001^*$	0.23
Stature (m)	1.74(0.1)	1.71(0.1)	1.76(0.1)	1.70(0.1)	0.14	0.90
BMI (kg/m^2)	23.1(1.5)	34.3(4.0)	24.7(0.4)	35.9(3.6)	$< 0.001^*$	0.12
Waist Circumference (cm)	85.6(4.3)	109.1(10.1)	91.1(7.4)	119.2(11.7)	$< 0.001^*$	0.01^*
Hip Circumference (cm)	97.9(2.7)	119.0(8.9)	103.2(3.0)	124.1(9.3)	$< 0.001^*$	0.04^*
Waist-to-Hip Ratio	0.86(0.0)	0.92(0.1)	0.89(0.1)	0.96(0.1)	0.01^*	0.15
Physical Activity (MET-min/wk)	1641(855)	1490(1546)	1870(953)	1335(1098)	0.40	0.93

^{A}Significant differences ($p < 0.05$, from ANOVA) are indicated by the * symbol.

intermittently maintaining an absolute force or moment, in the same postures and with the same data collection methods as those used for the MVCs. During the task, participants tracked their generated force/moment against a target as closely as possible based on real-time visual feedback. For hand grip the target force was 100 N, and for shoulder flexion the target moment was 9 Nm (above that required to support the arm mass). A prior study has shown that this target force is similar to the typical grip demands required by common screwdriving and carrying tasks.(34) From a static biomechanical analysis, the target shoulder moment was approximately equivalent to the effort required by a 50th percentile male to support a typical hand tool in the tested posture. On average, these targets equated to a relative demand of ∼28% MVC for the obese group and ∼31% for the non-obese group (including the torque required to support arm mass for the shoulder task). Both tasks were completed with a duty cycle of 0.75 and a cycle time of 30 sec; therefore, each 22.5-sec exertion period was followed by 7.5 sec of rest.

FIGURE 1. Posture used for the shoulder abduction exertion. (color figure available online)

Based on our prior work on sustained hand grip and shoulder flexion tasks, the cycle time here was chosen such that participants would be able to complete multiple cycles with a target mean endurance time of approximately 5–10 min. The specific duty cycle was used both to represent relatively long contraction times for intermittent tasks that may occur in construction or light manufacturing work and, based on pilot work, to lead to exhaustion for most participants during the pegboard task. This work-rest cycle continued until the participant indicated he or she could no longer track the target or 1 hr had elapsed.

For the Purdue pegboard task, participants were seated with the base of the pegboard at shoulder height and with the pegboard supported at an incline (Figure 2a, b). Participants were instructed to keep their back against the chair and to remain facing the pegboard. Participants completed assemblies during the intermittent work periods of the endurance task, and each assembly involved placing four pieces in sequence (pins, washers, and collars; Figure 2c). Mean relative task demand at the shoulder from the support of the arm weight was ∼15% MVC for both the non-obese and obese groups. To ensure a consistent task demand across participants, the task was paced with auditory tones at a rate of 20 beats per min. On the first beat, participants picked up a pin and placed it in a hole on the pegboard. On subsequent beats, they picked up and placed a washer over the pin, followed by a collar, and a second washer. After one assembly was complete, these steps were repeated at the next hole on the pegboard (working down from the top). The pegboard task was completed with the same duty cycle of 0.75, but a longer cycle time of 160 sec was used so that a sufficient number of assemblies could be completed for performance analysis. Previous work has shown that endurance time is sensitive to differences in duty

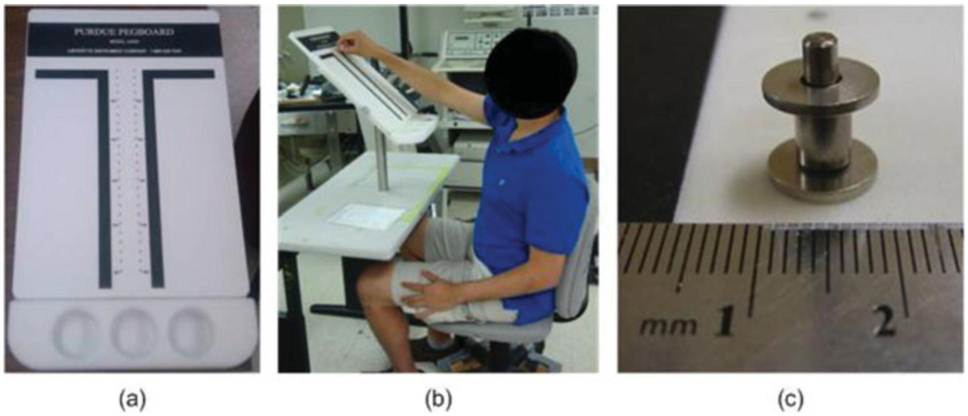


FIGURE 2. (a) Purdue pegboard; (b) posture used to complete the test; and (c) an assembly. (color figure available online)

cycle, but less so to cycle time;(35,36) therefore duty cycle was kept consistent across the tasks. At the start of each work period, participants started again at the first (top) hole on the pegboard. This work-rest cycle continued until the participant indicated he or she could no longer complete the task or 1 hr had elapsed.

During all endurance tasks, participants provided Ratings of Perceived Discomfort (RPDs) using a 10-point scale(37) for the relevant body part(s) at the end of each work period. For the hand grip, shoulder flexion, and pegboard tasks, RPDs were provided for distal upper extremity, shoulder, and upper arm, respectively. The scale was visible to participants throughout the tasks. Immediately following each endurance task, participants performed a single MVC for the relevant exertion to quantify strength loss.

Dependent Measures and Analysis

Endurance time was determined based on the number of full work-rest cycles completed in a given task, or the maximum value of 60 min. The rate of strength loss was quantified as the percentage change in MVC divided by the endurance time. RPDs were provided for relevant body parts as noted earlier. A measure of performance was calculated for each task: tracking ability for the hand grip and shoulder flexion tasks and the number of assemblies completed for the pegboard task. For the former, tracking performance was quantified as the duration, within each work period, that the participant remained within a $+/-5\%$ band around the target force/moment.(17) For the pegboard task, performance was quantified as the percent of assemblies completed compared to the target pace (10 assemblies per work period). If a participant met the target pace, their performance would be 100% for that period. Rates of increase in RPD and rates of decrease in performance (as a percent change) were both obtained using linear regression (vs. time).

Separate mixed-factor analyses of variance (ANOVAs) were used to assess the main and interactive effects of obesity, age, task, and gender, with presentation order included as a blocking variable. Note that higher levels of fatigue (or effects of fatigue) were considered evidenced by shorter endurance times and/or higher rates of strength loss, RPD increase, or performance decrement. Due to the exploratory nature of this work and the small sample size in each group, which was limited by available resources, the level of significance for all analyses was set at $p < 0.1$. Log transformation was used on the endurance time data to achieve homoscedasticity, for which summary statistics are presented as means (95% confidence intervals), after back-transformation to the original units. All other summary statistics are presented as means (SDs). Significant interaction effects were examined using simple effects testing or pairwise comparisons as relevant.

RESULTS

Endurance Time and Strength Loss

The main effect of obesity was significant ($F_{(1,24)} = 9.7$; $p = 0.0047$; $\eta^2 = 0.056$), and the non-obese group overall had ~60% longer endurance times (663 (493–891) s) than the obese group (415 (322–534) s). In addition, there were main effects of age ($F_{(1,24)} = 3.7$; $p = 0.065$; $\eta^2 = 0.022$), task ($F_{(2,48)} = 86.2$; $p < 0.0001$; $\eta^2 = 0.40$), and gender ($F_{(1,24)} = 16.5$; $p = 0.0005$; $\eta^2 = 0.095$). Longer endurance times were observed in the older (606 (452–813) s) versus young groups (453 (347–592) s) and among males (711 (547–925) s) versus females (386 (293–509) s). There was a significant obesity x task interaction ($F_{(2,48)} = 2.5$; $p = 0.0909$; $\eta^2 = 0.012$); the obese group had a significantly shorter endurance times for both the grip and pegboard tasks, whereas comparable values were found for shoulder flexion (Figure 3). Overall rates of strength loss were 4.0 (4.7)%/min, and these were consistent between the obese versus non-obese groups ($F_{(1,24)} = 0.52$; $p > 0.48$; $\eta^2 = 0.0043$) and the young versus older groups ($F_{(1,24)} = 0.26$; $p > 0.61$; $\eta^2 = 0.0021$). There was a significant obesity x gender interaction ($F_{(1,24)} = 3.3$; $p = 0.0818$; $\eta^2 = 0.027$), with obese males having higher rates of strength loss than non-obese males (Figure 4).

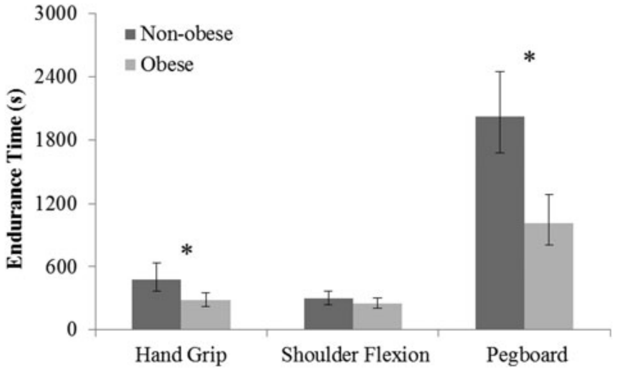


FIGURE 3. Mean endurance times by task for each obesity group. Error bars represent 95% confidence intervals, and the symbol* indicates a significant ($p < 0.1$) difference between obesity groups within a given task.

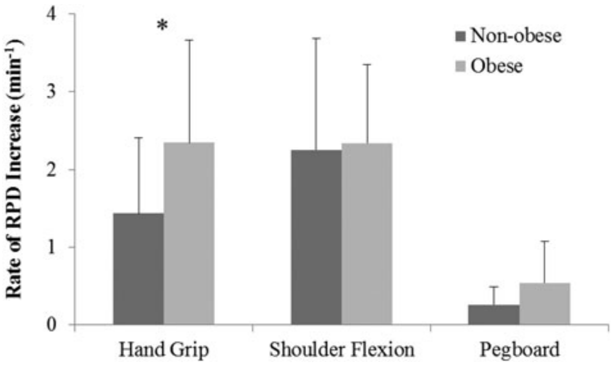


FIGURE 5. Mean rate of RPD increase by task for each obesity group. Error bars represent standard deviations. The symbol* indicates a significant ($p < 0.1$) difference between obesity groups within a given task.

RPDs

Obesity had a main effect on the rate of RPD increase ($F_{(1,24)} = 4.4$; $p = 0.047$; $\eta^2 = 0.027$), with the obese group (1.7 (1.3) min^{-1}) having rates ~32% higher overall than the non-obese group (1.3 (1.3) min^{-1}). Younger participants also had higher ($F_{(1,24)} = 5.1$; $p = 0.034$; $\eta^2 = 0.031$) rates of RPD increase compared to the older participants (1.8 (1.3) vs. 1.3 (1.2) min^{-1}). There was a significant obesity x task interaction ($F_{(2,48)} = 2.7$; $p = 0.078$; $\eta^2 = 0.018$); though rates were higher in the obese group for all three tasks, the difference in the hand grip task was the most substantial (~60% higher) and was the only one significant ($p = 0.003$; Figure 5).

Task Performance

Rates of performance decrement were higher ($F_{(1,24)} = 8.4$; $p = 0.008$; $\eta^2 = 0.079$) in the obese group (6.1 (10.0)%/min) than in the non-obese group (1.5 (5.4)%/min). There was also a significant obesity x gender interaction ($F_{(1,24)} = 3.8$; $p = 0.063$; $\eta^2 = 0.036$). The obese female group had rates of performance decrement more than six times higher than the non-obese female group ($p = 0.0022$), but similar ($p > 0.51$) rates were found between obesity groups among males (Figure 6, top). The effect of obesity on the rate of performance decrement was also dependent on task ($F_{(2,48)} = 4.0$; $p = 0.024$; $\eta^2 = 0.055$). There was no difference ($p > 0.95$) between obesity groups for the pegboard task, though the rate of tracking performance decrement was over seven times higher for the obese group than the non-obese group ($p = 0.0004$) for the hand grip task, and more than two times higher ($p = 0.06$) for the shoulder flexion task (Figure 6, bottom).

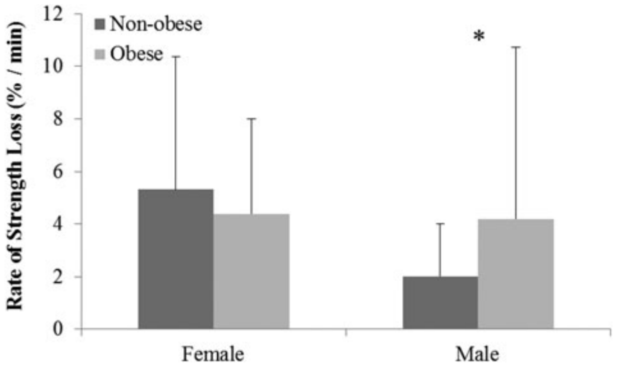


FIGURE 4. Mean rates of strength loss by gender for each obesity group. Error bars represent standard deviations. The symbol* indicates a significant ($p < 0.1$) difference between obesity groups within a given gender.

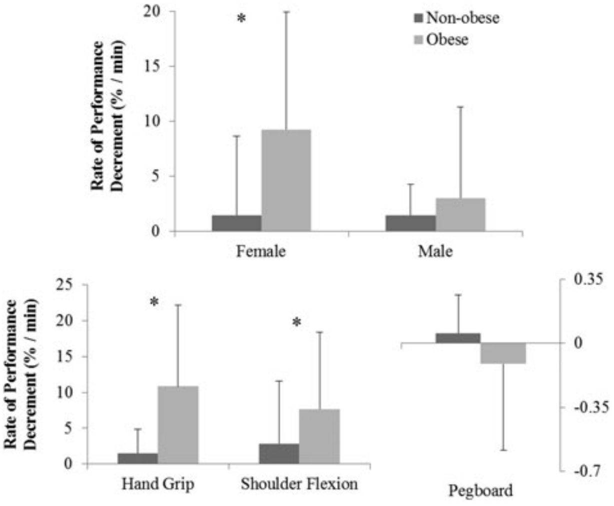


FIGURE 6. Mean rates of performance decrement by gender (top) and task (bottom) for each obesity group. Error bars represent standard deviations. The symbol* indicates a significant ($p < 0.1$) difference between obesity groups within a given task.

DISCUSSION

Effect of Obesity on Functional Performance

We hypothesized that individuals who are obese would have lower functional performance during several intermittent tasks. Supporting this, the non-obese group overall had ∼60% longer endurance times across the three tasks examined. A comparison of the relationship between relative exertion level and endurance showed that the data reasonably followed the traditional form of a decreasing power function for both the obese and non-obese groups.(38,39) Previous work(18) on shoulder flexion endurance during sustained isometric tasks—which involved participants of similar age, stature, and BMI as here—indicated that the non-obese group had ∼20% longer endurance than the obese group.

Another recent study on grip endurance during sustained exertions, with fixed relative loads, found BMI to be negatively correlated with endurance time among males.(16) The difference in magnitude between the prior and current outcomes likely resulted from the use of protocols examining sustained versus intermittent exertions, respectively. More generally, obesity-related differences in fatigue may be more evident when testing intermittent tasks. Decreases in muscle capillarity and blood flow that occur with obesity(11,12) could have limited muscle recoverability during rest periods in the intermittent tasks, thereby resulting in shorter endurance times. This is in line with the report by Hulens et al.,(40) who found that individuals who are obese require more oxygen than those who are lean when performing similar cycling exercise.

The interaction between obesity and gender on the rate of strength loss further supported the hypothesized effect of decreased functional performance with obesity. Obese males had higher rates of strength loss than non-obese males, indicating higher rates of fatigue development with obesity. Similarly, Maffiuletti et al.(41) found higher quadriceps strength loss in obese males during a constant duration voluntary fatigue protocol. Lower functional performance was also seen here during the hand grip and shoulder flexion tasks, where higher rates of tracking performance decrement were observed in the obese group.

Hulens et al.(40) reported that exercise was perceived to be more demanding by individuals who are obese and that obese women had higher levels of pain, consistent with the higher rates of RPD increase seen for the hand grip task in the current study. In earlier work,(17,18) which focused on sustained exertions, there was an absence of obesity-related impairments in rates of strength loss, fluctuation increase, and RPD increase. However, the current tasks included intermittent rest periods, and had relatively longer endurance times, which may have allowed for improved detection of performance differences.

Interactive Effect of Obesity and Age on Functional Performance

Based on prior evidence, obesity-related differences in functional performance were hypothesized to be more substantial with older age. Though main effects of age were observed for endurance times and rates of RPD increase, the current results did not support an obesity x age interactive effect. Older participants had longer endurance times for each of the intermittent, upper extremity tasks examined, and lower rates of RPD increase. For each task, pre-fatigue strength was similar for both age groups (within 8%), allowing for comparison to previous studies using fixed levels of relative task demands (i.e., fixed percentages of maximal capacity). The results here are consistent with previous reports of slower fatigue development with older age during fixed relative load tasks.(25,26,42) None of our measures showed an obesity x age interaction, though interpretation of this absence is limited due to having only eight participants in each age/obesity group and the inherent variability in endurance and fatigue measures.(43,44)

Task Differences in the Effect of Obesity on Functional Performance

We also hypothesized that the effect of obesity would be task-dependent, and more specifically that the difference between obesity groups would be more substantial during the pegboard task due to the required support and movement of arm mass. Consistent with this hypothesis, the non-obese group had nearly twice the endurance time in the pegboard task compared to the obese group, with substantially smaller inter-group differences of ∼70% for the hand grip task and ∼20% for the shoulder flexion task found. For the pegboard task, the relative demand at the shoulder from the support of the arm weight was ∼15% MVC for both groups. Therefore, the difference in endurance time cannot be attributed to a higher demand among those in the obese group (e.g., from supporting a heavier arm), and may instead be due to obesity-related differences in muscle physiology. With the impaired muscle blood flow noted above, muscle recoverability in the obese group may have been limited during the dynamic portions of the pegboard task, in addition to during the rest periods.

Though there were significant obesity-related performance decrements for the hand grip and shoulder flexion tasks, there were no effects of obesity on performance for the pegboard task. These results fail to support our hypothesis of a larger effect of obesity for the pegboard task and are inconsistent with previous reports of decreased performance with higher BMI. For a similar seated peg placement task, children who were obese performed slower than those who were non-obese,(22) and longer movement times were found for tasks that require controlled aiming of the upper extremity.(21) If similar effects were present here, we should have seen higher rates of performance decrement for the obese group, indicating that the participants had to move slower and could not keep pace with the metronome.

One possible explanation for the difference between the current study and that by Berrigan et al.(21) is that the latter had participants standing, which added a balance constraint that was not present here. Their observed obesity-related increases in movement times were attributed to constraints imposed by balance control difficulties, a suggestion supported by their subsequent work where equivalent performance was observed before and after weight loss in a seated posture.(45) In addition, neither D'Hondt et al.(22) or Berrigan et al.(21) involved endurance or fatigue testing, but rather a single measurement of performance. Rates of performance decrement during the pegboard task were relatively low (Figure 6), and there was relatively large variability of these decrements within the obese group. Thus, the current performance measure and/or sample size may not have been sensitive enough to detect obesity-related differences for this task.

Limitations

As mentioned previously, this study may be limited by the small sample size and the potential insensitivity of some dependent measures. Differences in underlying physiology were not assessed using direct measures, and future work is needed to test the hypothesized justifications for the differences observed here. In addition, only two levels of obesity and two levels of age were included; however, this allowed for separation between the groups to facilitate detection of obesity- and age-related differences and interaction effects. The BMI range was limited to control for the effects of possible co-morbidities that would likely be present at higher BMIs. While this allowed for isolation of obesity-related differences, it is unknown whether the participants represent the actual working population. The intermittent exertions used here may not relate directly to workplace tasks, and generalization of the current results may be limited beyond the examined muscle groups, load levels, and duty cycle. However, these tasks do replicate components of a variety of workplace demands and can form the basis for understanding how obesity may impact workplace task performance.

CONCLUSION

Both the obese and younger groups had shorter endurance compared to non-obese and older groups, respectively. There was no evidence of an interactive effect of obesity and age on endurance time. Results from other dependent measures also support obesity-related functional performance impairment, but not an interactive effect with age, which is contrary to previous findings of limited movement ability in an older obese population. Endurance time results also suggest that the effect of obesity was greatest for the less controlled, more dynamic pegboard task.

Performance declines with a higher BMI, which had been reported previously, were observed for the controlled intermittent tasks here. For these intermittent tasks, the observed impairments may reflect underlying physiological differences related to obesity that limited muscle recovery during the rest periods. This has implications for the design of work duration and task demand for the prevention of fatigue development. For example, workers who are obese may need longer rest breaks to return to their initial state of muscle function. Based on the increased fatigability found with obesity, workplace designers may also need to consider the addition of fixtures and supports to minimize the amount of time that body mass segments need to be supported. Further work is needed to examine whether the effects of these individual differences translate to workplace performance and/or injury risk.

REFERENCES

1. **Bureau of Labor Statistics (BLS):** "Nonfatal Occupational Injuries and Illnesses Requiring Days Away from Work, 2009." Available at http://www.bls.gov/opub/ted/2010/ted_20101118.htm (accessed July 20, 2012).
2. **Cohen, A.L., C.C. Gjessing, L.J. Fine, B.P. Bernard, and J.D. McGlothlin:** Elements of Ergonomics Programs. Cincinnati, Ohio: National Institute for Occupational Safety and Health, 1997.
3. **Niu, S.:** Ergonomics and occupational safety and health: An ILO perspective. *Appl. Ergon. 41*(*6*):744–753 (2010).
4. **World Health Organization (WHO):** Global Status Report on Noncommunicable Diseases 2010. Geneva: WHO, 2011.
5. **Østbye, T., J.M. Dement, and K.M. Krause:** Obesity and workers' compensation: Results from the Duke Health and Safety Surveillance System. *Arch. Intern. Med. 167*(*8*):766–773 (2007).
6. **Schmier, J.K., M.L. Jones, and M.T. Halpern:** Cost of obesity in the workplace. *Scand. J. Work Env. Hea. 32*(*1*):5–11 (2006).
7. **Tsai, A.G., D.F. Williamson, and H.A. Glick:** Direct medical cost of overweight and obes. in the USA: A quantitative systematic review. *Obes. Rev. 12*(*1*):50–61 (2010).
8. **Withrow, D., and D.A. Alter:** The economic burden of obesity worldwide: A systematic review of the direct costs of obesity. *Obes. Rev. 12*(*2*):131–141 (2010).
9. **Kuehl, K.S., Y. Kisbu-Sakarya, D.L. Elliot, et al.:** Body Mass Index as a predictor of firefighter injury and workers' compensation claims. *J. Occup. Environ. Med. 54*(*5*):579–582 (2012).
10. **Bureau of Labor Statistics (BLS):** "BLS Spotlight on Statistics: Older Workers." Available at http://bls.gov/spotlight/2008/older_workers (accessed July 20, 2012).
11. **Kern, P.A., R.B. Simsolo, and M. Fournier:** Effect of weight loss on muscle fiber type, fiber size, capillarity, and succinate dehydrogenase activity in humans. *J. Clin. Endocr. Metab. 84*(*11*):4185–4190 (1999).
12. **Newcomer, B.R., D.E. Larson-Meyer, G.R. Hunter, and R.L. Weinsier:** Skeletal muscle metabolism in overweight and post-overweight women: An isometric exercise study using ^{31}P magnetic resonance spectroscopy. *Int. J. Obesity 25*(*9*):1309–1315 (2001).
13. **Krotkiewski, M., G. Grimby, G. Holm, and J. Szczepanik:** Increased muscle dynamic endurance associated with weight reduction on a very-low-calorie diet. *Am. J. Clin. Nutr. 51*(*3*):321–330 (1990).
14. **Mandroukas, K., M. Krotkiewski, M. Hedberg, Z. Wroblewski, P. Björntorp, and G. Grimby:** Physical training in obese women. *Eur. J. Appl. Physiol. O. 52*(*4*):355–361 (1984).
15. **Kirkwood, S.P., F. Zurlo, K. Larson, and E. Ravussin:** Muscle mitochondrial morphology, body composition, and energy expenditure in sedentary individuals. *Am. J. Physiol.-Endoc. M. 260*(*1*):E89–E94 (1991).
16. **Eksioglu, M.:** Endurance time of grip-force as a function of grip-span, posture and anthropometric variables. *Int. J. Ind. Ergonom. 41*(*5*):401–409 (2011).
17. **Cavuoto, L.A., and M.A. Nussbaum:** Obesity-related differences in muscular capacity during sustained isometric exertions. *Appl. Ergon. 44*(*2*):254–260 (2013).
18. **Cavuoto, L.A.**, and **M.A. Nussbaum:** Differences in functional performance of the shoulder musculature with obesity and aging. *Int. J. Ind. Ergonom. 43*(*5*):393–399 (2013).
19. **de Looze, M., T. Bosch, and J. van Dieën:** Manifestations of shoulder fatigue in prolonged activities involving low-force contractions. *Ergonomics 52*(*4*):428–437 (2009).

20. **Tetteh, E.G., N. Latif, J.D. McGlothlin, and J. Peters:** Impacts of frequency and posture on body mass index in manual handling tasks. *Hum. Factor. Ergon. Man. 19*(*4*):329–343 (2009).
21. **Berrigan, F., M. Simoneau, A. Tremblay, O. Hue, and N. Teasdale:** Influence of obesity on accurate and rapid arm movement performed from a standing posture. *Int. J. Obesity 30*(*12*):1750–1757 (2006).
22. **D'Hondt, E., B. Deforche, I. De Bourdeaudhuij, and M. Lenoir:** Childhood obesity affects fine motor skill performance under different postural constraints. *Neurosci. Lett. 440*(*1*):72–75 (2008).
23. **Klein, C.S., G.D. Marsh, R.J. Petrella, and C.L. Rice:** Muscle fiber number in the biceps brachii muscle of young and old men. *Muscle Nerve 28*(*1*):62–68 (2003).
24. **Evans, W. J. and J. Lexell:** Human aging, muscle mass, and fiber type composition. *J. Gerontol. A Biol. Sci. Med. Sci.* 50A *(Special Issue)*: 11–16 (1995).
25. **Bazzucchi, I., M. Marchetti**, A. Rosponi, et al.: Differences in the force/endurance relationship between young and older men. *Eur. J. Appl. Physiol. 93*(*4*):390–397 (2005).
26. **Yassierli, M.A. Nussbaum, H. Iridiastadi, and L.A. Wojcik:** The influence of age on isometric endurance and fatigue is muscle dependent: A study of shoulder abduction and torso extension. *Ergonomics 50*(*1*):26–45 (2007).
27. **Houston, D.K., J. Ding, B.J. Nicklas, et al.:** The association between weight history and physical performance in the Health, Aging and Body Composition Study. *Int. J. Obesity 31*(*11*):1680–1687 (2007).
28. **Houston, D.K., J. Ding, B.J. Nicklas, et al.:** Overweight and obesity over the adult life course and incident mobility limitation in older adults: The Health, Aging and Body Composition Study. *Am. J. Epidemiol. 169*(*8*):927–936 (2009).
29. **Larsson, U., and E. Mattsson:** Functional limitations linked to high body mass index, age and current pain in obese women. *Int. J. Obesity 25*(*6*):893–899 (2001).
30. **Zoico, E., V. Di Francesco, J. Guralnik, et al.:** Physical disability and muscular strength in relation to obesity and different body composition indexes in a sample of healthy elderly women. *Int. J. Obesity 28*(*2*):234–241 (2004).
31. **Armstrong, N., and J. Welsman:** The physical activity patterns of European youth with reference to methods of assessment. *Sports Med. 36*:1067–1086 (2006).
32. **National Institutes of Health (NIH), National Heart, Lung, and Blood Institute (NHLBI), and North American Association for the Study of Obesity (NAASO):** The Practical Guide: Identification, Evaluation, and Treatment of Overweight and Obesity in Adults. Rockville, Md.: National Institutes of Health, 2000.
33. **Zhu, S., S. Heshka, Z. Wang, et al.:** Combination of BMI and waist circumference for identifying cardiovascular risk factors in whites. *Obesity 12*(*4*):633–645 (2004).
34. **Casey, J.S., R.W. McGorry, and P.G. Dempsey:** Getting a grip on grip force estimates: A valuable tool for ergonomic evaluations. *Prof. Saf. 47*(*10*):18–24 (2002).
35. **Iridiastadi, H., and M.A. Nussbaum:** Muscle fatigue and endurance during repetitive intermittent static efforts: Development of prediction models. *Ergonomics 49*(*4*):344–360 (2006).
36. **Iridiastadi, H., and M.A. Nussbaum:** Muscular fatigue and endurance during intermittent static efforts: Effects of contraction level, duty cycle, and cycle time. *Hum. Factors 48*(*4*):710–720 (2006).
37. **Borg, G.:** Psychophysical scaling with applications in physical work and the perception of exertion. *Scand. J. Work. Env. Hea. 16*(*Suppl 1*):55–58 (1990).
38. **Frey Law, L.A., and K.G. Avin:** Endurance time is joint-specific: A modelling and meta-analysis investigation. *Ergonomics 53*(*1*):109–129 (2010).
39. **Frey Law, L.A., J.M. Looft, and J. Heitsman:** A three-compartment muscle fatigue model accurately predicts joint-specific maximum endurance times for sustained isometric tasks. *J. Biomech. 45*(*10*):1803–1808 (2012).
40. **Hulens, M., G. Vansant, R. Lysens, A.L. Claessens, and E. Muls:** Exercise capacity in lean versus obese women. *Scand. J. Med. Sci. Spor. 11*(*5*):305–309 (2001).
41. **Maffiuletti, N., M. Jubeau, U. Munzinger, et al.:** Differences in quadriceps muscle strength and fatigue between lean and obese subjects. *Eur. J. Appl. Physiol. 101*(*1*):51–59 (2007).
42. **Ditor, D.S., and A.L. Hicks:** The effect of age and gender on the relative fatigability of the human adductor pollicis muscle. *Can. J. Physiol. Pharm. 78*(*10*):781–790 (2000).
43. **Clark, B.C., S.B. Cook, and L.L. Ploutz-Snyder:** Reliability of techniques to assess human neuromuscular function in vivo. *J. Electromyogr. Kines. 17*(*1*):90–101 (2007).
44. **Hinckson, E.A., and W.G. Hopkins:** Reliability of time to exhaustion analyzed with critical-power and log-log modeling. *Med. Sci. Sport. Exer. 37*(*4*):696–701 (2005).
45. **Berrigan, F., O. Hue, N. Teasdale, and M. Simoneau:** Obesity Adds Constraint on Balance Control and Movement Performance. In *Proceedings of the Human Factors and Ergonomics Society 52nd Annual Meeting*, New York, September 22–26, 2008, pp. 1364–1368.