Evaluating obesity-related differences in upper extremity and trunk muscular capacity

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ABSTRACT

Work-related musculoskeletal disorders (WMSDs), particularly overexertion injuries, represent a significant economic burden and involve substantial adverse personal outcomes. Two important contemporary changes in workforce demographics may be associated with an increase in the future incidence and cost of WMSDs. First, more than two-thirds of the US adult population is now either overweight or obese, a doubling of the prevalence of obesity over the past 30 years. Second, there has been a shift toward an older worker population, whose injuries often require more time away from work. 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. This research assessed obesity- and age-related differences in physical capacity by measuring localized muscle fatigue, endurance, and the effects of fatigue on psychomotor function. Three experiments were completed, progressing from controlled static to more complex intermittent and functional tasks. The work also examined whether obesity and age effects are modified by workplace/workstation configuration, specifically the extent to which body segment masses need to be supported. With obesity, strength was higher, but endurance time was lower, particularly for the more complex tasks. Interaction effects between obesity and age were seen in only a few measures across the studies and did not indicate a consistent effect. Outcomes of this research can facilitate the development of more effective (i.e., inclusive) guidelines to control WMSD risk and contribute to both proactive and reactive interventions to reduce excessive exposures to physical risk factors. Overall, the research goal is to help ensure that ergonomic guidelines and practice are appropriate (or are adapted) to accommodate the diverse and changing workforce.

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1 Introduction

Work-related musculoskeletal disorders (WMSDs) present a serious challenge in the workplace due to the associated economic burden and adverse effects on workers. Overexertion injuries, from causes such as manual material handling, are among the leading types of WMSDs, accounting for ~25% of work-related injuries (Liberty Mutual Research Institute for Safety, 2010) and costing up to $40 billion in the U.S. (Anderson and Budnick, 2009). For cases requiring days away from work, back injuries have the highest incidence rate, while shoulder and wrist injuries, on average, result in the most lost work time (BLS, 2010). Two important contemporary trends in workforce demographics may be associated with an increase in the future incidence and cost of workplace injuries: the increasing prevalence of obesity (Flegal et al., 2010) and the aging of the workforce (BLS, 2008).

Regarding the first trend, over two-thirds of the US adult population is either overweight or obese, and the prevalence of obesity has more than doubled over the past 30 years (Flegal et al., 2010; Ogden et al., 2007). In the worker population, almost 35% of workers are overweight and 30% are obese, respectively defined as having a body mass index (BMI = kg/m^2) between 25 and 30 or > 30 (Hertz et al., 2004). The prevalence of overweight and obesity among hourly manufacturing workers is almost 85% (Pollack et al., 2007); this is problematic since exertion and lifting injuries are more common at a higher BMI (Østbye et al., 2007). For example, workers with shoulder pain were twice as likely (Odds Ratio = 2.1) to have a BMI ≥ 29 kg/m^2 (Miranda et al., 2001) and distal upper extremity injuries occur twice as frequently in those with BMI > 40 kg/m^2 (Pollack et al., 2007). Workers' compensation claims and lost workdays are positively correlated with worker BMI, and lost workdays for workers who are highly obese are estimated to be up to 13 times that of workers who are not obese (Østbye et al., 2007). Employers incur other costs of obesity as well, including expenses for health insurance benefits, absenteeism, and lost productivity (Goetzel et al., 2010).

The second demographic trend is a shift in age distribution of the workforce. Over the past 30 years, there has been a doubling of the number of workers aged 65 and older (BLS, 2008) and the Bureau of Labor Statistics (2009) projects this trend to continue, estimating that workers over 55 will account for 25% of the worker population by 2018 (compared to 18% currently). With this increased number of older workers, the incidents of severe workplace injuries will likely increase, since the median lost workdays per injury increases with age (BLS, 2010). In addition to the problems associated with older age, the interaction of age with obesity can compound the effects. This may be a particularly critical future issue, since the rate of increase in obesity prevalence among adults over 65 is the highest among any age group (Chambers et al., 2010; Zamboni et al., 2005). Therefore, it is essential to study this interaction such that the needs and capacities of this growing worker segment are better understood.

Although the health and performance consequences of obesity have gained increasing attention in the literature, there are still major limitations regarding the effects of obesity on worker capacity and performance. More specifically, previous research has addressed the general effect of obesity on the risks of injury and illness, but has not carefully assessed the acute effects of obesity on muscle performance that may lead to these injuries. Existing studies have focused primarily on strength, particularly in the lower extremity, but with little attention to potential differences in handgrip and low back strength. Currently, there is no evidence regarding the shoulder, though it is a common site of WMSDs (BLS, 2010). It is reasonable to expect a different response for the upper extremity, since the relative lack of weight bearing in the upper extremity will alter the typical training effects that are thought to occur with increased body mass.

Endurance time serves as an important indicator for musculoskeletal function; however, the impacts of increased body mass and altered body composition on endurance time have not been studied. Studies of fatigue development in individuals who are obese have been hindered by small sample sizes, a failure to control for individual physical activity differences, and a lack of standardized work tasks (Maffiuletti et al., 2008; Maffiuletti et al., 2007; Tetteh et al., 2009). In the one study of shoulder muscle fatigue during an occupationally-relevant task (Tetteh et al., 2009), there was no control of posture, pace, or movement strategy and the approach did not isolate a specific muscle group. As such, several confounding factors may have been involved, masking the actual effect of obesity on muscle capacity. Given these limitations in existing evidence, research is needed to establish the acute muscle effects of obesity before analysis of complex conditions can be considered.

As for the obese older population, no studies have examined tasks with relevance to workplace demands, capacity, or performance. Instead, existing studies have considered a more general definition of functional limitations using daily living tasks or physical ability questionnaires. The tasks tested have primarily involved the lower extremity under light conditions and have rarely considered the impact of loading demands for upper extremity tasks. In addition, most of these studies have focused on women over 60 years old, which provides only a limited understanding of how the broader segment of the obese and aging workforce would perform.

The main objective of the current research was to identify and characterize obesity-related differences in the muscular capacity of commonly used muscles of the upper extremity and low back. Specific purposes were to: 1) determine the effects of obesity on muscular capacity during sustained isometric exertions; 2) assess whether age and obesity have interactive effects on shoulder capacity; and 3) identify the effects of age and obesity during intermittent static exertions. "Muscular capacity" here is considered in a broad sense, and includes assessments of endurance and acute fatigue effects (discomfort and performance). The main hypothesis was that obesity would have an adverse effect on muscular capacity, though that this effect would vary depending on the type of task and age. Three laboratory studies were completed to address this hypothesis. Outcome measures consisting of pre-fatigue strength, endurance time, and fatigue-related effects on strength, performance, and discomfort were evaluated.

These three laboratory studies contribute to the growing, but still limited, evidence on the impact of obesity on a worker's physiological ability. Identifying the influences of age and obesity on muscular capacity will facilitate the development of more inclusive ergonomic guidelines and more effective design of controls/interventions. For example, specific accommodations may be needed for workers who are obese, who represent one-third of the US workforce, thereby improving their quality of life, increasing workplace productivity, and reducing the associated healthcare costs with WMSDs. This dissertation is organized with one chapter for each study, where Chapter 2 focuses on obesity-related differences for isometric exertions, Chapter 3 focuses on obesity- and age-related differences in shoulder capacity, and Chapter 4 focuses on differences during intermittent tasks. Chapter 5 provides a summary of the main results of these studies, as well as the practical implications and suggestions for future work.

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2 Obesity-related differences in muscular capacity during sustained isometric exertions

Lora A. Cavuoto and Maury A. Nussbaum

Abstract

Over one-third of the world adult population is overweight or obese, and the prevalence continues to increase. Obesity is a risk factor for injury, and the growing prevalence may be associated with increases in the future incidence and cost of injuries. In this study, we examined obesity-related differences in muscular capacity during sustained isometric exertions involving hand grip, shoulder flexion, and trunk extension. Thirty-six young individuals who were obese or not obese (aged 18-29) completed these exertions at fixed levels of absolute loads involving low-moderate levels of effort. Individuals who were obese had an overall ~20% higher absolute strength, but ~20% lower relative strength. These differences were most evident in the hand grip and shoulder exertions. Parameters of fitted exponential relationships between endurance time and task demands (as a percentage of strength) were similar in both groups. Perceptual and performance responses were also consistent between groups. Accordingly, we conclude that obesity may not substantially influence muscular capacity for these tasks.

2.1 Introduction

Over 1.5 billion adults worldwide are either overweight or obese (WHO, 2011), respectively defined as having a body mass index (BMI) between 25 kg/m^2 and 30 kg/m^2 or greater than 30 kg/m^2 (Hertz et al., 2004), and the prevalence of obesity has more than doubled over the past 30 years (WHO, 2011). Aside from known health problems related to obesity, workers' compensation claims appear more likely among individuals who are obese, and related lost workdays and costs per claim rise with BMI (Østbye et al., 2007). The noted study further indicated that claims related to lifting and exertion, and injuries of the back, wrist/hand, and neck/shoulder, were all more common with a higher BMI. In addition, workers with shoulder pain were twice as likely to have a BMI $\geq$ 29 kg/m^2 (Miranda et al., 2001) and distal upper extremity injuries occur twice as frequently in those with BMI > 40 kg/m^2 (Pollack et al., 2007). Among the added costs incurred with obesity are workers' compensation claims, health insurance benefits, absenteeism, and lost productivity (Goetzel et al., 2010; Østbye et al., 2007), with an estimate of $600 in excess annual employer costs per employee that is obese (Goetzel et al., 2010).

Adequate muscle strength is necessary to support the additional mechanical loads associated with obesity. Current evidence shows obesity-related differences in elbow extension, quadriceps, and trunk muscle strengths (Hulens et al., 2001; Kitagawa and Miyashita, 1978; Maffiuletti et al., 2007; Rolland et al., 2004), however the evidence for hand grip strength has been mixed (Fogelholm et al., 2006; Hulens et al., 2001; Rolland et al., 2004). While the absolute muscle strength of individuals who are obese often exceeds that of individuals who are not obese (Blimkie et al., 1990; Miyatake et al., 2000), relative muscle strength (scaled to body mass) among the former is ~ 10% lower for knee extension, trunk flexion, and hand grip (Hulens et al., 2001). Differences at the muscle level may account for some of the divergence in obesity-related differences in strength between muscle groups. Muscles of the lower extremity and trunk are required for postural support, and therefore are expected to undergo chronic training due to the obesity-related additions in body mass, and leading to higher strength (Lafortuna et al., 2005). Muscles of the hand and arm, in contrast, are "executive" muscles that are less frequently recruited for support of body segment mass. Shoulder strength is an important measure, given that the shoulder is commonly involved in occupational activities, yet no information on obesity-related differences in shoulder strength could be found. For the shoulder, both function and fiber-type distribution are between values for postural and executive muscles, making it unclear how obesity will affect shoulder muscle strength.

Relatively less evidence is available regarding obesity-related effects on functional performance for tasks that require more than minimal levels of exertion. Functional performance, in this sense, includes assessments of endurance and acute fatigue effects (e.g., discomfort and motor control). These outcomes are important in terms of the quality of submaximal force production and in understanding general impairments of muscle function (Hortobagyi et al., 2004). In addition, fatigue-induced reductions in functional performance can lead to increased risk of injury, as well as decreased work efficiency or effectiveness (de Looze et al., 2009). Regarding endurance, obesity is associated with a decrease in capillary density, and the consequent impairments in blood flow (Kirkwood et al., 1991; Newcomer et al., 2001) can lead to a reduced ability to generate prolonged exertions. Supporting this, a recent study (Eksioglu, 2011) found a negative correlation between BMI and grip endurance time at a fixed relative load (30% of maximum force). In addition, individuals who are obese have longer arm movement times during the performance of rapid tasks (Berrigan et al., 2006), which can require higher muscle loading levels and, along with a reduced blood supply and lack of contractile support from the adipose tissue, may lead to a faster onset of muscle fatigue. Obesity is also associated with a higher proportion of fatigable and a lower proportion of fatigue resistant fibers in the quadriceps and abdominal muscles (Hickey et al., 1995; Kriketos et al., 1997; Krotkiewski et al., 1990; Tanner et al., 2002). Maffiuletti et al. (2007) found a significant difference in voluntary fatigue of the quadriceps, but stimulated isometric fatigue was unaffected by obesity. Neuromuscular control differences may account for this disparity (Maffiuletti et al., 2007), though the results regarding voluntary contraction are most relevant to typical occupational activities.

Existing evidence regarding muscle physiology and functional performance differences is limited to only a few muscle groups, and it is unclear if these findings translate to other muscles, particularly those with different functionality or fiber-type distributions. More generally, the effect of obesity on strength and functional performance may be muscle-specific, and needs to be explored further. Determining obesity-related differences can provide useful information for understanding the impact of obesity on the performance of occupational activities and the subsequent risk of injury, particularly for those tasks requiring static postures or repetitive motions that can be limited by fatigue development. The objective of this study was to expand upon available evidence regarding strength and functional performance, by assessing obesity-related differences in commonly-used muscle groups. Isometric tasks involving hand grip, shoulder flexion, and torso extension were examined, and these tasks were selected to allow for comparison between muscle groups varying in function, fiber-type distribution, and the requirement of supporting body segment masses. It was anticipated that individuals who are obese would have a higher absolute strength, but lower relative strength, for all three exertions, consistent with previous findings for hand grip and trunk strength. It was also hypothesized that there would be decreased functional performance for individuals who are obese, but that this difference would be dependent on the specific muscle group.

2.2 Methods

2.2.1 Participants

Thirty-six participants (aged 18-29 years) were recruited from the local community to form two groups of 18 – non-obese ($18.5 < \text{BMI} < 25$ kg/m^2) and obese ($30 < \text{BMI} < 40$ kg/m^2) – with equal numbers of males and females in each group. Participants completed an informed consent procedure approved by the Virginia Tech Institutional Review Board. All reported being sedentary to recreationally active, as determined using the short form International Physical Activity Questionnaire (Craig et al., 2003), and having no cardiovascular diseases, metabolic conditions, or musculoskeletal disorders of the upper extremity and torso. In addition, the equipment configuration limited shoulder flexion testing to the right arm, so right-hand dominant individuals were recruited and grip and shoulder flexion tasks were performed with the dominant limb. To ensure the results captured non-acute effects of obesity, participants were required to have a stable weight (within +/- 2 kg) for the six months prior to the experiment. Participants were height-matched at the group level, and the two groups had comparable levels of physical activity (summary data provided in Table 2.1). Significant group-level differences in waist and hip circumferences support that BMI differences were due to obesity and not another factor such as high muscularity (Duvigneaud et al., 2008; NIH et al., 2000; Zhu et al., 2004).

Table 2.1. Summary data from the two participant groups (mean (SD)). Significant differences between the two groups ($p < 0.05$; unpaired *t*-tests) are indicated by the symbol *.

Measure	Group Non-obese	 Obese	*p* value
Age (yr)	22.4 (2.2)	23.0 (3.8)	0.56
Body Mass (kg)	64.7 (9.0)	98.9 (13.0)	< 0.0001*
Stature (m)	1.69 (0.10)	1.72 (0.10)	0.52
BMI (kg/m^2)	22.5 (1.8)	33.6 (3.1)	< 0.0001*
Waist Circumference (cm)	81.1 (7.4)	105.9 (7.1)	< 0.0001*
Hip Circumference (cm)	97.7 (6.3)	116.1 (9.0)	< 0.0001*
Waist-to-Hip Ratio	0.83 (0.04)	0.92 (0.1)	< 0.0001*
Physical Activity (MET-min/wk)	918 (912)	1189 (1045)	0.41

2.2.2 Procedures

Participants completed a single experimental session, involving three different exertions: hand grip, shoulder flexion, and torso extension. Participants were initially familiarized with a 10-point scale (Borg, 1990) used to provide Ratings of Perceived Discomfort (RPDs) during the experiment. The remainder of the experimental session was divided into three periods representing each of the three exertions, with a 5 min rest period between each. The presentation order of these was counterbalanced using Latin Squares. At the start of each period, participants completed warm-up exercises and task familiarization that included brief, intermittent static and dynamic submaximal exertions involving hand grip, shoulder flexion, or torso extension.

Subsequently in each period, maximum voluntary contractions (MVCs) were completed for a given exertion. Grip strength was measured using a computerized grip dynamometer (microFET 4, Hoggan Health Industries Inc., West Jordan, UT) using a standardized grip testing posture (Figure 2.1a). Participants were seated with their upper arm at their side, elbow flexed 90 degrees, and wrist in a neutral posture with no forearm rotation. For shoulder flexion, participants sat in a commercial dynamometer (Biodex System 3 Pro, Biodex Medical Systems, Shirley, NY). The dynamometer was adjusted to that the participant was seated with their back reclined 20 degrees from vertical, their feet supported by a footrest, and their upper body and waist secured. Participants kept their shoulder flexed so that their arm was parallel to the ground with their forearm in a neutral posture (Figure 2.1b). For trunk extension, participants stood upright, with their feet slightly separated and their legs secured, and were connected to the same dynamometer described above using a custom fixture (Figure 2.1c). During both shoulder and trunk exertions, the dynamometer center-of-rotation was aligned with that of the glenohumeral and lumbosacral joints, respectively, the latter estimated via palpation. During MVCs, participants were instructed to ramp up to their maximum force, hold it, and then ramp down to rest over approximately 5 sec. They were given verbal encouragement and visual feedback of their force or moment output during the contractions. At least three MVC trials, separated by two minutes of rest, were completed for each exertion, or until peak forces/moments were non-increasing. Grip forces were sampled at 135 Hz and moments from the Biodex data were sampled at 1024 Hz. The latter were low-pass filtered using a 4th-order Butterworth filter with a 25 Hz cutoff frequency. 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.

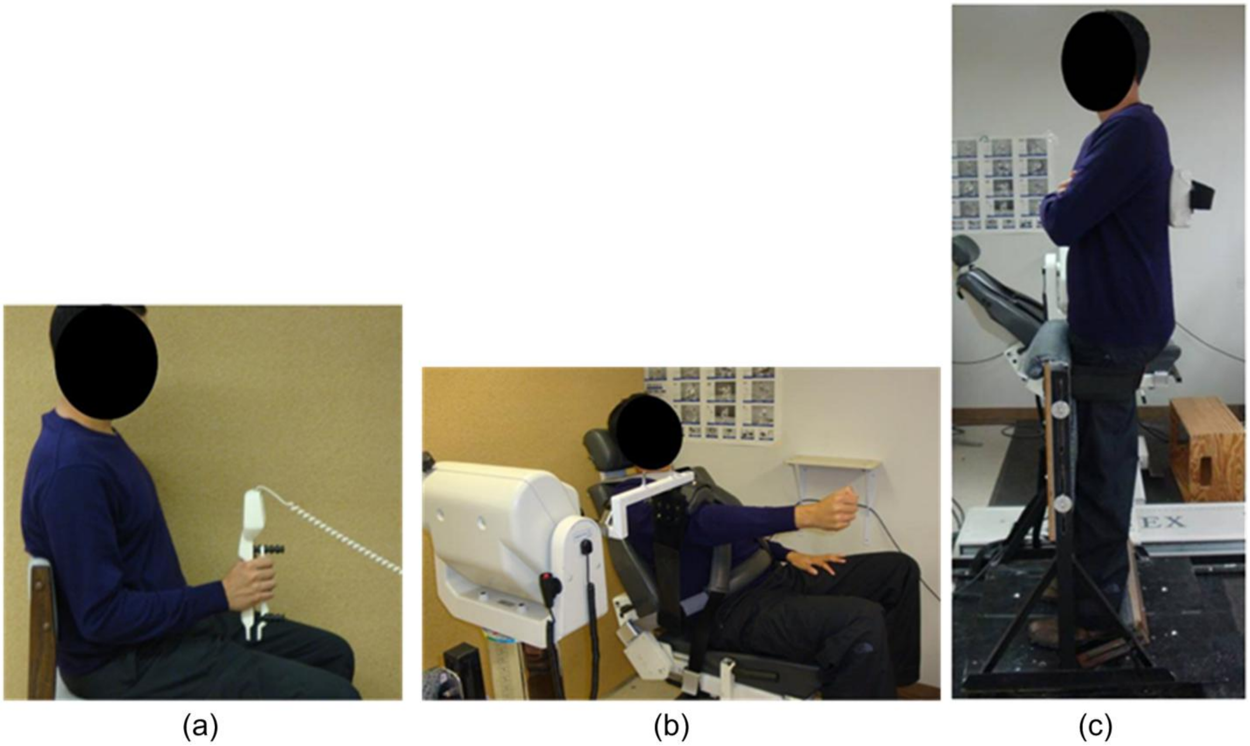
(a) (b) (c)

Figure 2.1. Postures used for the (a) hand grip, (b) shoulder flexion, and (c) torso extension tasks.

Following each series of MVCs and at least two minutes of rest, participants then completed an endurance task corresponding to one of the exertions. These endurance tasks involved maintaining an absolute force or moment isometrically, in the same postures and with the same data collection methods as were used for MVCs. Real-time visual feedback of the target force/moment was provided, and participants were instructed to track the target force as closely as possible and for as long as possible. For grip, the target force was 75 N, representing approximate grip demands for lifting, carrying, and screwdriving tasks (Casey et al., 2002). For shoulder flexion, participants maintained a target moment of 9 Nm (above that needed to support arm mass). This target represents the approximate external moment generated at the shoulder for a 50th percentile male holding a 1.5 kg load in the posture used. For back extension, the target torque was 50 Nm, and was selected to represent approximately 25% of MVC based earlier results using a similar procedure among individuals who are not obese (Yassierli et al., 2007).

Each endurance task ended when the participant indicated they could no longer continue to track the target. During the endurance tasks, participants provided RPDs for the tested body part (i.e., distal lower extremity, shoulder, or low back) at 30-second intervals; the noted 10-point 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.

2.2.3 Dependent Measures and Analysis

Dependent measures were obtained to describe pre-fatigue effects (prior to endurance tasks), endurance time, and fatigue-related effects (during endurance tasks). Pre-fatigue measures included absolute strength (MVC) and relative strength, the latter obtained by normalizing MVC to body mass (in kg). Endurance time was defined as the time at which the participant dropped ≥10% below the target without re-attaining it (Frey Law and Avin, 2010; Rudroff et al., 2011). Four fatigue-related measures were derived from data collected during the endurance tasks: rates of change in strength, force/moment fluctuations, and RPDs, along with peak values of RPD. Normalized rates of change in MVC (strength loss) were determined as percentage changes divided by the endurance time. Force/moment fluctuations were calculated as the standard deviation of the generated force divided by the mean, or the coefficient of variation (Tracy et al., 2005), and were obtained for 5 sec windows centered on 10% increments from 10 to 90% of the endurance time. Linear regression (vs. time) was used to obtain rates of changes in fluctuations (over the nine windows) and RPDs (at every 30 sec). In addition, maximum RPDs were recorded as the final rating provided prior to the endurance time.

Separate mixed-factor analyses of variance (ANOVAs) were used to assess the effects of group, task, and gender on each dependent measure, with presentation order included as a blocking variable. For one participant (male, obese), endurance and fatigue-related results from the torso task were discarded as clear outliers based on the generalized extreme Studentized deviate test (Kutner et al., 2005). The level of significance for all analyses was set at $p < 0.05$, and parametric model assumptions were assessed. Pre-fatigue and endurance time measures were log transformed to achieve homoscedasticity. Summary data are presented as means (95% confidence intervals), with back-transformation used as needed so that these are all in the original units. Given the purpose of this work, the presentation of results focuses primarily on main and interactive effects related to obesity. Of note, task order was not significant for any of the dependent measures. Significant interaction effects were examined using simple effects analyses as needed. Effect sizes (η^2) were determined and are reported for each effect test (Cohen, 1988). Relationships between endurance times and task demands (as % of absolute strength) were analyzed separately for each obesity group using non-linear regression. Exponential relationships were used, in the form of $\mathrm{Y} = b_1 \mathrm{e}^{-b_2 \mathrm{X}}$, and between-group differences in derived model parameters (b_1 and b_2) were evaluated using *t*-tests. Power functions were also explored, but the results were comparable and are hence not reported.

2.3 Results

2.3.1 Pre-Fatigue Strength

The obese group overall had 21% higher absolute strength ($F_{(1,32)} = 12.58$; $p = 0.0012$; $\eta^2 = 0.012$). While the obesity x task interaction was not significant ($F_{(2,62)} = 2.01$; $p = 0.14$; $\eta^2 = 0.0011$), differences in absolute strength related to obesity were more evident for the hand grip and shoulder flexion exertions (Figure 2.2). In contrast, relative strength was 21% lower in the obese group ($F_{(1,32)} = 19.56$; $p = 0.0001$; $\eta^2 = 0.019$). The obesity x task interaction was again not significant ($F_{(2,62)} = 2.08$; $p = 0.13$; $\eta^2 = 0.0011$), though differences in relative strength were more substantial for torso exertion.

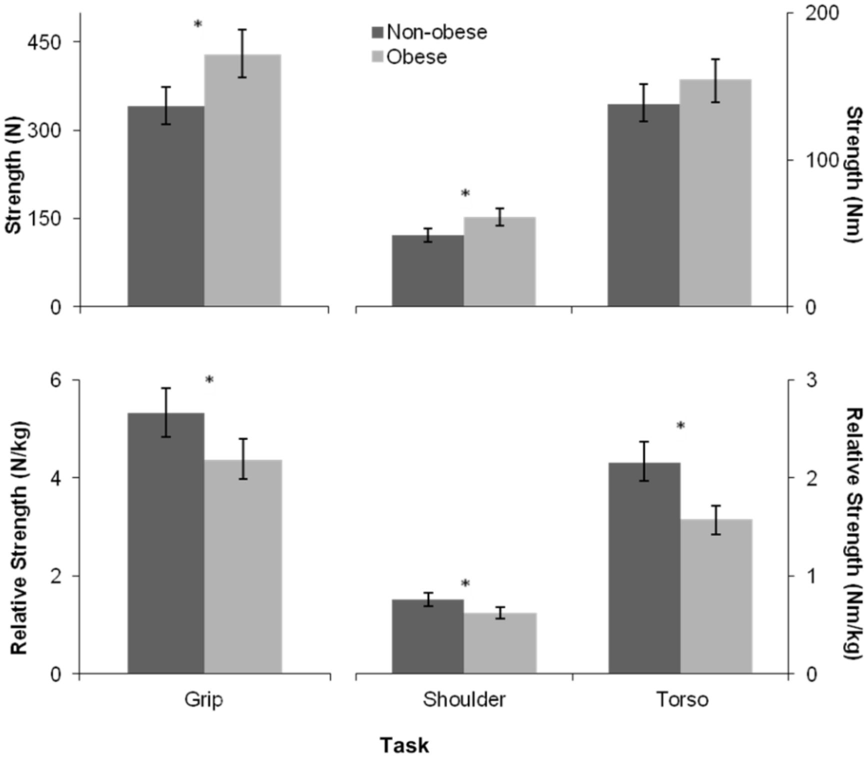

Figure 2.2. Mean absolute strength (top) and relative strength (normalized by body mass; bottom) for hand grip, shoulder flexion, and torso extension tasks. Error bars represent 95% confidence intervals, and the symbol * indicates a significant (p<0.05) difference between the non-obese and obese groups.

2.3.2 Endurance Time

Overall, the obese group had 3-15% longer endurance times in the three endurance tasks, though neither the main effect of obesity ($F_{(1,32)}= 1.05$; $p = 0.31$; $\eta^2 = 0.0084$) or the obesity x task interaction effect ($F_{(2,61)}= 0.46$; $p = 0.63$; $\eta^2 = 0.0021$) were significant. Relationships between endurance time and task demand for each task were comparable between obesity groups for all three tasks (Figure 2.3). Parameters of the fitted exponential models (b_1 and b_2) did not differ between groups in either the hand grip ($p > 0.64$) or shoulder flexion tasks ($p > 0.18$). For torso extension, differences between obesity groups approached significance ($p = 0.065$ for parameter b_1 and $p = 0.058$ for parameter b_2). A potential outlier was apparent in the torso extension data (see Figure 2.3). Reanalysis without this data point, however, did not yield any substantial differences.

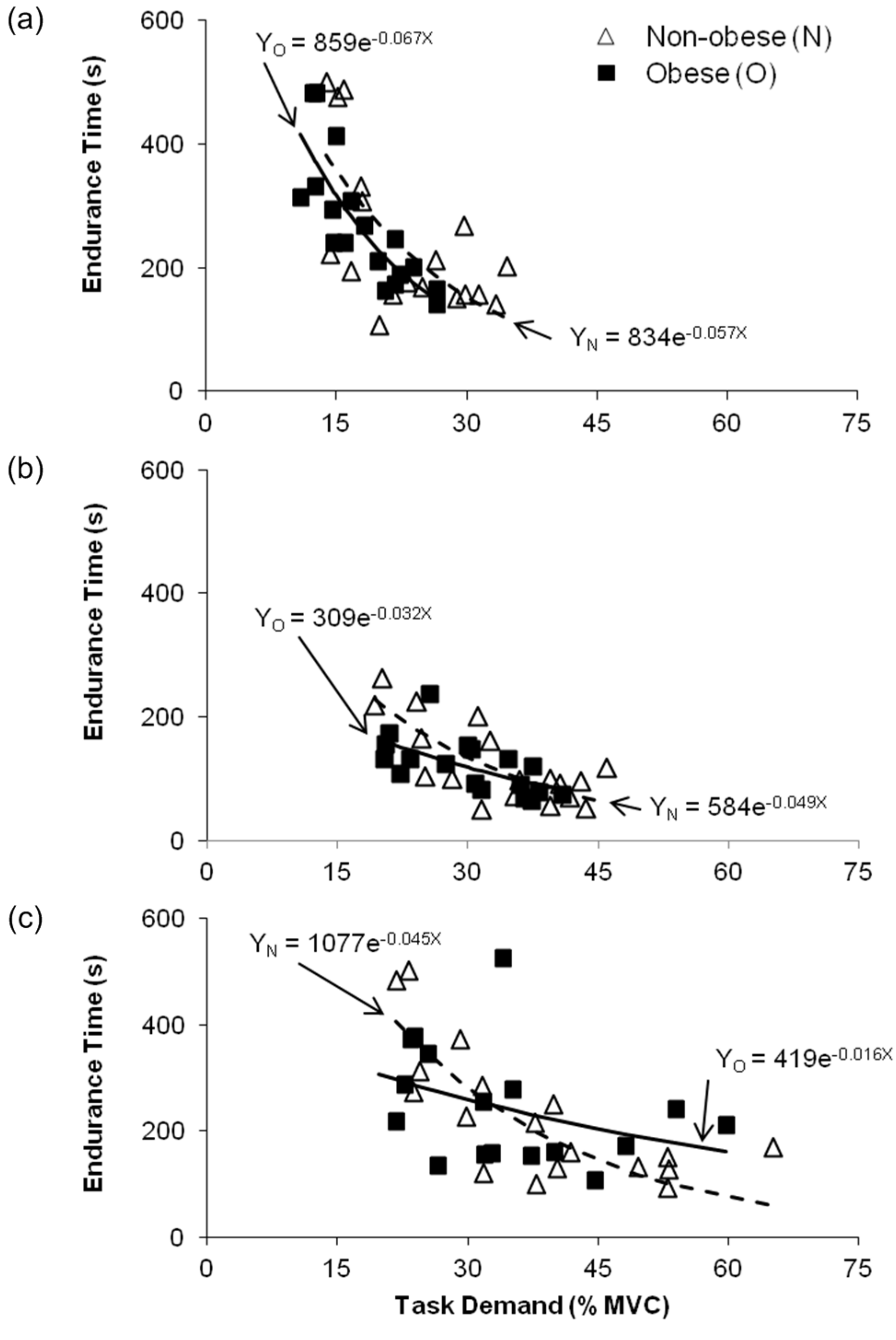

Figure 2.3. Relationships between endurance times and relative task demands fit with exponential curves ($Y = b_1 e^{b_2 X}$) for the (a) hand grip, (b) shoulder flexion, and (c) torso extension endurance tasks

2.3.3 Fatigue-Related Effects

Normalized strength loss did not differ between groups ($F_{(1,32)}$= 0.0030; p = 0.96; $\eta^2 = 1.9\text{x}10^{-7}$) and overall was 7.9 (6.7-9.0) %/min^{-1}. Rates of increases in fluctuations over the endurance trials were $1.2\text{x}10^{-4}$ ($7.3\text{x}10^{-5}$-$1.7\text{x}10^{-4}$) s^{-1} and did not differ between groups ($F_{(1,32)}$= 0.20; p = 0.65; η^2 = 0.0034). The non-obese group had a significantly ($F_{(1,32)}$ = 4.46; p = 0.043; η^2 = 0.037) higher rates of RPD increase than the obese group, at 0.057 (0.049-0.065) vs. 0.047 (0.039-0.054) s^{-1}, respectively. In particular, the non-obese female group had 53% higher slopes than the other groups combined (obesity x gender interaction $F_{(1,61)}$ = 5.95; p = 0.021; η^2 = 0.048). At the end of the endurance task, participants reached an RPD of 8.6 (8.2-8.9), and there was not a significant main effect of obesity ($F_{(1,32)}$= 0.52; p = 0.48; η^2 = 0.0093).

2.4 Discussion

2.4.1 Pre-Fatigue Differences

Differences in absolute strength between groups found here are consistent with existing evidence of higher values among individuals who are obese. This was expected, since the added body mass with obesity includes some additional muscle mass (Hulens et al., 2001; Lafortuna et al., 2005). While only the hand grip and shoulder flexion exertion differences were significant, a similar difference was also evident for torso extension. Previous studies of trunk strength have found significant differences, as well as a positive correlation between body mass and flexion strength (Bayramoglu et al., 2001) and higher absolute flexion and extension strengths among women who are obese women versus those who are not (Hulens et al., 2001). Previous evidence regarding hand grip has been mixed, with findings of increased (Fogelholm et al., 2006; Miyatake et al., 2000), equivalent (Hulens et al., 2001; Rolland et al., 2004), and decreased (Kitagawa and Miyashita, 1978) absolute strength among individuals who are obese. The present study supports an increase in hand grip strength. Difference in grip posture may explain some of the divergence in results. The current study had participants seated with the arm adducted and the elbow bent 90°, consistent with the posture used by Fogelholm et al. (2006). For the other studies, participants either were standing with their arm fully extended (Hulens et al., 2001; Rolland et al., 2004) or their arm extended and abducted 30° (Kitagawa and Miyashita, 1978). The current study also controlled for age, stature, and physical activity between the groups, thus reducing potential confounding effects (Hulens et al., 2001). Age-related declines in strength have been reported for multiple muscles (Frontera et al., 2008; Hughes et al., 1999), including hand grip (Stenholm et al., 2011), and there may have been interactive effects of age and obesity that contributed to the results from Miyatake et al. (2000) and Hulens et al. (2001), which examined populations ranging from 20 to over 60 years old. In addition, low levels of physical activity may impair muscle strength (Neder et al., 1999), however the participant groups in the current study had comparable low levels of physical activity. Each of the previous studies noted included a similar range of BMI as the current study and controlled for stature between groups.

New strength information for shoulder flexion is also provided, a previously untested exertion with respect to obesity. Most previous reports of obesity-related differences in strength have focused on muscles of the lower extremity (Maffiuletti et al., 2007) or trunk (Bayramoglu et al., 2001), and the higher absolute strength has been explained as the result of a chronic training effect (Lafortuna et al., 2005). For muscles involved in weight-bearing and required to move body segment mass(es), it is possible that muscle mass adapts and leads to greater (absolute) force output (Lafortuna et al., 2005) . For hand grip and shoulder flexion, such a training effect is less likely involved, since there are lower levels of body masses supported or moved. However, the current findings are consistent with earlier results indicating increased upper extremity absolute strength with BMI ≥ 25 kg/m^2 (Pescatello et al., 2007; Zoeller et al., 2008). One possible explanation is additional muscle mass in the upper extremity, regardless of training, due to support of the arm mass during regular activities of daily living. This can be combined with a shift to greater proportions of type IIB fibers (Tanner et al., 2002) that use the small glycogen supply surrounding the muscle to generate a high, but short, strength output (Saltin et al., 1977). Another suggested possibility is decreased antagonistic co-contraction leading to higher voluntary force or torque output (Blimkie et al., 1990).

Relative strengths (scaled to total body mass) were also considered, to account for differences in body size, and strength per unit mass was lower in the obese group for all three exertions. This is consistent with scaled strength measurements for knee extensors with obesity among adolescents (Blimkie et al., 1990) and adults (Maffiuletti et al., 2007). Since strength may not be directly proportional to body mass (Folland et al., 2008), additional analysis was conducted using an allometric scaling approach, based on the theoretical relationship between strength and muscle cross-sectional area (Nevill et al., 1992). After normalizing strength using $\text{strength}_{\text{norm}} = \text{strength} \times \text{mass}^b$, where b = -0.67 for force values and b = -1 for torque values (Jaric, 2002), the main effect of obesity remained significant ($p = 0.0005$). However, the significant obesity x task interaction ($p = 0.0029$) showed that there was no difference between the groups for the hand grip task. When previous studies have normalized for fat-free mass there have been conflicting results of either no difference between individuals who are obese and non-obese (Maffiuletti et al., 2007; Pescatello et al., 2007) or impaired strength for individuals who are obese (Duvigneaud et al., 2008; Hulens et al., 2001). Reduced relative strength may indicate damaged muscle capacity and fitness in the obese group (Hulens et al., 2001), differences in muscle fiber type and metabolic function (Duvigneaud et al., 2008; Tanner et al., 2002), or an inability to achieve full motor unit activation (Blimkie et al., 1990). Implications of a lower strength capacity may include poor performance on higher complexity tasks required in work, particularly for tasks involving manual material handling.

2.4.2 Endurance

Based on previous reports of obesity-related impairments, an obesity-related decrease in muscle capacity was hypothesized. While the obese group had slightly longer endurance times at the same absolute loads, these differences were not significant. In a recent study, there was a negative correlation between BMI and grip endurance time for males in a relative load task (Eksioglu, 2011). Kankaanpää et al. (1998) and Fogelholm et al. (2006) also found that torso endurance capacity is decreased for women with higher BMIs when performing a modified Sørensen back endurance test. Differences in protocols between these and the current study likely account for the differing results. Specifically, Eksioglu (2011) tested sustained contractions at 30% MVC, compared to the absolute target used in the current study and that ranged from 14-35% MVC for the non-obese group and 11-27% MVC for the obese group during the hand grip task. For the torso extension task, the protocols used by Kankaanpää et al. (1998) and Fogelholm et al. (2006) involved the participants lying prone with only their lower body supported by a table. Participants were required to support their upper body mass and maintain a horizontal position, making the task more demanding with an elevated mass due to obesity. In contrast, the current study had participants standing upright, minimizing body mass support by the low back muscles, thus testing the effect of the added task demand.

Traditionally, endurance time during isometric tasks has been used as an indicator of muscle fatigue, the suitability of different tasks, and the need for scheduling rest breaks (Mathiassen and Åhsberg, 1999). Here, the relationship between endurance times and relative task demands were comparable between groups for both hand grip and shoulder flexion, though the difference approached significance for torso extension. Relative load and maximum holding time are related following unique exponential or power models that vary by joint (Frey Law and Avin, 2010). Fitted exponential curve parameters for the non-obese group in the present study closely match parameters reported in a recent meta-analysis (Frey Law and Avin, 2010). This was true as well for the obese group, though parameter differences for torso extension approached significance. This suggests that for torso extension, unlike hand grip and shoulder flexion, obesity may impact the relationship between relative task demand and endurance time. It also indicates that current ergonomics approaches, such as using Rohmert's curve for work-rest scheduling (Rohmert, 1973), may be an oversimplification to apply to all workers. Such a muscle-dependency in the effects of obesity on endurance may be attributable to an underlying muscle dependency in obesity-related differences in fiber-type distributions. Among individuals who are not obese, paraspinal muscles have a higher proportion of slow-twitch fibers than those of the forearm or shoulder (Jørgensen, 1997; Manta et al., 1996; Srinivasan et al., 2007), and paraspinal muscles may be more greatly affected by shifts to more fast-twitch fibers with obesity.

2.4.3 Fatigue-Related Effects

While it was expected that the obese group would show impaired muscular performance, the rates of strength loss and fluctuation increase were the same for both groups. These results conflict with a previous finding of obesity-related increases in strength loss for a voluntary knee fatigue protocol (Maffiuletti et al., 2007), though the noted study used an equivalent test duration during the isokinetic maximal intensity task. In addition, the study by Maffiuletti et al. (2007) involved participants with BMI > 35 kg/m^2. The absence of significant differences here may indicate that obesity-related neuromuscular differences are unlikely except for more extreme levels of obesity. The non-obese group had a significantly higher rate of RPD increase, which was probably due to the slightly longer endurance times for the obese group, with the highest slopes for the non-obese female group being caused by their shorter endurance times. However, the maximum RPD reached did not differ between groups, indicating a similar level of perceived discomfort at task failure. Correlations between RPD slopes and rates of strength loss were highest for the obese male group ($r = 0.48$) and lowest for the non-obese male group ($r = 0.20$), indicating that the former may have more accurate perceptions of fatigue. One previous study of perceptual responses to resistance exercise found no obesity- or gender-related differences (Levinger et al., 2009), though higher post-exercise levels of fatigue were reported by the non-obese male group than the other groups. There is thus some consistency, in that non-obese males provide higher rates of discomfort change at lower rates of strength loss, indicating higher and perhaps less accurate levels of perceived fatigue.

2.4.4 Limitations

A limitation of this study is that obesity was only considered categorically (i.e., obese and non-obese groups). Although a substantial portion of the population is overweight ($25 \leq \text{BMI} < 30$ kg/m^2), this category was not included, to achieve a separation between the tested groups and thereby improve the ability to determine obesity-related differences. In addition, those in a more extreme category (i.e., BMI > 40 kg/m^2) were excluded due to the likelihood of co-morbidities that could affect muscular capacity. Participants only performed three simple (static) endurance tasks in specific controlled postures, and each of the tasks was done at only one absolute loading level. Further, these tasks involved force/moment control, wherein participants were asked to maintain a given force/moment against a static fixture. Such a situation may not represent common tasks that require supporting an inertial load in a controlled posture, and endurance (or, time to task failure) is longer for force-controlled versus posture-controlled tasks across multiple muscle groups (Hunter et al., 2002; Rudroff et al., 2010). Therefore, in practice, differences in fatigability and endurance with obesity can be dependent on the task demands, and the current results have an unclear level of generality with respect to other tasks. Finally, the current results provide evidence only related to voluntary capacity, and do not isolate underlying physiological differences with obesity.

2.5 Conclusions

With respect to strength, the results of this study were consistent with previous findings that indicate higher absolute, but lower relative strength, for individuals who are obese. Endurance time (or, time to task failure) for both groups was proportional to relative demands, with some evidence for obesity-related differences in torso extension. Differences in fatigue perception may also exist with obesity, particularly among males. Overall, however, and contrary to expectations, obesity had only subtle influences on fatigue, perception, and performance during these basic isometric tasks. Future work should investigate obesity-related impairments in functional performance for more complex tasks.

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3 Differences in functional performance of the shoulder musculature with obesity and aging

Abstract

An increasing prevalence of obesity and the aging of the workforce may lead to higher rates of workplace injuries. In this study, we examined the main and interactive effects of obesity and age on functional performance during sustained isometric exertions involving shoulder flexion in two postures. Four groups (non-obese young, non-obese older, obese young, and obese older), with eight participants in each, completed two endurance tasks at absolute target levels. Strength was ~25% higher for individuals who were obese. In addition, both obesity and age had effects on endurance time, with the obese group having shorter endurance and the older group having longer endurance. We also found that obesity and age had an interactive effect on endurance time, although the results did not provide a conclusive indication of functional performance impairment for individuals who are older and obese.

3.1 Introduction

Work-related musculoskeletal disorders (WMSDs) represent a serious challenge in the workplace due to their associated economic burden and adverse effects on workers' quality of life. Overexertion injuries are among the leading types of WMSDs (Anderson and Budnick, 2009) and for cases requiring days away from work, shoulder and wrist injuries result in the most lost work time (BLS, 2010). Two important contemporary trends in workforce demographics may be associated with an increase in the future incidence and cost of these workplace injuries: the increasing prevalence of obesity (Flegal et al., 2010) and the aging of the workforce (BLS, 2008).

The prevalence of obesity worldwide has nearly doubled over the past 30 years (WHO, 2011) and almost 85% of hourly manufacturing workers are either overweight or obese (Pollack et al., 2007), defined as having a body mass index (BMI = kg/m^2) of 25 - 30 or > 30, respectively. Those with class I or II obesity ($30 < BMI < 40\ kg/m^2$) have higher musculoskeletal injury rates than those with $BMI < 25\ kg/m^2$ (Odds Ratio = 1.54; Pollack et al., 2007). Individuals who are obese are over 60% more likely to be absent from work than those who are not obese, and obesity-related work absence costs employers an estimated $4 billion each year (Cawley et al., 2007). With the added physical demands imposed by obesity, there may be implications for worker fatigue development, which can ultimately affect performance and the risk of injury. Additional mechanical requirements from upper extremity masses can lead to increased arm movement times during the performance of rapid tasks (Berrigan et al., 2006). With a longer task duration, the upper extremity muscles must support a heavier arm for more time.

Few studies have considered the relationship between obesity and endurance. For a sustained hand grip task at 30% MVC, a fairly strong correlation (r ~ –0.6) was found between BMI and endurance time (Eksioglu, 2011). Similarly, reductions in endurance with higher BMI have been observed for static trunk extension tasks requiring support of the entire upper body mass (Fogelholm et al., 2006; Kankaanpää et al., 1998). The hand grip task required minimal body mass support, compared to the more substantial support required for trunk extension task. Common occupational tasks using the upper arm and shoulder necessitate body mass support in between these two levels. It is reasonable to expect a different endurance response with obesity for the upper extremity, since the relative lack of weight bearing in contrast to the lower extremity will alter the typical chronic training effects that are thought to occur with increased body mass (Lafortuna et al., 2005). In our earlier study of obesity-related differences in strength and endurance during sustained isometric exertions (Chapter 2), we found higher levels of shoulder strength in individuals who are obese, but did not see any differences in endurance time for a prolonged static task at a fixed level of task demand. However, this earlier work considered only a single posture and only young participants.

Aging is of particular interest, since over the past 30 years there has been there has also been a doubling of the number of workers aged 65 and older (BLS, 2008). The Bureau of Labor Statistics (2009) projects this trend to continue, estimating that workers over 55 will account for 25% of the worker population by 2018 (compared to 18% currently). With this increased number of older workers, the prevalence of severe workplace injuries will likely increase since the median lost workdays per injury increases with age (BLS, 2010). When considering aging alone, there are significant changes to muscle physiology that also affect muscular capacity.

Older adults lose their force-generating ability, as evidenced by strength reductions (Frontera et al., 2008) that result in part from slower contractile properties and loss/shrinkage of fibers (Thompson, 2009).

Addressing the increased prevalence of individuals who are older and obese, some recent research has focused on potential interactive effects of obesity and aging on musculoskeletal and functional changes. There are conflicting findings of increased (Rolland et al., 2004) as well as similar (Miyatake et al., 2000) absolute strength with old age and obesity, perhaps a result of diverging influences of age-related decreases and obesity-related increases in muscle force production. In addition, older individuals who are obese have higher rates of reported limitations in movement and performance of daily activities than those who are non-obese (Alley and Chang, 2007). Tests of walking, stair climbing, flexibility, and balance, in conjunction with self-reports, have confirmed that there is both a performance decline and an increased risk of mobility limitation in individuals who are older and obese (Houston et al., 2007; Houston et al., 2009; Larsson and Mattsson, 2001; Zoico et al., 2004). One recent longitudinal survey of workers found the combination of age > 40 and BMI > 30 kg/m^2 to have the strongest association with upper extremity tendonitis (Werner et al., 2005). While this evidence points toward functional consequences, most prior research has concentrated on basic activities of daily living, and therefore the overall ergonomic relevance may be limited.

Although the health and performance consequences of obesity and aging have gained increasing attention in the literature, there are still major limitations regarding the effects on work-related functional performance. Here, we define functional performance as encompassing endurance and acute fatigue effects (particularly regarding discomfort and motor control). Functional performance is an important consideration for the design of tools, workstations, and work tasks; however, the impacts of obesity and age on functional performance have only received minimal attention in the literature. The purpose of this study was to assess whether age and obesity have interactive effects on shoulder capacity for prolonged static tasks. Two specific tasks were used, involving two postures differing in the extent to which support of upper extremity body mass was needed. It was hypothesized: 1) that there would be interactive effects of obesity and age on shoulder strength; 2) that there would be decreased functional performance for individuals who are obese; 3) that this effect on functional performance would be more substantial with older age; and 4) that the effect of obesity on functional performance would be larger when there was a greater need for supporting body segment mass.

3.2 Methods

3.2.1 Participants

Thirty-two participants (aged 18-25 and 50-65 years) completed the study, and were recruited from the university and local community to form four groups with four males and four females in each: non-obese ($18.5 < \text{BMI} < 25$ kg/m^2) young, obese ($30 < \text{BMI} < 40$ kg/m^2) young, non-obese older, and obese older. These age ranges were intended to capture individuals at the typical start and end of working life, and the BMI range for the obese group was used to avoid the effects of likely co-morbidities present at higher levels. Participants completed an informed consent procedure approved by the Virginia Tech Institutional Review Board. The equipment configuration limited testing (of shoulder flexion) to the right arm, so only right-hand dominant individuals were included. The Global Physical Activity Questionnaire was used to assess the physical activity of the participants (Armstrong and Bull, 2006). Participants were height-matched at group levels within age and obesity groups and had comparable levels of physical activity (summary data on the four groups are provided in Table 3.1). Waist and hip circumference values support that BMI differences were due to obesity and not another factor such as high muscularity (Duvigneaud et al., 2008; National Institutes of Health (NIH) et al., 2000; Zhu et al., 2004).

Table 3.1. Summary data from the four participant groups (mean (SD)). Significant differences ($p < 0.05$, from ANOVA) are indicated by the * symbol.

	Group					
Measure	Non-obese Young	Obese Young	Non-obese Older	Obese Older	Obesity *p*-value	Age *p*-value
Age (yr)	20.8(2.5)	22.3(2.1)	57.0(5.0)	54.4(2.8)	0.63	<0.001*
Body Mass (kg)	69.0(6.1)	101.3(12.2)	75.0(5.9)	106.8(17.7)	<0.001*	0.17
Stature (m)	1.74(0.1)	1.72(0.1)	1.75(0.1)	1.71(0.1)	0.30	0.91
BMI (kg/m^2)	22.7(1.8)	34.1(2.8)	24.4(0.9)	36.4(3.3)	<0.001*	0.03*
Waist Circumference (cm)	82.5(5.7)	108.2(7.0)	89.5(5.0)	119.8(12.8)	<0.001*	0.003*
Hip Circumference (cm)	94.8(4.9)	117.7(8.7)	103.1(4.6)	123.8(5.7)	<0.001*	0.002*
Waist-to-Hip Ratio	0.87(0.1)	0.92(0.1)	0.87(0.1)	0.97(0.1)	0.005*	0.37
Physical Activity (MET-min/wk)	1250(1216)	1065(1030)	1455(908)	1253(1211)	0.62	0.62

3.2.2 Procedures

Participants completed two experimental sessions on different days, separated by at least two days to minimize any effects from residual fatigue or muscle soreness. Each experimental session involved strength testing and an isometric shoulder endurance task in one of two postures (shown in Figure 3.1). These postures were intended to roughly simulate an individual holding an object (e.g., tool) in front of the body vs. supporting it overhead, and with the former involving a more substantial need to support segmental upper extremity masses. In the first posture (Figure 3.1a), the participant's arm was kept parallel to the ground and with the elbow extended. In the second posture (Figure 3.1b), the shoulder was flexed 135 degrees, with an included elbow angle of 90 degrees, so that the lower arm was at 45 degrees from vertical. In the following, "extended" and "flexed" denote the respective postures, based on the relative orientations of both the shoulder and elbow. For both postures, participants held their wrist in a neutral posture and their hand in a relaxed fist. Segment orientations were measured using an inclinometer, and the presentation order of the postures was counterbalanced.

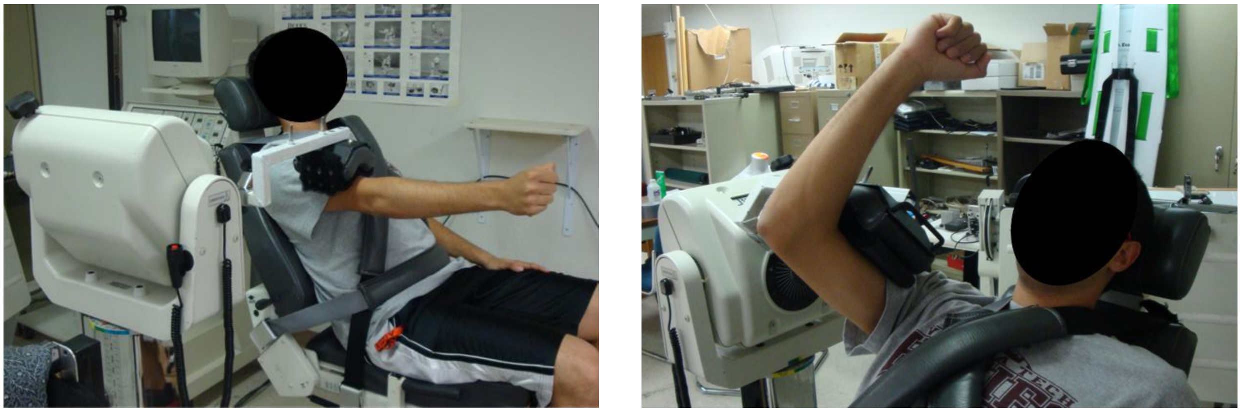
(a) (b)

Figure 3.1. Arm postures used for the two strength testing and endurance tasks, a) extended posture and b) flexed posture. Note that participants needed to be semi-reclined so that the dynamometer axis of rotation could be aligned with that of the shoulder.

Following an initial warm-up period, participants performed a series of isometric maximum voluntary contractions (MVCs), involving shoulder flexion in the posture being tested in a given session. MVCs were completed using a commercial dynamometer (Biodex System 3 Pro, Biodex Medical Systems, Shirley, NY). During these, the participant’s upper body and waist were secured, their feet were supported by a footrest, and the dynamometer center-of-rotation was aligned with the glenohumeral joint. Participants were asked to progressively build to a maximum exertion, hold it, and then ramp down to rest, while maintaining the test posture and pressing their upper arm against the padded fixture. Over the five seconds of each MVC, participants were given verbal encouragement and visual feedback of their moment output. At least three MVC trials were completed, each separated by two minutes of rest, until peak moments were non-increasing. Moment data were collected at 1024 Hz and hardware low-pass filtered with a 15 Hz cutoff frequency. Corrections were made for the gravitational effects on the dynamometer fixture and body segments, and the maximum moment across MVC trials was recorded as the participant's MVC.

After strength testing, participants rested for at least two minutes and then completed an endurance task in one of the previously described shoulder postures. The task involved isometrically generating an absolute moment of 9 Nm above that needed to support arm mass, and moments were recorded continuously with the same methods as those for MVCs. This fixed external load was used to represent the approximate external moment at the shoulder for a 50th percentile male holding a 1.5 kg object in the posture shown in Figure 3.1a. A computer monitor displayed the generated and target moments throughout the task, and participants were instructed to maintain the generated moment as close to the target as possible for as long as possible. The task continued until the participant indicated they could no longer track the target. During the endurance tasks, participants provided ratings of perceived discomfort (RPDs) for the shoulder at 15-second intervals, using a 10-point scale (Borg, 1990) that was visible to them throughout the task. Strength loss was quantified by a post-task MVC in the relevant posture performed right after the end of the endurance task.

3.2.3 Dependent Measures and Analysis

Pre-fatigue strength (MVC) and endurance time were obtained for each of the two shoulder postures. Rates of change in strength, moment fluctuations, and RPDs were calculated from data collected during the endurance tasks to assess fatigue-related effects. The rate of strength loss was determined as the percentage change in MVC divided by the endurance time. To quantify moment fluctuations, the data were first separated into consecutive, non-overlapping 5 sec windows throughout each endurance task. Then, the coefficient of variation for each window was obtained as the standard deviation of the generated force divided by the mean (Tracy et al., 2005). Linear regression (vs. time) was used to obtain rates of changes in fluctuations (over the windows) and RPDs (at every 15 sec). In addition, the final rating given prior to the endurance time was recorded as the maximum RPD.

Separate mixed-factor analyses of variance (ANOVAs) were used to assess the main and interactive effects of obesity, age, task, and gender on each dependent measure. Presentation order was included as a blocking variable. Due to the small sample size in each group, and which was limited by available resources, the level of significance for all analyses was set at $p <$ 0.1. For one participant (male, young, obese), endurance and fatigue-related results from the flexed task were discarded as clear outliers using the generalized extreme Studentized deviate test (Kutner et al., 2005). Endurance times and rates of RPD increase were log transformed to achieve homoscedasticity. All summary data are presented as means (95% confidence intervals), with the data back-transformed to the original units as needed. Post-hoc analyses were used to examine significant interaction effects as needed. Pairwise comparisons were considered between obesity levels within each gender and age group across both tasks. For interactions with task type, pairwise comparisons of the flexed vs. extended tasks were completed for each group. Associations between the rates of strength loss and RPD increase were assessed using coefficients of correlation (ρ) from bivariate correlations, separately for each of the four participant groups.

3.3 Results

The obese group overall had ~25% higher strength ($F_{(1,24)} = 42.5$; $p = <0.0001$; $\eta^2 = 0.13$), and there was a significant gender x obesity interaction ($F_{(1,24)} =12.7$; $p = 0.0016$; $\eta^2 = 0.037$).

Regarding the latter, obesity had relatively less influence on strength among females versus males (Figure 3.2). There was not a significant effect of age on strength ($p = 0.49$) or an obesity x age interaction ($p = 0.30$).

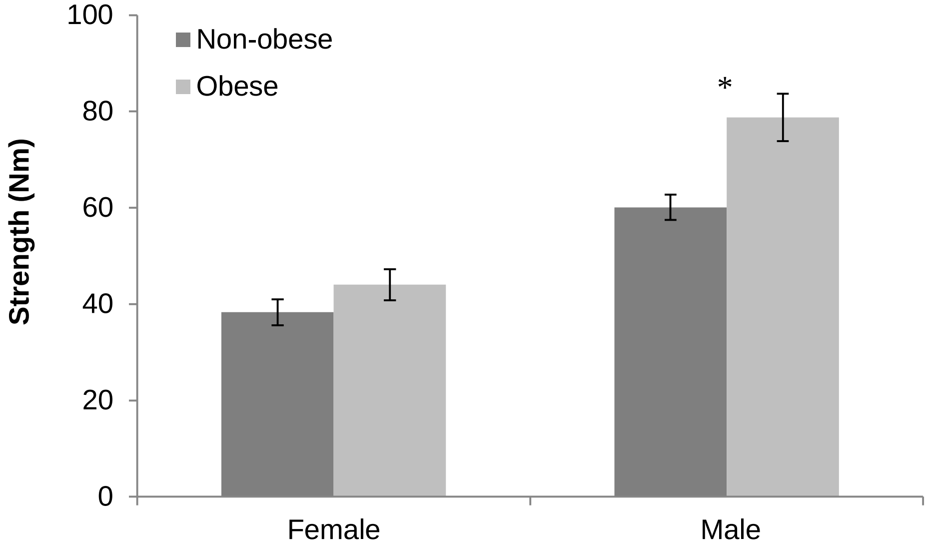

Figure 3.2. Mean strength by obesity and gender grouping. Error bars represent 95% confidence intervals, and the symbol * indicates a significant ($p<0.1$) difference between the non-obese and obese groups within gender.

There was a main effect of obesity on endurance time ($F_{(1,24)} = 5.70$; $p = 0.025$; $\eta^2 = 0.031$), with the non-obese group having ~18% longer time to task failure (166 (143-193) s) than the obese group (138 (115-167) s). There were also main effects of age ($F_{(1,24)} = 8.52$; $p = 0.0076$; $\eta^2 = 0.045$) and gender ($F_{(1,24)} = 111$; $p < 0.0001$; $\eta^2 = 0.52$). The older group (169 (143-201) s) had ~24% longer endurance than the younger group (136 (115-160) s), and endurance time was over twice as long for males vs. females (218 (196-243) vs. 107 (94-121) s). In addition, there was a significant gender x obesity x age interaction ($F_{(1,24)} = 20.8$; $p = 0.0001$; $\eta^2 = 0.095$; Figure 3.3). Shorter endurance times were observed for the female obese young and male obese older groups compared to the non-obese groups, whereas among young males the obese group had a longer endurance time than the non-obese group. There was a significant obesity x age x task interaction effect ($F_{(1,23)} = 3.42$; $p = 0.0772$; $\eta^2 = 0.0094$; Figure 3.4). Pairwise comparisons revealed a 47% difference in endurance times between tasks for the non-obese older group. Within the obese groups, differences of ~27% and ~31% in endurance times between tasks were found for the young and older groups respectively, although only the difference for the young group was significant.

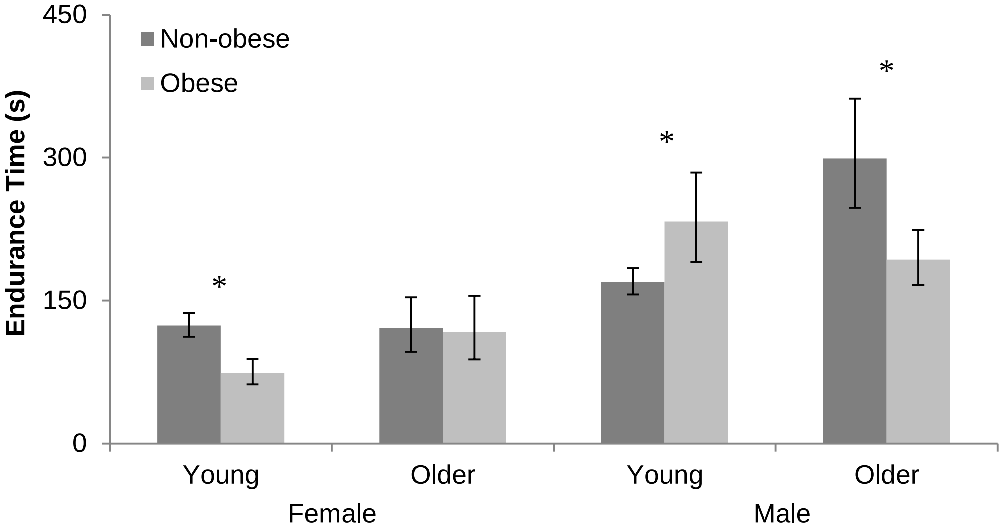

Figure 3.3. Mean endurance times by gender for each age and obesity group. Error bars represent 95% confidence intervals. The symbol * indicates a significant (p<0.1) difference between non-obese and obese groups within each gender and age group.

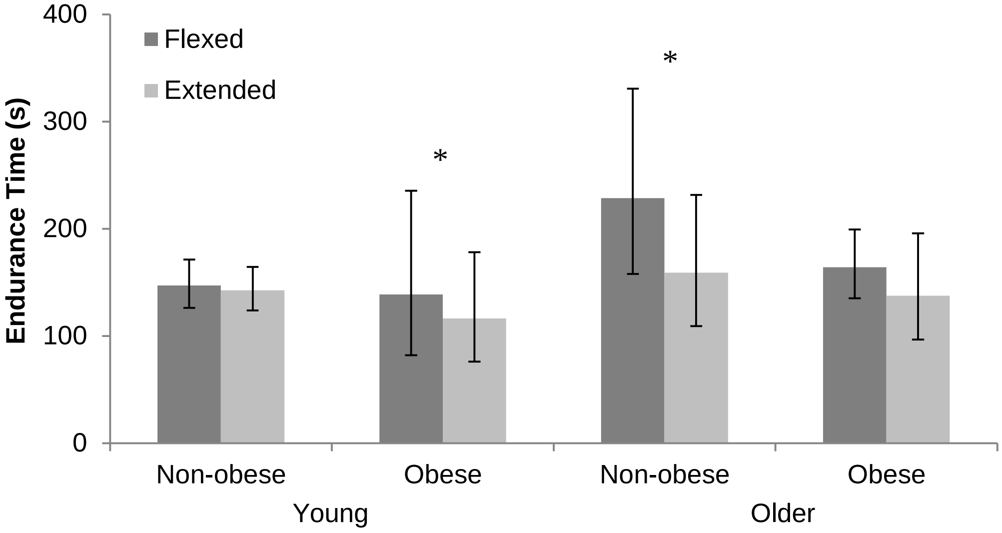

Figure 3.4. Mean endurance times for each age group by obesity and task. Error bars represent 95% confidence intervals. The symbol * indicates a significant ($p<0.1$) difference between the flexed and extended tasks within each obesity and age group.

The rate of strength loss overall was 0.12 (0.11-0.14) %/s, and was not significantly affected by obesity, age, or their interaction ($p > 0.13$). Rates of increase in moment fluctuation were also consistent across the four groups ($p > 0.54$). Obesity did not have an effect on the rate of RPD increase ($p > 0.31$), though there was a significant ($F_{(1,22)} = 22.2$; $p = 0.0001$; $\eta^2 = 0.14$) effect of age. Specifically, the younger group had ~48% higher rates (0.074 (0.063-0.088) vs. 0.050 (0.042-0.061) s^{-1}). Females also had higher rates of RPD increase ($F_{(1,22)} = 76.3$; $p = <0.0001$; $\eta^2 = 0.46$) and there was a gender x obesity x age interaction ($F_{(1,22)} = 15.5$; $p = 0.0007$; $\eta^2 = 0.081$, Figure 3.5). For young female and older male participants, rates of RPD increase were higher for obese vs. non-obese groups, but this effect of obesity was reversed among younger male participants. The effect of task on rate of RPD increase was dependent on both obesity and age ($F_{(1,23)} = 4.06$; $p = 0.057$; $\eta^2 = 0.012$, Figure 3.6). Both the non-obese older ($p = 0.0006$) and obese younger groups ($p = 0.019$) had higher RPD rates for the extended task compared to the flexed task. Maximum RPD was significantly ($F_{(1,23)} = 4.84$; $p = 0.038$; $\eta^2 = 0.15$) lower for the older group (8.8 (8.2-9.4)) compared to the younger group (9.7 (9.5-9.9)). Correlations between the rates of strength loss and RPD increase revealed comparable ρ values for each of the four obesity/age groups (ranging from 0.64-0.72).

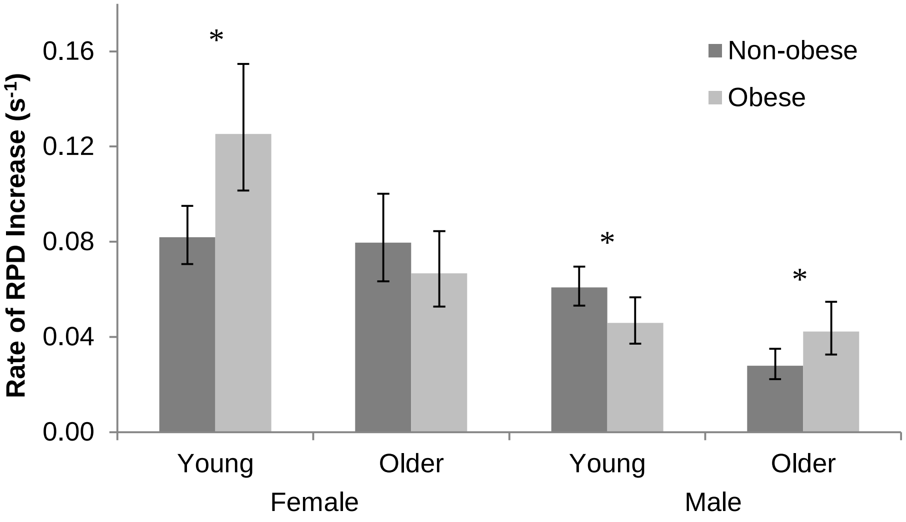

Figure 3.5. Gender differences in the rate of RPD increase by age and obesity. Error bars represent 95% confidence intervals. The symbol * indicates a significant ($p<0.1$) difference between the non-obese and obese groups within each gender and age group.

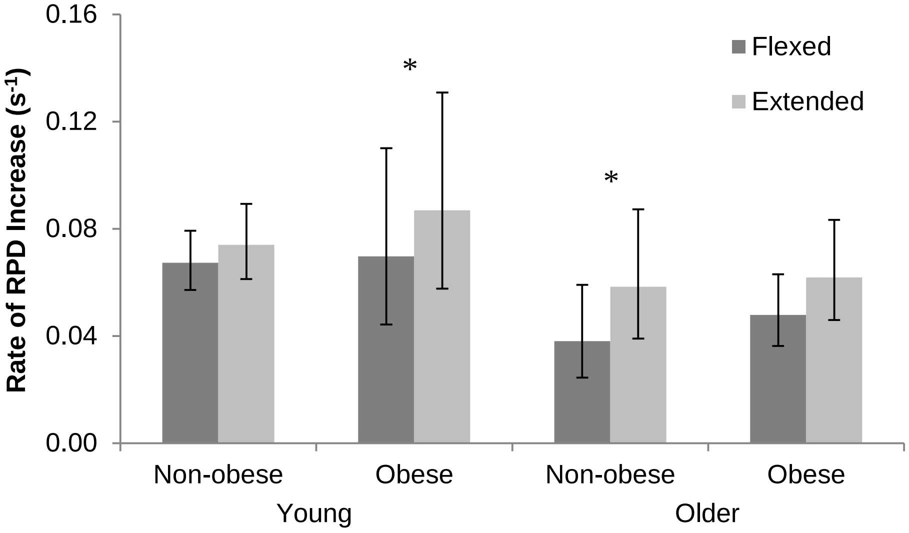

Figure 3.6. Rates of RPD increase for each age group by obesity and task. Error bars represent 95% confidence intervals. The symbol * indicates a significant (p<0.1) difference between the flexed and extended tasks within each obesity and age group.

3.4 Discussion

3.4.1 Effects of obesity and age on strength

We observed a ~25% higher shoulder strength for the obese group, consistent with our earlier study (Chapter 2) where the obese group had ~24% higher shoulder flexion strength. This is also consistent with previous evidence of a positive correlation between body mass and isometric shoulder flexion and abduction strength (Lannersten et al., 1993). However, the current results conflict with a separate study that found no obesity-related differences in upper limb strength for muscles (*triceps brachii* and pectorals) not regularly involved in body mass support (Lafortuna et al., 2005). In the present work, strength differences related to obesity differed between genders (Figure 3.2), with a larger influence of obesity evident among males. The noted study by Lannersten et al. (1993) found a similar effect, with lower correlations between body mass and strength for females than males. Earlier assessments of body compositions suggest that obese males experience increases in fat-free mass equivalently to increases in fat mass, while females gain mostly fat mass (Lafortuna et al., 2004; Lafortuna et al., 2005). These assessments were focused on the lower limb, however if such a gender difference in body composition occurs in the shoulder musculature, it would account for the noted gender differences in strength.

Although strength differed with obesity, there was no main effect of age or interactive effects of obesity and age on muscle strength. Therefore, our first hypothesis of an interactive effect between obesity and age on strength was not supported. The absence of age-related differences conflicts with previous reports of an age-related strength decline and specific findings for the shoulder that suggest 10-20% reductions in isometric shoulder strength among similar-aged participants (Hughes et al., 1999; Yassierli et al., 2007). However, the current results are consistent with those from Lannersten et al. (1993), who found no difference in shoulder flexion strength between older and younger females, although they did report that older males had 89% of the shoulder flexion strength of younger males. Individual variation between the study samples and the specific shoulder postures used may partially explain these differences. For example, Hughes et al. (1999) kept the elbow at 90 degrees for all tests of shoulder strength; elbow posture affects the external moment at the shoulder during flexion and may have affected moment generating ability. Lannersten et al. (1993) used a similar posture to the current “extended” posture (Figure 3.1a) for determining shoulder flexion strength. Further, neither study reported matching their groups based on height or physical activity level, two factors that are positively correlated with strength (Lannersten et al., 1993; Neder et al., 1999).

3.4.2 Functional performance with obesity

Based on previous evidence suggesting functional impairments with obesity, we hypothesized that there would be decreased functional performance for individuals who are obese, as measured by endurance time, motor control, and discomfort. The non-obese group had ~18% longer endurance time, supporting this hypothesis, and is consistent with a previous study of grip endurance for males that found a negative correlation between BMI and endurance time when exerting at 30% MVC (Eksioglu, 2011). In the current study, we used fixed, absolute load levels for the endurance task. Based on the observed differences in strength, the task was thus performed at a different relative demand for each participant. Specifically, exertions for the obese group were approximately 5% MVC lower than for the non-obese group. Traditionally, relative load and maximum holding time are related following an exponential model, with decreased endurance at higher levels of relative load (e.g., Garg et al., 2002; Mathiassen and Åhsberg, 1999). Thus, the lower relative demand for the obese group should have resulted in a longer endurance time. That the obese group did not have a longer endurance time may suggest impaired functional performance in this group. In contrast, and opposing the hypothesis, rates of strength loss and moment fluctuation increase were equivalent between the obese and non-obese groups. An absence of obesity-related differences in these measures is consistent with our earlier results on sustained shoulder flexion endurance within a younger population (Chapter 2). It is thus possible that the measures used and/or the current sample size may not have been sensitive enough to detect obesity-related neuromuscular differences. There is also substantial intra- and inter-individual variability of endurance and fatigue measures (e.g., Clark et al., 2007; Hinckson and Hopkins, 2005).

3.4.3 Interactive effect of obesity and age on functional performance

We also hypothesized that the decrease in functional performance for individuals who are obese would be more substantial with older age. We did see several effects related to age in our results, specifically that the older group had longer endurance than the younger group. Further, higher rates of RPD increase were observed for the younger group, likely related to their shorter endurance times. Age-related increases in endurance time have been reported for sustained exertion tasks at a fixed relative load (Avin and Frey Law, 2011; Bazzucchi et al., 2005; Yassierli et al., 2007). In the current study, the fixed absolute load was approximately 30% MVC for both age groups, and the main effect of age is consistent with these previous findings. However, there was inconclusive evidence found here to support the hypothesized interactive effect of obesity and age. Among females, the obese young group had shorter endurance times than the non-obese young, whereas the older groups had similar times between obesity levels. Among males, conflicting effects were seen, wherein obesity led to shorter endurance for the older group but longer endurance for the young group. The magnitude of endurance time differences for the obese vs. non-obese participants was consistent within the different age and gender groups (36-41%, Figure 3.3). In addition, complementary pairwise differences were seen for rates of RPD increase, with shorter endurance time resulting in higher rates of RPD increase. To the authors' knowledge, this is the first study to examine an interactive effect of age and obesity on muscle endurance and the related acute fatigue effects, and these conflicting outcomes may have resulted from the small size and the large variability of measures noted above. Further, differences in motivation both between sessions and between participants and groups may have affected the endurance times. For example, results showing a main effect of age on maximum RPD may indicate that the younger participants were working harder. Correlations between the rates of strength loss and RPD increase were consistent across all groups. This implies that participants had similar abilities to assess their fatigue development, however it does not eliminate the possible influence of motivation.

3.4.4 Interactive effect of task and obesity on functional performance

Our final hypothesis was that the effect of obesity on functional performance would be dependent on the need for support of body segment mass. Specifically, a larger effect of obesity was expected in the extended vs. flexed postures due to the larger external shoulder moments generated in the former. However, this hypothesis cannot be accepted based on the conflicting task-related differences found. Among the obese groups, endurance time in the flexed posture was consistently ~30% longer than for the extended posture for both the young and older participants (Figure 3.4). For the non-obese groups, only a minor difference in between-task endurance time was observed for the young group, while a much more substantial difference was seen for the older group. Anticipated differences in endurance time related to posture can be predicted from the mean relative demands and using exponential parameters determined for the shoulder by Frey Law and Avin (2010). For both the obese and non-obese groups, the relative demand in the flexed posture was approximately 5% MVC lower than for the extended posture (24 vs. 29 and 29 vs. 34 % MVC, respectively). This leads to a predicted shortening of endurance time for the extended posture of ~28%, which is comparable to the observations for the obese group. The non-obese groups, however, did not follow such a prediction. Further inspection of the data revealed that two participants in the non-obese older group had endurance times in flexed posture trials that were relatively long, and that these times were somewhat inconsistent with the respective extended posture trials for the specific participants as well as relative to other participants in this group. Given the small sample, these few data points were likely influential, and may have been due to differences in motivation and/or familiarization between sessions.

3.4.5 Limitations

Limitations related to sample size and dependent measures were noted earlier. An additional limitation of this study is the inclusion of only two levels of obesity and only individuals with BMI < 40 kg/m^2, though only ~6% of the population has BMI > 40 kg/m^2 (Flegal et al., 2010). Further, only two age groups were considered. Similar to the use of only two obesity groupings, the middle age of the population was not included to achieve a separation between the tested groups and thereby to improve the ability to detect age-related differences and obesity x age interaction effects. Generalization of the present results may be limited, specifically to other muscle groups, postures, and tasks than those examined here.

3.5 Conclusions

Results of this study showed higher strength for obese individuals, consistent with previous findings. However, previously reported age-related strength declines were not observed. Both obesity and age had effects on endurance time, with the obese group having shorter endurance and the older group having longer endurance. Some evidence also suggested that obesity and age have an interactive effect on endurance time, although the results did not provide a conclusive indication of functional performance impairment for individuals who are older and obese. For the tested sustained isometric tasks, the combined influence of obesity and age did not have a conclusive effect on functional performance. The effects observed here may differ for a pseudo-static or dynamic task that involves movement allowing for recovery during the task, since such tasks involve reported limitations in movement ability with older age and obesity. Further work is needed under more realistic task conditions to explore the likely complex effects of these individual differences.

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4 The influence of obesity and age on functional performance during intermittent upper extremity tasks

Abstract

The prevalence of obesity has doubled over the past 30 years and this increase is associated with higher healthcare costs, rates of workplace injury, and lost workdays. In this study, the main and interactive effects of obesity and age on functional performance were assessed during three intermittent static exertions: hand grip, shoulder flexion, and a simulated assembly task using the upper extremity. 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 level of task demands. 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, RPD increase, and declines in task performance. These observed impairments may reflect underlying physiological differences among individuals who are obese. 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: Obesity; Aging; Endurance; Intermittent exertions; Functional performance

4.1 Introduction

Work-related injuries can result in decreased productivity, lost workdays, lower work quality, and worker dissatisfaction (BLS, 2010; Cohen et al., 1997; Niu, 2010). 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, and who are classified as overweight (WHO, 2011). Over the past 30 years, the prevalence of obesity (defined as a BMI > 30 kg/m^2) has more than doubled (WHO, 2011). Workers who are obese have up to 13 times as many lost workdays per workplace incident (Østbye et al., 2007), in addition to higher rates of injury (Schmier et al., 2006), direct medical costs (Tsai et al., 2010; Withrow and Alter, 2010), and workers compensation claims (Kuehl et al., 2012). Similarly, the past 30 years have seen a doubling of workers over 65 years old (BLS, 2008). Injuries and illnesses become more severe as age increases, with workers over 55 missing a median of 12 days of work per injury (BLS, 2010).

Obesity is associated with physiological changes at the muscle level, including a decrease in capillary density (Kirkwood et al., 1991) and less blood flow to muscle (Newcomer et al., 2001), limiting the supply of oxygen and energy sources to skeletal muscle. Typical interventions for obesity such as training and weight loss appear insufficient for returning capillary density to normal levels (Kern et al., 1999; Krotkiewski et al., 1990; Mandroukas et al., 1984). Combined with limited blood flow, obese muscle cells have a decrease in the relative amount and size of the mitochondria necessary to provide energy (Kirkwood et al., 1991; Newcomer et al., 2001).

When performing sustained contractions, these physiological changes reduce recovery efficiency and may thereby lead to a faster onset of muscle fatigue (Newcomer et al., 2001). In support of this, Eksioglu (2011) reported an inverse relationship between BMI and endurance time during sustained isometric contractions at 30% of maximum. One of our earlier studies 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 absolute target levels (Chapter 2). However, in another of our studies, which included both young and older adults, we found shorter shoulder flexion endurance times with obesity (Chapter 3). Fatigue-induced reductions in muscle capacity can lead to increased risk of injury, as well as decreased work performance (de Looze et al., 2009). Recently, Tetteh et al. (2009) 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 (Berrigan et al., 2006). For seated tasks that remove the mechanical demands of additional inertial load from body mass support, obese children have been shown to have poorer performance in a fine motor control task (peg placing) compared to non-obese and overweight children (D'Hondt et al., 2008).

With respect to aging, there is a selective reduction of fatigable muscle fibers (Klein et al., 2003; Lexell, 1995), leading to slower fatigue development and longer endurance with age when tasks are performed at fixed levels relative to individual strength (Bazzucchi et al., 2005; Yassierli et al., 2007). Previous examinations of activities of daily living have indicated that older age and obesity lead to an increased risk of mobility limitation, particularly for walking and lower extremity tasks (Houston et al., 2007; Houston et al., 2009; Larsson and Mattsson, 2001; Zoico et al., 2004). 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 an interactive effect of obesity and age on endurance time for sustained isometric exertions (Chapter 3). For the older obese population, no studies to the authors' knowledge have examined tasks with direct relevance to workplace demands, capacity, or performance.

Therefore, 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 here 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.

4.2 Methods

4.2.1 Participants

Thirty-two participants from the university and local community were recruited into four groups of eight each (4 males, 4 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 co-morbidities 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 (Armstrong and Bull, 2006). Each of the four groups had comparable statures and levels of physical activity (summary data on the four groups provided in Table 4.1).

Table 4.1. Summary data from the four participant groups (mean (SD)). Significant differences ($p < 0.05$, from ANOVA) are indicated by the * symbol.

	Group					
Measure	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

4.2.2 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 for 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, IN). 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 that 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 the latter 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, UT) in the standardized testing posture described in Chapter 2 (Figure 2.1a). For shoulder flexion, participants sat in a commercial dynamometer (Biodex System 3 Pro, Biodex Medical Systems, Shirley, NY). The dynamometer was adjusted and the participant was seated using the same posture as Chapter 2 (Figure 2.1b). For shoulder abduction, participants sat upright in the Biodex with their shoulder abducted so that their arm was parallel to the ground (Figure 4.1). During both shoulder exertions, the dynamometer center-of-rotation was aligned with that of the glenohumeral joint. MVC trials were conducted as described earlier (Chapters 2 and 3). 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.

Figure 4.1. Posture used for the shoulder abduction exertion.

Following the MVCs and at least 2 minutes of rest, participants completed an endurance task for one of the three exertions. The hand grip and shoulder flexion endurance tasks involved intermittently maintaining an absolute force or moment, in the same postures and with the same data collection methods as were 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 (Figure 4.2). 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, as in Chapters 2 and 3). Both tasks were completed with a duty cycle of 0.75 and a cycle time of 30 seconds; therefore, each 22.5-second exertion period was followed by 7.5 seconds of rest. Based on our prior work on sustained hand grip and shoulder flexion tasks, these parameters were chosen such that participants would be able to complete multiple cycles with a target mean endurance time of approximately 5-10 minutes. This work-rest cycle continued until the participant indicated they could no longer track the target.

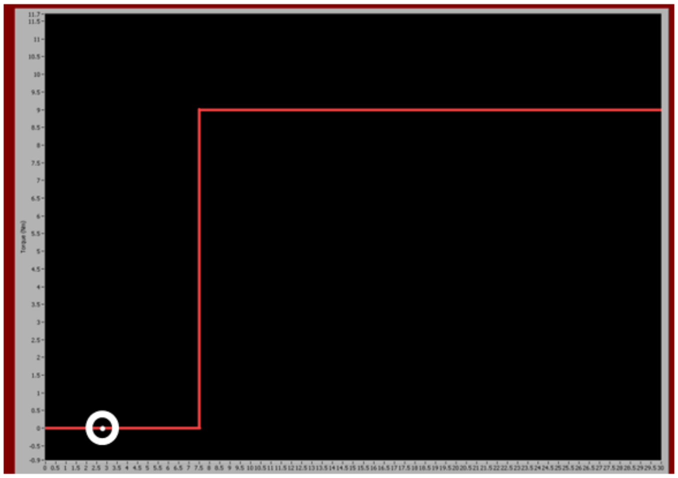

Figure 4.2. Visual feedback presented during the hand grip and shoulder flexion endurance tasks.

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 4.3a-b). Participants were instructed to keep their back against the chair and to remain facing the pegboard throughout the task. 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 4.3c). To ensure a consistent task demand across participants, the task was paced with auditory tones at a rate of 20 beats per minute. 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 seconds was used so that a sufficient number of assemblies could be completed for performance analysis. 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 they could no longer complete the task or one hour had elapsed.

[redacted]

(a) (b) (c)

Figure 4.3. (a) Purdue pegboard; (b) the posture used to complete the test; and (c) an assembly.

During all endurance tasks, participants provided Ratings of Perceived Discomfort (RPDs) using a 10-point scale (Borg, 1990) 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.

4.2.3 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 minutes. 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. For the pegboard task, performance was quantified as the number of assemblies completed compared to the target pace (10 assemblies per work 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.

4.3 Results

4.3.1 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) vs. young groups

(453 (347-592) s), and among males (711 (547-925) s) vs. 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 (Figure 4.4). Overall rates of strength loss were 4.0 (4.7) %/min, and these were consistent between the obese vs. non-obese groups ($F_{(1,24)} = 0.52$; $p > 0.48$; $\eta^2 = 0.0043$) and the young vs. 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 4.5).

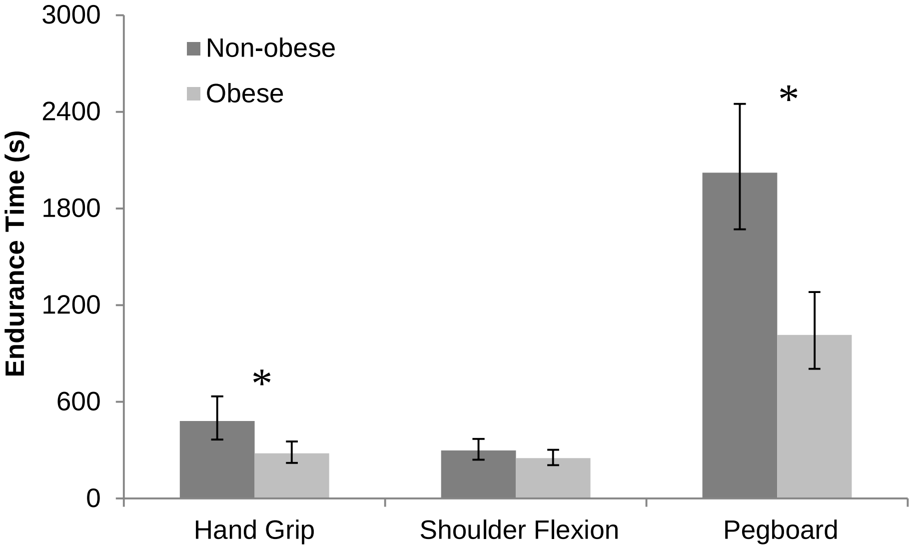

Figure 4.4. Mean endurance times by task for each obesity group. Error bars represent 95% confidence intervals, and the symbol * indicates a significant ($p<0.1$) difference between obesity groups within each task.

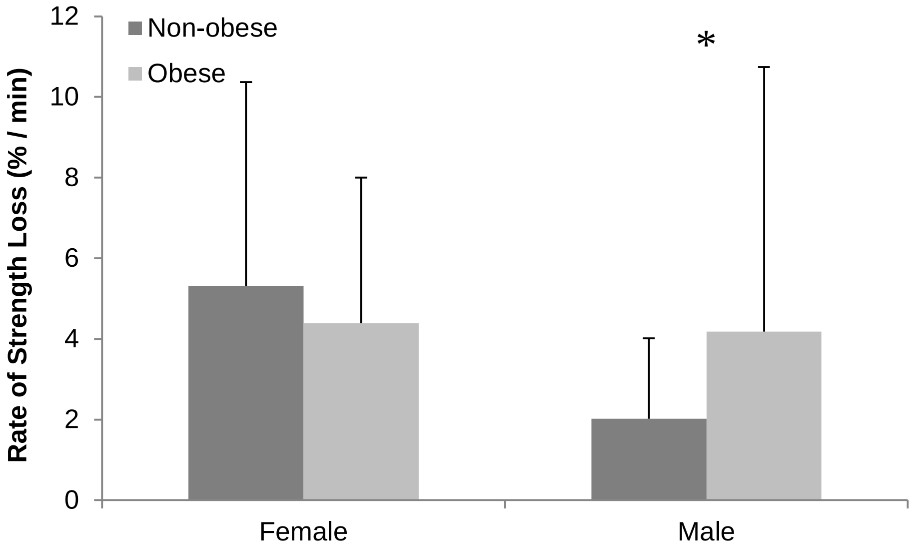

Figure 4.5. Mean rates of strength loss by gender for each obesity group. Error bars represent standard deviations. The symbol * indicates a significant ($p<0.1$) difference between obesity groups within each gender.

4.3.2 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 4.6).

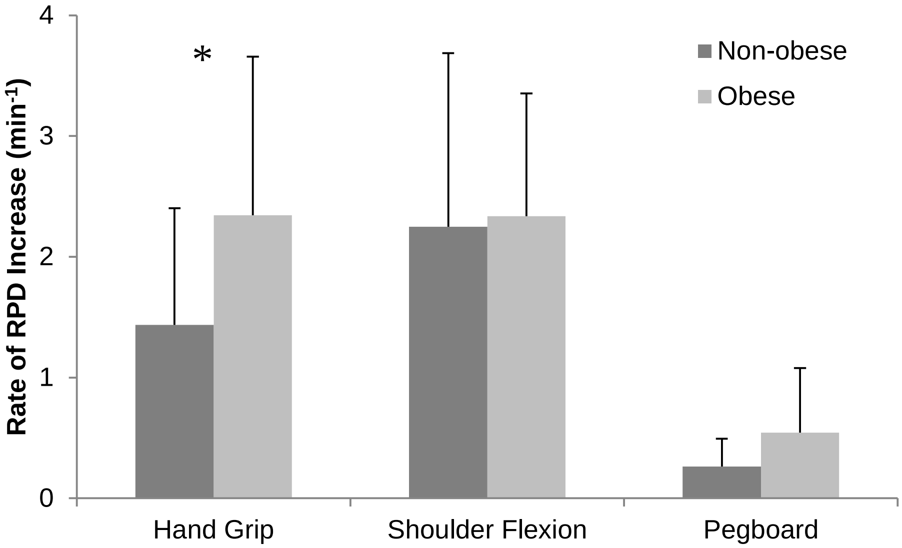

Figure 4.6. Mean rate of RPD increase by task for each obesity group. Error bars represent standard deviations. The symbol * indicates a significant ($p<0.1$) difference between obesity groups within each task.

4.3.3 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 4.7, 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 4.7, bottom).

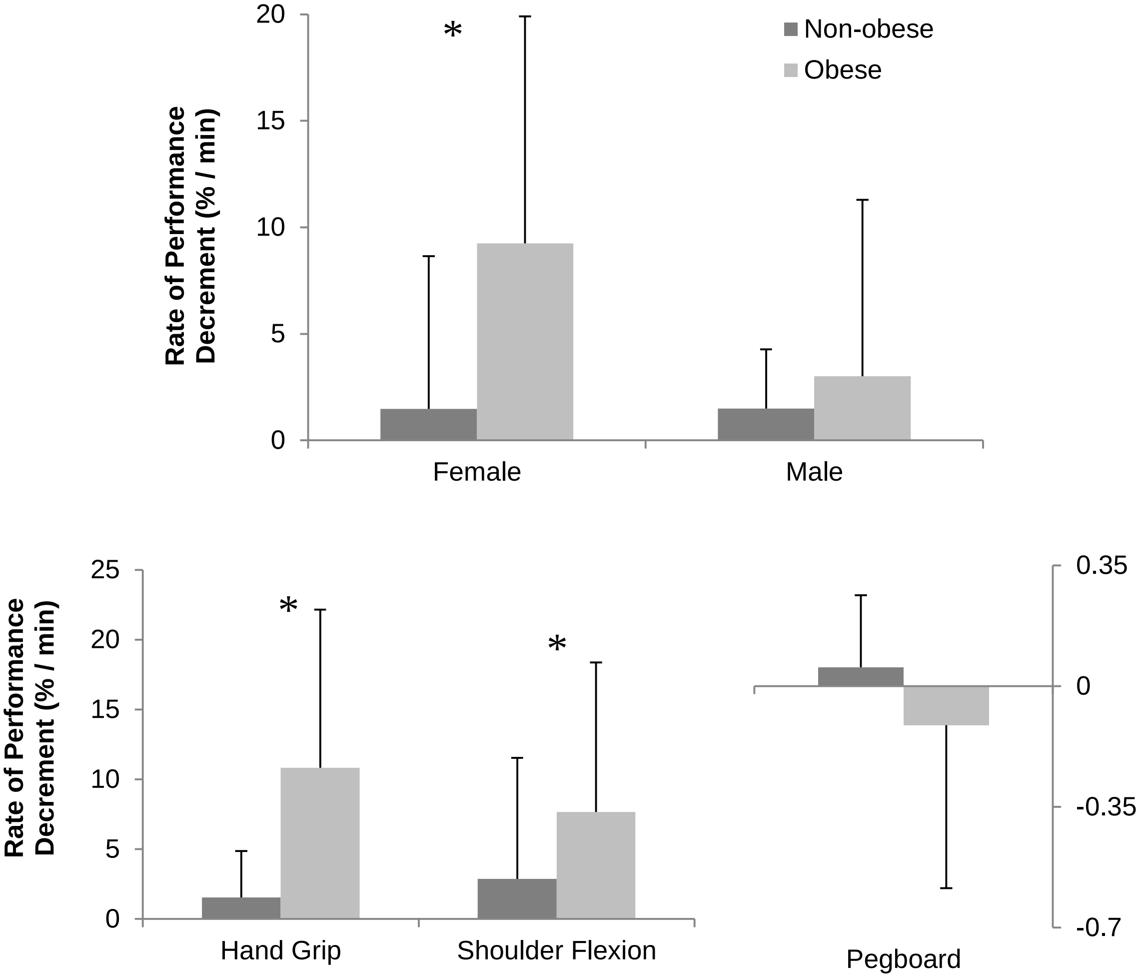

Figure 4.7. Mean rates of performance decrement by gender (top) and task (bottom) for each obesity group. Error bars represent standard deviations. The symbol * indicates a significant (*p*<0.1) difference between obesity groups within each task.

4.4 Discussion

4.4.1 Effect of obesity on functional performance

We hypothesized that individuals who are obese would have lower functional performance during the intermittent tasks. Supporting this, the non-obese group overall had ~ 60% longer endurance times across the three tasks examined. Our previous work (Chapter 3) on shoulder flexion endurance during sustained isometric tasks – which involved participants of similar age, stature, and BMI breakdown 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 in a small sample of males (Eksioglu, 2011). The difference in magnitude between the prior and current outcomes likely resulted from protocols examining sustained vs. 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 (Kirkwood et al., 1991; Newcomer et al., 2001) 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. (2001), who found that individuals who are obese require more oxygen than those who are lean when performing similar cycling exercise.

Further support for the hypothesized effect of decreased functional performance with obesity was observed in the interaction between obesity and gender on the rate of strength loss. Obese males had higher rates of strength loss than non-obese males, indicating higher rates of fatigue development with obesity. Similarly, Maffiuletti et al. (2007) found higher strength loss in obese males for the quadriceps 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. (2001) 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 our earlier work (Chapters 2 and 3), 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.

4.4.2 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). Our results here are consistent with previous reports of slower fatigue development with older age during fixed relative load tasks (e.g., Bazzucchi et al., 2005; Ditor and Hicks, 2000; Yassierli et al., 2007). 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 (e.g., Clark et al., 2007; Hinckson and Hopkins, 2005).

4.4.3 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 for 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 (D'Hondt et al., 2008), and longer movement times were found for tasks that require controlled aiming of the upper extremity (Berrigan et al., 2006). 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. (2006) is that the latter had participants standing, which added a balance constraint that was not present here. In addition, neither D’Hondt et al. (2008) or Berrigan et al. (2006) involved endurance or fatigue testing, but rather a single measurement of performance. Visual inspection of the current pegboard performance data revealed that the rates of performance decrement were relatively low (Figure 4.7) and that there was relatively large variability of the data 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.

4.4.4 Limitations

As mentioned above, this study may be limited by the small sample size and the potential insensitivity of some dependent measures. 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 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. 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.

4.5 Conclusions

In summary, 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. Further work is needed to examine whether the effects of these individual differences translate to workplace performance and/or injury risk.

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5 Conclusions and Recommendations

Approximately 20% of medical costs in the US are related to obesity, and it is likely that these costs will continue to increase as the prevalence of obesity rises (Cawley and Meyerhoefer, 2012). Obesity is also associated with work-related costs, such as increased injury rates, higher absenteeism, and lost productivity (Goetzel et al., 2010). Previous relevant work has focused on obesity-related changes in strength, balance, and activities of daily living, though little research has been done regarding endurance differences and fatigue development. The aim of this dissertation was to understand better the effects of obesity and age on strength, endurance, and performance, particularly for tasks/demands relevant to those in the workplace. Three laboratory studies were used to evaluate these effects using a variety of endurance tests involving the upper extremity and low back. Specific purposes of these studies were to: 1) determine the effects of obesity on functional performance during sustained isometric exertions; 2) assess whether age and obesity have interactive effects on shoulder capacity; and 3) identify the effects of obesity and age during intermittent static exertions.

5.1 Effect of obesity on functional performance

Consistent with the results from previous studies, we found increased absolute strength for individuals who are obese across our three studies. Strength differences reported for the shoulder in Chapters 2 and 3 add to existing literature that had focused on the lower extremity, hand grip, and torso. From the first study (Chapter 2), and contrary to expectations, obesity had only subtle influences on fatigue, perception, and performance during basic isometric tasks. For similar sustained isometric tasks in the second study (Chapter 3), there was a main effect of obesity on endurance time, with the obese group having overall shorter endurance than the non-obese group, particularly among young females and older males. When task complexity was increased in the third study (Chapter 4), obesity led to shorter endurance times compared regardless of age and gender. It is likely that the intermittent tasks in the third study revealed muscle blood flow and recovery limitations that occur with obesity (Kirkwood et al., 1991; Newcomer et al., 2001). The existence of a functional performance impairment related to obesity was not strongly supported by the other fatigue and task performance measures used in the first two studies. However, during the intermittent hand grip and shoulder flexion tasks, task performance was negatively affected by obesity. The specific measures and sample sizes used in the three studies may not have been sensitive enough to detect some of the differences related to obesity.

5.2 Interactive effects of obesity and age on functional performance

Age was included as an independent variable in Chapters 3 and 4, and it was expected that the effect of obesity would be greater among older participants. Previous work has indicated that movement ability declines in the older obese population, and that these individuals have difficulties completing activities of daily living (Houston et al., 2009; Larsson and Mattsson, 2001; Zoico et al., 2004). The current studies indicate only a few interactions between obesity and age, with no conclusive results regarding the combined influence of obesity and age on functional performance. To our knowledge, our two studies were among the first to examine the interactive effects of age and obesity on muscle endurance and related effects of acute fatigue. Due to the exploratory nature of the work, the conflicting outcomes may have been from a small sample size and large variability within the data, particularly since some of the same participants were used in both studies. In addition, since the tasks were voluntary endurance tasks, differences in motivation between sessions and between participants may have affected the endurance times.

5.3 Interactive effects of obesity and task

We expected that the effect of obesity on functional performance would be larger when supporting body segment mass was essential to the task. This was tested explicitly in the second study, in which the two arm postures were selected to manipulate the level of body segment mass support by the shoulder. From the results presented in Chapter 3, we found conflicting task-related differences. Participants had a longer endurance for the flexed posture compared to the extended posture, as expected, however inconsistent group-level differences were seen for the non-obese young and non-obese older groups. Results from the third study (Chapter 4) were more consistent with respect to endurance time, where the pegboard task resulted in the largest obesity-related declines in endurance time, though there were no significant obesity-related effects on performance for the pegboard task. Previous studies involving similar fine motor control tasks have shown decreased task performance with increased BMI (Berrigan et al., 2006; D'Hondt et al., 2008), and visual inspection of the data revealed higher rates of performance decline for the obese group during the pegboard endurance task. However, these groups were small and there was a large amount of variability in the obese group data. The expected obesity-related performance impairments may be observed if similar tests are performed with a larger sample.

5.3 Research Contributions

To address some important limitations of previous research, the current work considered the effects of obesity on muscular capacity of multiple upper extremity and torso muscle groups for several basic tasks involving prolonged and intermittent static demands. This work has provided a better understanding of the demands and capabilities of obese individuals when performing tasks that require extensive use of the upper body. Through the consideration of muscle fatigability under absolute loading, real world working conditions were replicated more closely in this work. More importantly, the muscle groups tested are commonly afflicted by work-related injuries, but have received little attention in the obesity literature. Another area that has received little focus is the older obese population, despite the demographic trends described earlier. Rather than using self-report or measures of activities of daily living as in previous research, the current work compared the functional performance limitations that occur in an older obese population using objective measures of musculoskeletal output to relate more directly to work task performance. With the growing prevalence of obesity, it remains necessary to identify differences in muscular capacity that may influence worker performance or increase the risk of work-related injuries.

5.4 Future Directions

Common methods of testing muscular capacity rely on voluntary contractions to assess individual muscle strength and endurance. While these methods relate to applied situations, it is essential to understand the underlying muscle properties to effectively prevent and rehabilitate work-related injuries. The current work identified differences between obese and non-obese, young and older individuals, based on several voluntary measures. Going forward, it is important to explore unanswered questions related to changes in muscle physiology and neuromotor control, particularly for muscles of the upper extremity. To answer these questions, future work can use stimulation protocols to quantify the ability of obese individuals to generate true maximum exertions and to determine stimulated fatigability. In addition, lack of motivation and lower pain tolerance can limit the measured physical abilities of obese individuals.

Therefore, future investigations should consider how these psychophysical factors influence muscle capacity, which can allow for better health promotion strategies.

To bring the current research to practice, studies should consider how the effects of aging and obesity apply to jobs in a diverse set of industries. This is especially important since the prevalence of obesity is projected to increase over the next decades. It is also necessary to address how ergonomic practice and guidelines must be modified to accommodate the diverse workforce. Based on the current findings, interventions modifying work-rest scheduling and demand levels to limit fatigue development should be developed and evaluated. Despite the common implementation of workplace programs designed for weight loss and personal health improvement, there is limited evidence on the effectiveness of such programs. Further longitudinal research is necessary to investigate the benefits of these interventions on reducing the risk of injury and improving worker performance. Research is needed to study the efficacy of individual modifications (increasing worker capacities) and the effectiveness of engineering and administrative controls for work re-design (reducing job demands).

5.5 Overall Conclusions

Overall, this dissertation contributes to the growing, but still limited, research on the impact of obesity on functional performance. The findings suggest that obesity may impair endurance of the upper extremity, particularly as tasks become more complex. Substantially reduced endurance times may have implications for determining work-rest schedules based on task demand and predicted endurance times. In addition, the observations may indicate physiological differences in individuals who are obese, and which may limit their workplace task performance. Identifying the impacts of age and obesity on functional performance is necessary to facilitate the development of more inclusive ergonomic guidelines and more effective design of controls and interventions. The results of this work can contribute to determining whether specific accommodations may be needed for obese workers to improve their quality of life, increase their workplace productivity, and reduce the associated healthcare costs of WMSDs.

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APPENDIX

Appendix A: Informed Consent Form

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

Informed Consent for Participants In Research Projects Involving Human Subjects

Title of the Research Study

Evaluating upper extremity and trunk muscular capacity

Investigators

Lora A. Cavuoto – (239) 777-6436 – Department of Industrial and Systems Engineering
Maury A. Nussbaum, Ph.D. – (540) 231-6053 – Department of Industrial and Systems Engineering

I. Purpose of this Study

The aim of this study is to examine muscular capacity under controlled conditions. Multiple tasks involving muscles of the arm, shoulder, and low back will be considered. The tasks will be used to simulate basic parts of work tasks to determine physical demands and outcomes. The goal is to better understand how muscle strength and endurance are affected. This will allow for workplace design that considers more of the worker population.

II. Procedures

All parts of this study will take place in the Industrial Ergonomics and Biomechanics Lab. When you arrive, you will be briefed of the study protocol. You will then be asked if you have any questions and asked to sign this informed consent form. At the start of the experiment, you will be given practice performing the endurance tasks until you feel comfortable with them. The tasks may include hand grip, shoulder, and low back exertions or a peg placement task. After the practice period, you will perform the tasks for a long amount of time at a moderate, sub-maximal exertion level. Each task will continue until you are not able to sustain the target any longer. Multiple measures will be used to determine physical responses to the tasks. These measures may include heart rate, force output, and your perceptions of the physical demand. The experiment is expected to take about 2 hours.

III. Risks

The risks involved in this study are minimal. The overall physical work required for this experiment is not significantly more than for common work tasks. However, there is a small risk of muscle strain and discomfort. After the experiment, you may feel some residual muscle soreness for up to about 48 hours.

IV. Benefits

You will receive no direct benefit from being in this study. The scientific community will benefit through the added information that is expected to result from this study. This will contribute to designing safer jobs.

V. Extent of Anonymity and Confidentiality

The results of this study may be presented at meetings or in publications. Your identity will not be disclosed. All participants in this study will be identified based only on their unique identifying number. Only the researchers will have access to these identifying numbers.

VI. Compensation

You will be paid $15 / hour for your participation in this study.

VII. Freedom to Withdraw

You are free to withdraw from the study at any time without penalty. If you choose to withdraw, you will be compensated for the portion of the study that you completed.

VIII. Approval of Research

This research project has been approved, as required, by the Institutional Review Board for Research Involving Human Subjects at Virginia Polytechnic Institute and State University.

IX. Subject Responsibilities

I voluntarily agree to participate in this study.

X. Subject's Permission

I have read and understand the Informed Consent and conditions of this project. I have had all of my questions answered. I hereby acknowledge the above and give my voluntary consent:

____ ____________

Participant's signature Date

____ ____________

Experimenter's signature Date

Should I have any questions about this research or its conduct, and research subjects' rights, and whom to contact in the event of a research related injury to the subject, I may contact:

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