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Ergonomics Studies on Obese Individuals: Joint Range of Motion and Executive Functions

비만인의 관절가동범위 및 실행기능에 관한 인간공학 연구

2021 년 8 월

서울대학교 대학원
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이 논문을 공학박사 학위논문으로 제출함

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Abstract

Ergonomics Studies on Obese Individuals: Joint Range of Motion and Executive Functions

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Obesity is prevalent worldwide and its prevalence is expected to increase in the near future. Therefore, understanding how obesity impacts physical and cognitive performance would need to be studied, and, it could help identify and address potential occupational issues through ergonomics design of work systems. In the physical ergonomics, joint range of motion (RoM) is a fundamental research topic as many daily-life and work activities are affected by body flexibility. Also, a significant proportion of the workforce in many countries are pre-obese or obese and the prevalence of these physical conditions is expected to increase in the near future. Therefore, understanding how pre-obesity and obesity impact workers' body flexibility would benefit the design of various products and systems for pre-obese/obese users, and, help address potential occupational issues. In many daily life and work activities, people perform cognitive tasks as well as physical/postural holding tasks. The physical/postural holding tasks and cognitive tasks are conducted immediately or concurrently. Therefore, relationships between physical/postural loading and cognitive performance need to be studied. Also, obesity effects on cognitive performance immediately after or during physical/postural loading

need to be examined – obesity is prevalent worldwide and its prevalence is expected to increase in the near future.

Despite the importance mentioned above, understanding how obesity impacts physical and cognitive performance is still insufficient. The previous studies in relation to the obesity effects on joint range of motion examined only a limited set of joint motions and were focused on particular subsets of the pre-obese/obese population. In the physical/postural loading effects on cognitive performance, few studies examined the obesity effects on cognitive performance immediately after or during physical/postural loading. Therefore, this study aimed to investigate the obesity effects on joint RoM and obesity effects on cognitive performance immediately after or during physical/postural loading. To accomplish the objectives, three major studies were conducted.

In the study 1, the pre-obesity and obesity effects on joint range of motion (RoM) for twenty-two body joint motions were investigated. A publicly available joint RoM dataset was analyzed. Three BMI groups (normal-weight, pre-obese, and obese) were statistically compared in joint RoM. The pre-obese and obese groups were found to have significantly smaller RoM means than the normal-weight for elbow flexion and supination, hip extension and flexion, knee flexion, and ankle plantarflexion. The pre-obese and obese groups exhibited no significant inter-group mean RoM differences except for knee flexion; for knee flexion, the obese group had significantly smaller RoM means than the pre-obese.

In the study 2, the obesity effects on cognitive performance immediately after physical task were examined. Manual load lifting/lowering task was employed for the physical task. Obesity had two groups based on the BMI (normal-weight and obese). In the cognitive task, three core executive functions (shifting, updating, and inhibition) were employed. To measure shifting, updating, and inhibition, Number-letter task, Letter-memory task, and Stroop task were used, respectively. One trial consisted of three repeats of a combination of physical and cognitive tasks. Executive functions were slightly improved immediately after a moderate amount of physical loading; however, immediately after a severe amount of physical loading, performance of executive functions generally deteriorated. Also, different patterns of the physical loading effects on executive functions between normal-weight and obese groups were found. Obese and normal-weight groups did not differ in executive functions for physical loading level 1. Immediately after a moderate amount of physical loading, executive functions were significantly improved for the normal-weight group; however, no such significant improvement was found for the obese group.

In the study 3, the obesity effects on cognitive performance during postural holding task were investigated. Three kinds of postures based on the OWAS were employed for postural holding tasks. During the postural holding task, each participant was instructed to maintain the postures on the force plate, and, the center of pressure (CoP) signals were collected to obtain postural sway data. Obesity had two groups based on the BMI (normal-weight and obese). In the cognitive task, three core executive functions (shifting, updating, and inhibition) were employed. To measure shifting, updating, and inhibition, Number-letter task, Letter-memory task, and Stroop task were used, respectively. One trial consisted 30 seconds of postural holding task and 90 seconds of concurrent postural holding and cognitive tasks. Executive functions generally deteriorated as postural loading increased. Also, different patterns of the postural loading effects on executive functions between normal-weight and obese groups were found. For the obese group, executive functions significantly deteriorated between postural loading level 1 and 2; however, no such significant deterioration was found for the normal-weight group. Between postural loading level 2 and 3, executive functions deteriorated for both

the normal-weight and obese groups; however, the deterioration of executive functions was more pronounced for the obese group.

The findings mentioned above improved our understanding of obesity effects on cognitive performance immediately after or during physical/postural loading as well as obesity effects on body flexibility. The knowledge provided in the study 1 would be useful for the ergonomics design of work tasks (e.g., lifting, lowering, and other materials handling tasks) and products and systems (e.g., vehicles, workstations, and furniture) for high BMI individuals. Also, the knowledge mentioned in the study 1 may guide the development of sophisticated digital human models representing differently sized individuals. The findings provided in the study 2 and 3 would be helpful to provide the ergonomics guidelines for daily life and work activities. Physical or postural loading-related changes in cognitive performance should be considered in the working environment and daily life. Especially, in the working environment, a severe amount of physical/postural loading needs to be avoided for workforce productivity as well as safety - the workforce productivity may decrease as cognitive performance deteriorates. Also, different patterns of the physical/postural loading effects on executive functions between normal-weight and obese groups should be considered in the working environment and daily life. Especially, in the working environment, for obese individuals, moderate as well as severe physical/postural loading needs to be avoided.

Keywords: Obesity, Joint range of motion, Executive functions, Physical loading, Postural loading

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Chapter 1

Introduction

1.1 Research Background

According to the World Health Organization (2021a), 39% of the world's adult population were overweight and 13% were obese in 2016. Also, the number of obese people has nearly tripled from 1975 to 2016. The prevalence of these physical conditions is expected to increase in the near future (Finkelstein et al., 2012; World Health Organization, 2021a). Therefore, understanding how obesity impacts physical and cognitive performance would need to be studied, and, it could help identify and address potential occupational issues through ergonomics design of work systems.

In the physical ergonomics, joint range of motion (RoM) is a fundamental research topic as many daily-life and work activities are affected by body flexibility - in ergonomics and related disciplines, body flexibility is often measured in terms of joint RoM (Chaffin, Anderson, and Martin, 2006; Kroemer et al., 1997). Also, a significant proportion of the workforce in many countries, including both developed and developing ones, are pre-obese or obese and the prevalence of these physical conditions is expected to increase in the near future (Finkelstein et al., 2012; World Health Organization, 2021a). Therefore, understanding how pre-obesity and obesity impact workers' body flexibility would benefit the design of various products and systems for pre-obese/obese users, and, help address potential occupational issues.

In many daily life and work activities, people perform cognitive tasks as well as physical or postural holding tasks. The physical/postural holding tasks and cognitive tasks are conducted immediately or concurrently. For example, in case of factory workers, they search information on computers immediately after lifting and carrying goods. Also, they monitor screens with maintaining various postures, such as sitting, standing, reaching, kneeling, or twisting postures. Similarly, in case of daily life, people organize and schedule their daily activities or read newspapers and magazines immediately after sweeping, vacuuming, washing dishes, doing laundry, or cleaning bathrooms. Also, they search information on mobile phones with sitting on couches or chairs, lying on bed, or standing on the floor. Bus or truck drivers follow a planned route according to a time schedule during driving. Also, they obey traffic signals and signs during driving. The driving postures consist of sitting, reaching, holding, or twisting. In case of firefighters, they operate the nozzle at appropriate pressure and flow, maintain situational awareness, and find out optimum rescue route immediately after/during extinguishing fires. During the extinguishing fires, they maintain various postures, such as standing, holding, squatting, kneeling, or twisting. Office workers plan and organize work activities immediately after paper shredding, office cleaning, packing, or moving some materials. Also, they make a report with prolonged sitting postures or make a presentation with prolonged standing postures. In case of doctors, they perform a surgery with prolonged standing, twisting, holding, or stooping postures. The performing a surgery is highly complex and mentally demanding task, and, it related to several cognitive functions and processes, such as perception, attention, and deliberate thinking (Marquardt et al., 2015). Therefore, relationships between physical/postural loading and cognitive performance need to be studied. Also, obesity effects on cognitive performance immediately after or during physical/postural loading need to be examined – as mentioned earlier, the number of obese people has nearly tripled from 1975 to 2016, and it is projected that prevalence of obesity will increase in the near future (Finkelstein et al., 2012; World Health Organization, 2021a).

In spite of the importance mentioned above, understanding how obesity impacts physical and cognitive performance is still insufficient. One research gap is pre-obesity and obesity effects on joint RoM. The previous studies in general examined only a limited set of joint motions and were focused on particular subsets of the pre-obese/obese population (Escalante et al., 1999a,b; Joao et al., 2014; Park et al., 2010). Second gap is obesity and physical/postural loading effects on cognitive performance. The previous studies found that physical/postural loading adversely affected on cognitive performance (DiDomenico and Nussbaum, 2011; Kang, Lee, and Jin, 2021; Kerr et al., 1985; Lorist et al., 2002; Nibbeling et al., 2014; Smith et al., 2016; Son et al., 2019; Son, 2018; Stephenson et al., 2020). Also, obesity negatively affected physical function and performance (Blimkie, Sale, and Bar-Or, 1990; Cavuoto and Nussbaum, 2013; Corbeil et al., 2019; De Stefano et al., 2015, Du, Zhu, and Jiao, 2017; Escalante et al., 1999a,b; Houston et al., 2007; Hue et al., 2007; Hulens et al., 2001; Joao et al., 2014; Kejonen et al., 2003; Kitagawa and Miyashita, 1978, Koushyar et al., 2017; McGraw et al., 2000; Miyatake et al., 2000; Park et al., 2010; Singh et al., 2009; Singh et al., 2015; Teasdale et al., 2007; Tomlinson et al., 2016). Given the results mentioned above, compared to normal-weight individuals, obese individuals would have different cognitive performance immediately after or during physical/postural loading. However, few studies examined the obesity effects on cognitive performance immediately after or during physical/postural loading.

1.2 Research Objectives

This study investigated the obesity effects on physical and cognitive performance. The dissertation consisted of three major studies in relation to the research objectives. The objectives of the current study were as follows:

- Study 1) To identify and characterize the pre-obesity and obesity effects on joint RoM for a large set of joint motions considering a wide range of BMI,

- Study 2) To examine the obesity effects on cognitive performance immediately after physical task. Executive functions were employed for cognitive performance. Manual load lifting/lowering task was used for physical task, and

- Study 3) To investigate the obesity effects on cognitive performance during postural holding task. Executive functions were employed for cognitive performance. Three kinds of postures based on the Ovako Working Posture Analyzing System (OWAS; Karhu, Kansi, and Kuorinka, 1977) were used for postural holding task.

1.3 Dissertation Outline

This dissertation consisted of three major studies in relation to the research objectives presented in Chapter 1.2. In the study 1, pre-obesity and obesity effects on joint range of motion were examined. In the study 2, obesity effects on executive functions immediately after manual load lifting/lowering task were investigated. In the study 3, obesity effects on executive functions during postural holding task were examined. The overall structure of this dissertation took the form of six chapters (Figure 1.1). Brief descriptions of the chapters were presented below.

In Chapter 1, research background and objectives were described. Also, the overall structure of the dissertation was presented.

In Chapter 2, previous studies on the relationship between obesity and physical performance or obesity and cognitive performance were reviewed. Also, previous studies on the relationship between physical/postural loading and cognitive performance were reviewed. The definition and importance of executive functions were presented.

In Chapter 3, pre-obesity and obesity effects on joint range of motion for twenty-two body joint motions were examined. A publicly available joint RoM dataset was analyzed. Three BMI groups (normal-weight, pre-obese, and obese) were statistically compared in joint RoM.

In Chapter 4, obesity effects on executive functions immediately after physical task were investigated. Manual load lifting/lowering task was employed for the physical task. Obesity had two groups based on the BMI (normal-weight and obese). In the cognitive task, three core executive functions (shifting, updating, and inhibition) were employed. To measure shifting, updating, and inhibition, Number-letter task, Letter-memory task, and Stroop task were used, respectively.

In Chapter 5, obesity effects on executive functions during postural holding task were examined. Three kinds of postures based on the OWAS (Karhu, Kansi, and Kuorinka, 1977) class were employed for postural holding tasks. Obesity had two groups based on the BMI (normal-weight and obese). In the cognitive task, three core executive functions (shifting, updating, and inhibition) were employed. To measure shifting, updating, and inhibition, Number-letter task, Letter-memory task, and Stroop task were used, respectively.

In Chapter 6, a brief summary and implications of this study were presented. Also, some limitations of this study were described along with future research ideas.

Chapter 1. Introduction	
• **Research Background and Objectives**	

Chapter 2. Related Literature	
• **Obesity Effects on Physical Function and Performance**	• **Physical Loading Effects on Cognitive Performance**
• **Postural Loading Effects on Cognitive Performance**	• **Obesity Effects on Cognitive Performance**
• **Executive Functions**	

Chapter 3. Pre-obesity and Obesity Effects on Joint Range of Motion	
• **A Publicly Available Passive RoM Dataset**	• **Twenty Two Body Joint Motions**
• **Three BMI Groups (normal-weight, pre-obese, and obese)**	

Chapter 4. Obesity Effects on Executive Functions immediately after Manual Load Lifting/Lowering Task	
• **Two BMI Groups (normal-weight and obese)**	• **Executive Functions (shifting, updating, and inhibition)**
• **Manual Load Lifting/Lowering Task**	

Chapter 5. Obesity Effects on Executive Functions during Postural Holding Task	
• **Two BMI Groups (normal-weight and obese)**	• **Executive Functions (shifting, updating, and inhibition)**
• **Postural Holding Task**	

Chapter 6. Conclusion
• **Summary and Implications**
• **Limitations and Future Works**

Figure 1.1: The overall structure of the dissertation

Chapter 2

Related Literature

2.1 Obesity Effects on Physical Function and Performance

Multiple research studies examined obesity effects on physical function and performance, such as muscular strength, joint range of motion, biomechanical stress, postural control, gait speed, 50-meter dash, standing long jump, and pull-ups.

Some studies investigated obesity effects on muscular strength (Blimkie, Sale, and Bar-Or, 1990; Cavuoto and Nussbaum, 2013; Hulens et al., 2001; Kitagawa and Miyashita, 1978; Koushyar et al., 2017; Miyatake et al., 2000; Tomlinson et al., 2016). These studies demonstrated that compared to non-obese individuals, obese individuals had higher absolute muscular strength, but had lower body-mass normalized muscular strength (relative muscular strength).

Some studies examined obesity effects on joint range of motion (Escalante et al., 1999a,b; Joao et al., 2014; Park et al., 2010). These studies found that joint range of motion (RoM) generally decreased with increasing BMI.

Some studies identified obesity effects on low back biomechanical stresses during manual lifting tasks (Corbeil et al., 2019; Singh et al., 2015). Corbeil et al. (2019) found that external moments at L5/S1 during manual lifting tasks were greater for obese handlers than for healthy-weight handlers. Singh et al. (2015) reported that during manual load lifting, obese group had significantly larger mean L5/S1 disc compression forces compared to normal-weight group.

Some studies investigated obesity-associated changes in postural control using postural sway measures (Hue et al., 2007; Kejonen et al., 2003; McGraw et al., 2000; Singh et al., 2009; Teasdale et al., 2007). These studies found that obesity was associated with increased postural sway, that is, obesity adversely affected postural control.

Some studies examined obesity effects on physical performance (De Stefano et al., 2015; Du, Zhu, and Jiao, 2017; Houston et al., 2007). Houston et al. (2007) and De Stefano et al. (2015) provided that obesity negatively affected physical performance using the short physical performance battery (SPPB). The SPPB consisted of a balance test, a chair stand test, and a gait speed test. Du, Zhu, and Jiao (2017) demonstrated that obesity was associated with poor physical performance, such as 50-meter dash, standing long jump, and pull-ups.

Overall, obesity negatively affected diverse physical function and performance, such as muscular strength, joint range of motion, biomechanical stress, postural control, gait speed, 50-meter dash, standing long jump, and pull-ups. This means that obese individuals might experience more exertion or difficulty during physical activity.

2.2 Physical Loading Effects on Cognitive Performance

Multiple research studies demonstrated that physical loading adversely affected cognitive performance (DiDomenico and Nussbaum, 2011; Lorist et al., 2002; Nibbeling et al., 2014; Smith et al., 2016; Son et al., 2019). DiDomenico and Nussbaum (2011) reported that high frequency of movement adversely affected arithmetic task performance (the number of correct responses). Lorist et al. (2002) found that choice reaction task (CRT) performance decreased as degree of motor fatigue increased, that is, reaction times and the percentage of incorrect responses increased with increasing degree of motor fatigue. Son et al. (2019) identified the effects of backpack weight on performance of working memory tasks. Corsi block task (Corsi, 1972), digit span task (Wechsler, 1939), and 3-back task (Kirchner, 1958) were employed for the working memory tasks. This study showed that performance of the working memory tasks decreased as backpack weight increased. Nibbeling et al. (2014) found that exercise-induced fatigue seemed to negatively influence math task performance. All participants were male soldiers. A 10-minute high-intensity running exercise was employed for exercised-induced fatigue. Smith et al. (2016) showed that cognitive performance was negatively affected by high intensity exercise. In this study, all participants were habitually active adults. Go/No-Go task (Pontifex et al., 2009) was used for cognitive task. Treadmill running was employed for exercise intensity. Cognitive performance (reaction time, omission error rate, and decision error rate) was measured in three exercise sessions (rest, moderate, and high) lasting 10 min each.

Some previous studies found that physical loading positively affected cognitive performance (Hogervorst et al., 1996; Johnson et al., 2016; Park and Etnier, 2019). Hogervorst et al. (1996) found that cognitive performance was improved after bicycle ergometer exercise. Reaction time task and Stroop task (Stroop, 1935) were employed for cognitive task. Johnson et al. (2016) demonstrated that cognitive performance was improved immediately after exercise. All participants were older adults (60 years or older). Stroop inhibition test (Stroop, 1935) was used for cognitive task. Two types of physical activity were employed: aerobic exercise (a cycle ergometer), resistance exercise (bench press, leg curls, seated row exercise, squat rack, and bicep curls). Park and Etnier (2019) demonstrated that cognitive performance was improved immediately after exercise. All participants were high school students, and performed a 20-minute stationary ergometer exercise. After exercise, cognitive tests were administered. Stroop test (Stroop, 1935), Symbol Digit Modalities test (Smith, 1982), and Tower of London test (Shallice, 1982) were employed for cognitive task.

Some previous studies reported that cognitive performance was improved after or during moderate physical loading; however, after or during severe physical loading, cognitive performance decreased (Davey, 1973; Basahel, 2012). Davey (1973) demonstrated that cognitive performance was improved after moderate physical exertion (from 0.5 to 2 min); however, after severe physical exertion (from 5 to 10 min), cognitive performance decreased. Brown and Poulton test (Brown and Poulton, 1961) which relies on short term memory was employed for cognitive task. A bicycle ergometer was used to induce physical exertion. Basahel (2012) reported that cognitive performance was improved during medium level of physical workload; however, cognitive performance decreased during high level of physical workload. In this study, participants concurrently performed physical and cognitive tasks. Auditory arithmetic task and tone Localization task were used to measure cognitive performance. Two types of physical activity were employed: bicycle ergometer exercise and box lifting task. In bicycle ergometer exercise, low, medium, and high physical workload were defined as 20%, 50%, and 80% maximum workload capacity, respectively. In box lifting task, load weight had three levels in relation to the body mass, that is, low, medium, and high physical workload were defined as 8%, 14%, and 20% of body mass, respectively.

Some previous studies demonstrated that physical exertion level did not significantly affect cognitive performance (Bard and Fleury, 1978; Côté, Salmela, and Papathanasopoulu, 1992; Fleury et al., 1981; Pankok et al., 2016; Tomporowski, Ellis, and Stephens, 1987). Pankok et al. (2016) found that physical exertion level did not significantly affect cognitive performance. All participants were highly fit young males between 18 and 25 years of age. Stop-signal task (Verbruggen et al., 2008) was used for cognitive task. Treadmill jogging was used to induce physical exertion, and, VO_2max levels were used to define physical exertion levels. Bard and Fleury (1978) demonstrated that exercise to exhaustion did not significantly affect cognitive performance. All participants were young males. Metabolic fatigue was induced by working to exhaustion on a bicycle ergometer. Visual search tasks such as letter detection task and spatial location task were employed for cognitive tasks. Fleury et al. (1981) found that exercise to exhaustion did not significantly affect cognitive performance. All participants were young males. Metabolic fatigue was induced by working to exhaustion on a treadmill. Visual search task such as letter detection task was employed for cognitive task. Côté, Salmela, and Papathanasopoulu (1992) demonstrated that exercise to exhaustion did not significantly affect cognitive performance. Metabolic fatigue was induced by working to exhaustion on a stationary bicycle. A verbal 5-choice RT task was employed for cognitive task. Tomporowski, Ellis, and Stephens (1987) found that exercise to exhaustion did not significantly affect cognitive performance. All participants were college-age subjects. Metabolic fatigue was induced by working to exhaustion on a treadmill. Memory tests were employed for cognitive tasks.

Overall, physical loading effects on cognitive performance still remain equivocal despite a substantial number of investigations in the area. It may be attributed to the methodological discrepancies across different studies, that is, different methods for physical loading or measures for cognitive performance.

2.3 Postural Loading Effects on Cognitive Performance

Multiple research studies demonstrated that postural loading adversely affected cognitive performance (Kang, Lee, and Jin, 2021; Kerr et al., 1985; Son, 2018; Stephenson et al., 2020). Stephenson et al. (2020) found that cognitive performance was negatively affected by postural fatigue (muscular fatigue). Participants were healthy adults aged 18 to 52 years. Postural fatigue was induced by holding static position for as long as possible. Participants were asked to maintain a static shoulder flexion angle of 70° to 90°, with pronated wrists and extended elbows. 5-N weights were strapped to each wrist. Tracking and system-monitoring tasks were used to measure cognitive attentional resources. Kang, Lee, and Jin (2021) found that using the standing workstation decreased cognitive performance compared to the sitting workstation. Paced Auditory Serial Addition Test (PASAT; Gronwall and Sampson, 1974), and Stroop test (Stroop, 1935) were employed for cognitive tasks. Son (2018) demonstrated that cognitive performance significantly decreased as postural loading increased. Working memory tasks such as Corsi block task (Corsi, 1972), digit span task (Wechsler, 1939), and 3-back task (Kirchner, 1958) were employed for cognitive tasks. Postural loading levels were based on Ovako Working Posture Analyzing System (OWAS) proposed by Karhu, Kansi, and Kuorinka (1977). Kerr et al. (1985) found that spatial memory performance decreased during maintaining a difficult standing balance position compared to sitting position.

Some previous studies demonstrated that postural loading did not significantly affect cognitive performance (Bantoft et al., 2016; Dault, Frank, and Allard, 2001; Russell et al., 2016; Schwartz et al., 2018). Bantoft et al. (2016) found that there was no significant difference in cognitive performance between sitting, standing, or walking conditions. Digit span forward (Wechsler, 1997), Digit span backward (Wechsler, 1997), Digit symbol coding subtest (Wechsler, 1997), Letter number sequencing subtest (Wechsler, 1997), 24 item Victoria version Stroop test (Strauss, Sherman, and Spreen, 2006), Choice reaction time test, and Paced Auditory Serial Addition Task (PASAT; Strauss, Sherman, and Spreen, 2006) were employed for cognitive tasks. Dault, Frank, and Allard (2001) demonstrated that there was no significant difference in working memory performance between three postures (sitting, shoulder width stance, and tandem stance). Russell et al. (2016) showed no statistically significant difference in cognitive performance between the sitting and standing conditions. 24 item Victoria version Stroop test (Strauss, Sherman, and Spreen, 2006), Four-choice visual reaction time test, Digit symbol coding subtest (Wechsler, 2008), Trail making test (Strauss, Sherman, and Spreen, 2006), Letter number sequencing subtest (Wechsler, 2008), and Digit span subtest (Wechsler, 2008) were employed for cognitive tasks. Schwartz et al. (2018) showed no statistically significant difference in cognitive performance between alternating, standing or sitting postures. Working speed, reaction time, and concentration performance were used for cognitive tasks.

Overall, postural loading adversely affected cognitive performance or did not affect cognitive performance, that is, postural loading effects on cognitive performance still remain equivocal despite a substantial number of investigations in the area. It may be attributed to the methodological discrepancies across different studies, that is, different methods for postural loading or measures for cognitive performance.

2.4 Obesity Effects on Cognitive Performance

Multiple research studies found that obesity is negatively associated with cognitive performance (Boeka and Lokken, 2008; Fergenbaum et al., 2009; Gunstad et al., 2007; Sabia et al., 2009). Gunstad et al. (2007) demonstrated that overweight and obese adults exhibited poorer performance in executive functions than normal weight adults. This study used Verbal interference, Switching of attention-letter/number, and Maze errors (Walsh, 1978) for test of executive functions. Boeka and Lokken (2008) showed that extremely obese individuals performed poorly on cognitive performance as compared to normative data. Rey complex figure test (CFT; Rey, 1941) and Wisconsin card sorting test (WCST; Grant and Berg, 1948) were used for cognitive tests. Fergenbaum et al. (2009) demonstrated that obese individuals had lower cognitive performance compared to normal-weight individuals. Trail making test (Strauss, Sherman, and Spreen, 2006) was used for cognitive test. Sabia et al. (2009) found that obesity was associated with lower cognitive performance. The 30-item Mini-Mental State Examination (MMSE; Folstein, Folstein, and McHugh, 1975), AH4-I (Alice Heim 4-I; Heim, 1970), and phonemic and semantic fluency (Borkowski, Benton, and Spreen, 1967) were used for cognitive tests.

Some studies found that there were no associations between obesity and cognitive performance (Gunstad et al., 2007; Kuo et al., 2006; Ward et al., 2005; Wolf et al., 2007). Ward et al. (2005) demonstrated that cognitive performance was not associated with BMI. The battery of neuropsychological tests (Spreen and Strauss, 1998) including Wechsler adult intelligence scale-third edition (WAIS-III), the Rey auditory verbal learning test (RAVLT), and Trail making test was used for cognitive tests. Kuo et al. (2006) found that there were no differences in performance of global cognition, memory, reasoning between obese and normal-weight individuals. Gunstad et al. (2007) found that there were no differences in attention performance between obese and normal-weight individuals. This study employed Digit span forward, Choice reaction time, Switching of attention-number, and Span of visual memory for attention tests. Wolf et al. (2007) showed that there were no associations between BMI and cognitive performance. Visual Reproductions, paired associates, and logical memory were used for cognitive tests.

Some research studies demonstrated that obesity is positively associated with cognitive performance (Han et al., 2009; Kuo et al., 2006). Kuo et al. (2006) found that overweight and obese individuals exhibited better performance on the visuospatial speed of processing than normal-weight individuals. All participants were elderly (age $\geq$ 65). Han et al. (2009) showed that increased BMI and percent body fat (PBF) positively affected cognitive performance for elderly individuals (age $\geq$ 60). A total score for the Consortium to Establish a Registry for Alzheimer's Disease (CERAD) neuropsychological battery (Chandler et al., 2005) was used as an index of the cognitive performance.

Overall, obesity effects on cognitive performance still remain equivocal despite a substantial number of investigations in the area. It may be attributed to the methodological discrepancies across different studies, that is, different measures for cognitive performance or participants' characteristics.

2.5 Executive Functions

Executive functions are defined as a set of the general-purpose control mechanisms that regulate the dynamics of human cognition and action (Miyake and Friedman, 2012; Miyake et al., 2000). The Baddeley's model (Baddeley, 1986) referred to the executive functions as the central executive system that is responsible for the control and regulation of cognitive processes - among the three components of the working memory (phonological loop, visuospatial sketchpad, and central executive), the central executive system controls and regulates the phonological loop and the visuospatial sketchpad.

Executive functions have been an important research topic in cognitive psychology and ergonomics as they are a core component of self-regulation or self-control ability (Mischel et al., 2011; Miyake and Friedman, 2012; Moffitt et al., 2011), and they also allow people to concurrently perform multiple tasks (Himi et al., 2019; Lezak et al., 2004). Also, executive functions are essential for every aspect of life, such as mental and physical health, quality of life, school readiness and success, job success, marital harmony, and public safety (Bailey, 2007; Baler and Volkow, 2006; Barch, 2005; Blair and Razza, 2007; Borella, Carretti, and Pelegrina, 2010; Broidy et al., 2003; Brown and Landgraf, 2010; Crescioni et al., 2011; Davis et al., 2010; Denson et al., 2011; Diamond, 2005; Diamond, 2013; Duncan et al., 2007; Eakin et al., 2004; Fairchild et al., 2009; Gathercole et al., 2004; Lui and Tannock, 2007; Miller, Barnes, and Beaver, 2011; Morrison, Ponitz, and McClelland, 2010; Penades et al., 2007; Riggs et al., 2010; Tavares et al., 2007).

According to the Miyake et al.'s model (Miyake et al., 2000), executive functions consist of three core executive functions: shifting, updating, and inhibition. The shifting function represents the ability to shift between multiple tasks, operations, or mental sets.

The updating function means updating and monitoring of working memory representations by replacing outdated information with new relevant information. The inhibition represents the ability to deliberately inhibit dominant, automatic, or prepotent responses when necessary.

Chapter 3

Pre-obesity and Obesity Effects on Joint Range of Motion

3.1 Introduction

Joint range of motion (RoM) has been and continues to be a fundamental research topic in physical ergonomics as many daily-life and work activities are affected by body flexibility - in ergonomics and related disciplines, body flexibility is often measured in terms of joint RoM (Chaffin, Anderson, and Martin, 2006; Kroemer et al., 1997). As part of the efforts to enhance our knowledge on human body flexibility, much research has been conducted to determine the relationships between joint RoM and personal variables, such as age, gender, and body mass index (BMI; an obesity measure). Many previous studies examined age-associated changes in joint RoM (Allander et al., 1974; Boone and Azen, 1979; Buckwalter and DiNubile, 1997; Doriot and Wang, 2006; Grimston et al., 1993; James and Parker, 1989; McGill, Yingling, and Peach, 1999; Roach and Miles, 1991; Sforza et al., 2002; Soucie et al., 2011; Stubbs, Fernandez, and Glenn, 1993). These studies found that joint RoM generally decreased with increasing age. James and Parker (1989), Araújo (2004), Doriot and Wang (2006), Chung and Wang (2009), Soucie et al. (2011), and Hoffman (2014) investigated the effects of gender on joint RoM. These studies reported that women had greater joint mobility than men for many body joint motions. Escalante et al. (1999a,b), Park et al. (2010), and Joao et al. (2014) examined obesity-associated changes in joint RoM. Obesity was found to be associated with reduced RoM for some of the body joint motions considered.

The effects of pre-obesity (overweight) and obesity on joint RoM are an important research issue in physical ergonomics as a significant proportion of the workforce in many countries, including both developed and developing ones, are pre-obese or obese (Finkelstein et al., 2012; World Health Organization 2021a). According to the World Health Organization (2021a), the number of obese people has nearly tripled from 1975 to 2016. It is projected that prevalence of obesity will increase in the near future (Finkelstein et al., 2012). Understanding how pre-obesity and obesity impact workers' body flexibility would help identify and address potential occupational issues for the affected workers through the ergonomics design of physical work systems. Also, it would benefit the design of various products and systems for pre-obese/obese users and also the development of digital human models representing differently sized individuals.

Despite previous research efforts, however, the current body of knowledge on the pre-obesity and obesity effects on joint RoM is insufficient. The previous studies in general examined only a limited set of joint motions and were focused on particular subsets of the pre-obese/obese population: Escalante et al. (1999a) examined shoulder and elbow flexion. Escalante et al. (1999b) investigated hip and knee flexion. Joao et al. (2014) investigated hip and knee joint motions. The subjects of Escalante et al. (1999a,b) were elderly people aged 65 to 79 years. Joao et al. (2014) examined children (age ranging from 6 to 12 years). Park et al. (2010) considered many joint motions in both the upper and lower body areas; however, the study examined only two obesity categories, that is, the non-obese ($20kg/m^2$<BMI<$25kg/m^2$) and extremely obese (BMI>$40kg/m^2$) categories – the BMI range of $25\sim40kg/m^2$ was not considered. Also, only male subjects participated in their study.

To improve our understanding of pre-obesity and obesity effects on body flexibility, and, contribute to the ergonomics design for pre-obese/obese individuals, the aim of this chapter was to identify and characterize the pre-obesity and obesity effects on joint RoM for a large set of joint motions considering a wide range of BMI.

The main hypotheses of this chapter were as follows:

- H1) Obese and pre-obese individuals generally have smaller joint RoM than the normal-weight, and,
- H2) RoM reductions associated with pre-obesity and obesity are observed for only part of the joint motions.

H1 was based on the fact that pre-obese and obese individuals generally have excess fat in their body, and, such extra fat would hinder inter-segmental rotations at body joints (Chaffin, Anderson, and Martin, 2006; Escalante et al., 1999a,b; Gilleard and Smith, 2007; Laubuch, 1969; Park et al., 2010). H2 was based on the fat accumulation and distribution pattern of the human body. Fat accumulation occurs non-uniformly across different body regions when people become obese (Arner, 1997; Park et al., 2010) - some areas, such as the abdomen, buttock, and thigh, in the human body tend to deposit fat more easily than others.

3.2 Research Methods

3.2.1 Publicly Available Dataset

This study utilized a publicly available normal joint RoM dataset provided by Centers for Disease Control and Prevention (Centers for Disease Control and Prevention, 2010). The dataset was collected to offer reference values for normal passive joint RoM for both genders across a wide range of age and also examine gender- and age-associated variation in joint RoM.

Healthy male and female volunteers between 2 and 69 years of age from the US population were recruited in diverse areas (community gatherings, schools, workplaces, etc.). All of the participants were able to ambulate without any assistance devices and had BMI less than 35 kg/m^2. Participants who had connective tissue disorder, history of joint surgery, neurological diseases, joint injury, a bone fracture within the past 6 months, a joint sprain or dislocation within the past 3 months, pregnancy, and diabetes were excluded (Soucie et al., 2011).

Six hundred seventy-four subjects (313 males and 361 females) aged between 2 and 69 were included in the dataset. The dataset consisted of passive RoM data pertaining to twenty-two joint motions. The joint motions were: shoulder flexion, elbow extension, elbow flexion, elbow pronation, elbow supination, hip extension, hip flexion, knee extension, knee flexion, ankle dorsiflexion, and ankle plantarflexion. Note that all joint motions were measured bilaterally by 9 licensed physical therapists according to the reference manual and training video provided by Centers for Disease Control and Prevention (Centers for Disease Control and Prevention, 2010). To standardize joint RoM measurement procedures, the therapists took part in a 1 day training before measuring joint RoM. With the training, joint RoM measurements of the therapists differed 5 degrees or less. Standard goniometers were used to measure joint RoM. Each joint was moved passively to its full extent, and the joint RoM was measured to the nearest 1 degree (Soucie et al., 2011). Detailed descriptions of the subjects and the measurement procedure are provided in Soucie et al. (2011).

3.2.2 Dataset for Analysis

The RoM dataset was divided into three subsets corresponding to three BMI groups (normal-weight, pre-obese, and obese) and the three BMI groups were compared in joint RoM. The normal-weight group consisted of the subjects with BMI greater than or equal to 18.5 kg/m^2 and less than 25kg/m^2. The pre-obese group had BMI greater than or equal to 25 kg/m^2 and less than 30kg/m^2. The obese group belonged to the class I obesity category (30kg/m^2$\leq$BMI$<$35kg/m^2) of the World Health Organization classification (World Health Organization, 2021b).

Among the 674 subjects (313 males and 361 females) in the public dataset, 204 subjects (103 males and 101 females) younger than 20 years old or with BMI less than 18.5 kg/m^2 (underweight) were excluded. A total of 470 subjects (210 males and 260 females) were left for the statistical analyses – they were 231 normal-weight (71 males and 160 females), 174 pre-obese (101 males and 73 females) and 65 obese (38 males and 27 females) subjects (Table 3.1).

Table 3.1: Summary of the age, height, body mass and BMI data for the three BMI groups

Dimensions	Normal-weight (n=231, M=71, F=160)	Pre-obese (n=174, M=101, F=73)	Obese (n=65, M=38, F=27)
	Mean ± SD	Mean ± SD	Mean ± SD
Age (years)	41.5 ± 13.9	44. 8 ± 13.5	46.9 ± 12.8
Height (cm)	168.4 ± 9.7	171.3 ± 10.6	171.8 ± 12.0
Body mass (kg)	63.4 ± 9.4	79.9 ± 11.0	94.3 ± 12.9
BMI (kg/m²)	22.2 ± 1.6	27.1 ± 1.4	31.8 ± 1.2

Note: “M” and “F” denote male and female, respectively.

3.2.3 Statistical Analyses

A series of two-way analyses of covariance (ANCOVAs) were performed to test for differences in RoM means among the BMI and gender groups. In the ANCOVAs, age was chosen as a covariate. Subsequently, a series of pairwise comparisons (post-hoc tests) were conducted to fully examine the pattern of mean differences among the BMI groups (pre-obese−normal-weight, obese−pre-obese, and obese−normal-weight). The Bonferroni adjustment was used for the pairwise comparisons. Statistical Package for the Social Sciences (SPSS) Statistics version 24.0 (SPSS Inc., Chicago, IL) was used to carry out all statistical analyses. The α-level was set at 0.05 for all statistical analyses.

3.3 Results

3.3.1 Age Effects on Joint RoM

As for the age effects on RoM, the ANCOVAs found that joint RoM decreased with increasing age for fifteen out of the twenty-two joint motions examined (Table 3.2). The joint motions were: shoulder flexion, elbow extension and right elbow supination, hip extension and flexion, knee flexion, and ankle dorsiflexion and plantarflexion. For these 15 joint motions, the regression coefficient estimates for the age factor were all negative (-) indicating inverse relationships between age and joint RoM. No significant age-associated changes were found for elbow flexion, elbow pronation, left elbow supination, and knee extension.

3.3.2 Gender Effects on Joint RoM

Regarding the gender effects on RoM, the ANCOVAs revealed that the female group had significantly larger RoM means than the male for eighteen out of the twenty-two joint motions (Table 3.3): shoulder flexion, elbow extension, flexion, pronation and supination, hip flexion, knee extension and flexion, and ankle plantarflexion. No significant inter-group mean RoM differences were found for hip extension and ankle dorsiflexion. No significant interaction effects between BMI and gender were found except for left knee flexion.

Table 3.2: Regression coefficient estimates for the age factor

Body joint	Type of motion		Regression Coefficient Estimate	*p*-value
Shoulder	Flexion	Left	-0.171	**< .001***
		Right	-0.188	**< .001***
Elbow	Extension	Left	-0.058	**< .001***
		Right	-0.057	**.001***
	Flexion	Left	-0.023	.255
		Right	-0.031	.127
	Pronation	Left	-0.035	.135
		Right	-0.008	.740
	Supination	Left	-0.048	.086
		Right	-0.081	**.001***
Hip	Extension	Left	-0.069	**.003***
		Right	-0.062	**.005***
	Flexion	Left	-0.068	**.012***
		Right	-0.092	**.001***
Knee	Extension	Left	-0.012	.182
		Right	-0.013	.176
	Flexion	Left	-0.082	**< .001***
		Right	-0.106	**< .001***
Ankle	Dorsiflexion	Left	-0.040	**.043***
		Right	-0.055	**.006***
	Plantarflexion	Left	-0.177	**< .001***
		Right	-0.165	**< .001***

*Indicates significant at the .05 level.

Table 3.3: Gender group range of motion means and standard deviations and inter-group mean differences for the joint motions

Body joint	Type of motion		Male (°)	Female (°)	Mean difference (°) Female – Male	*p*-value
Shoulder	Flexion	Left	166.3 ± 9.2	170.0 ± 7.9	3.7	**< .001***
		Right	166.9 ± 8.4	170.3 ± 8.2	3.4	**.001***
Elbow	Extension	Left	0.4 ± 4.1	4.2 ± 5.3	3.8	**< .001***
		Right	-0.2 ± 4.3	4.2 ± 5.5	4.4	**< .001***
	Flexion	Left	144.5 ± 6.1	148.9 ± 5.9	4.4	**< .001***
		Right	143.7 ± 6.2	149.4 ± 6.0	5.7	**< .001***
	Pronation	Left	77.2 ± 7.1	81.1 ± 6.6	3.9	**< .001***
		Right	77.4 ± 6.8	81.8 ± 6.7	4.4	**< .001***
	Supination	Left	84.0 ± 8.2	89.7 ± 8.9	5.7	**< .001***
		Right	83.7 ± 7.2	88.2 ± 7.8	4.5	**< .001***
Hip	Extension	Left	15.8 ± 6.4	17.2 ± 7.3	1.4	.833
		Right	15.4 ± 6.0	17.5 ± 6.9	2.1	.073
	Flexion	Left	128.9 ± 7.9	132.0 ± 8.7	3.1	**.025***
		Right	128.9 ± 8.0	132.5 ± 8.7	3.6	**.028***
Knee	Extension	Left	0.8 ± 2.2	1.5 ± 3.0	0.7	**.009***
		Right	0.7 ± 2.4	1.3 ± 3.1	0.6	**.039***
	Flexion	Left	135.3 ± 6.7	139.6 ± 7.0	4.3	**.004***
		Right	135.7 ± 7.4	139.9 ± 7.6	4.2	**.007***
Ankle	Dorsiflexion	Left	12.4 ± 5.8	12.5 ± 5.8	0.1	.892
		Right	12.3 ± 5.8	12.9 ± 6.0	0.6	.493
	Plantarflexion	Left	52.1 ± 8.7	59.2 ± 9.4	7.1	**< .001***
		Right	52.3 ± 8.9	59.6 ± 9.9	7.3	**< .001***

*Indicates significant at the .05 level.

3.3.3 Pre-obesity and Obesity Effects on Joint RoM

To examine the pre-obesity and obesity effects on RoM, the mean RoM differences between the three BMI groups were statistically tested using ANCOVAs. The results of the ANCOVAs are presented in Tables 3.4 and 3.5. The tables provide the group RoM means and standard deviations for the three BMI groups and also the inter-group mean RoM differences for the joint motions at each of the five body joints (shoulder, elbow, hip, knee, and ankle). In each table, statistically significant inter-group mean RoM differences are indicated with asterisks. The results of the pairwise comparisons (post-hoc tests) are indicated with alphabet characters (A, B, and C) and p-values in each table. Also, the significant inter-group mean RoM differences found for the joint motions at the elbow, hip, knee, and ankle joints are graphically illustrated in Figures 3.1–3.4 with 95% confidence intervals (CI).

No significant inter-group mean differences between the BMI groups were found for shoulder flexion (Table 3.4).

At the elbow joints, significant mean RoM differences between the BMI groups were found for elbow flexion and supination (Table 3.4). For each of these elbow joint motions, the pre-obese and obese groups were found to have significantly smaller RoM means than the normal-weight (Table 3.4, Figure 3.1). However, no such significant mean RoM differences were found between the pre-obese and obese groups.

At the hip joints, significant mean RoM differences between the BMI groups were found for hip extension and flexion (Table 3.5). For each of these hip joint motions, the pre-obese and obese groups were found to have significantly smaller RoM means than the normal-weight (Table 3.5, Figure 3.2). However, no such significant mean RoM differences were found between the pre-obese and obese groups.

Table 3.4: BMI group range of motion means and standard deviations and inter-group mean differences for the upper body (shoulder and elbow) joint motions

Joint	Motion		Normal-weight group (°)	Pre-obese group (°)	Obese group (°)	p-value	Mean difference (°) (Pairwise comparison p-value): Pre-obese – Normal-weight	Obese – Pre-obese	Obese – Normal-weight
Shoulder	Flexion	Left	169.3 ± 8.4	167.4 ± 9.2	167.2 ± 8.5	.832	-1.9	-0.2	-2.1
		Right	169.6 ± 8.4	167.9 ± 8.4	167.9 ± 8.4	.987	-1.7	0	-1.7
Elbow	Extension	Left	3.3 ± 5.4	1.9 ± 4.6	1.8 ± 5.3	.860	-1.4	-0.1	-1.5
		Right	2.9 ± 5.4	1.6 ± 5.4	1.6 ± 5.6	.967	-1.3	0	-1.3
	Flexion	Left	149.0 ± 6.1 (A)	145.4 ± 6.1 (B)	143.6 ± 5.5 (B)	**< .001***	-3.6 (< **.001***)	-1.8 (.151)	-5.4 (< **.001***)
		Right	149.2 ± 6.0 (A)	145.0 ± 6.5 (B)	143.5 ± 6.8 (B)	**< .001***	-4.2 (< **.001***)	-1.5 (.330)	-5.7 (< **.001***)
	Pronation	Left	80.1 ± 6.9	78.5 ± 7.1	79.1 ± 7.7	.850	-1.6	0.6	-1.0
		Right	80.8 ± 6.7	78.8 ± 7.6	79.1 ± 6.7	.456	-2.0	0.3	-1.7
	Supination	Left	90.3 ± 9.0 (A)	83.9 ± 8.4 (B)	84.6 ± 6.9 (B)	**< .001***	-6.4 (< **.001***)	0.7 (1.000)	-5.7 (**.002***)
		Right	88.5 ± 8.3 (A)	83.8 ± 6.9 (B)	84.3 ± 5.6 (B)	**< .001***	-4.7 (< **.001***)	0.5 (1.000)	-4.2 (**.030***)

Note: Different alphabet characters (A, B, and C) indicate significant mean RoM differences between pairwise comparisons. *Indicates significant at the .05 level.

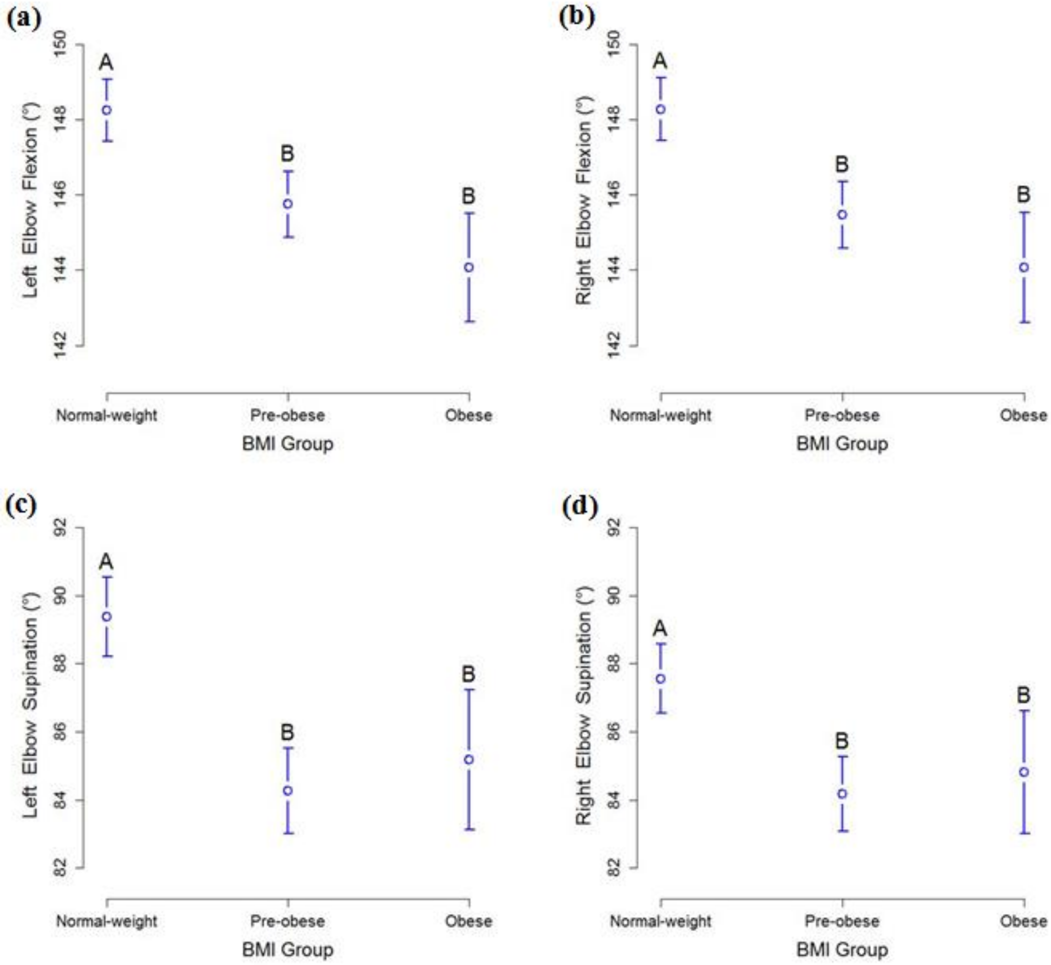

Figure 3.1: BMI group mean RoM values and 95% confidence intervals for the elbow flexion and supination: (a) left elbow flexion, (b) right elbow flexion, (c) left elbow supination, and (d) right elbow supination

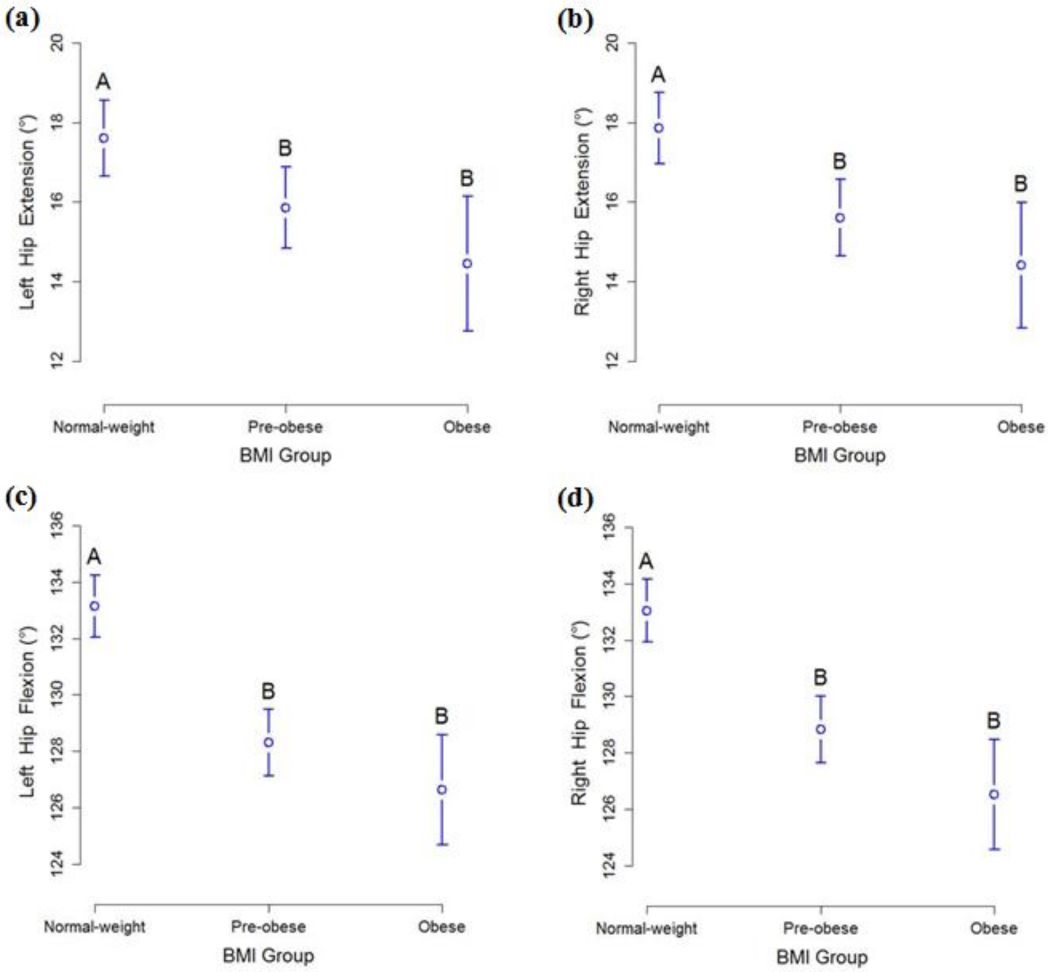

Figure 3.2: BMI group mean RoM values and 95% confidence intervals for the hip extension and flexion: (a) left hip extension, (b) right hip extension, (c) left hip flexion, and (d) right hip flexion.

At the knee joints, significant mean RoM differences between the BMI groups were found for knee flexion (Table 3.5). For knee flexion, the pre-obese and obese groups were found to have significantly smaller RoM means than the normal-weight (Table 3.5, Figure 3.3); also, the obese group had a significantly smaller RoM mean than the pre-obese.

At the ankle joints, significant mean RoM differences between the BMI groups were found for ankle plantarflexion (Table 3.5). For ankle plantarflexion, the pre-obese and obese groups were found to have significantly smaller RoM means than the normal-weight (Table 3.5, Figure 3.4). However, no such significant mean RoM differences were found between the pre-obese and obese groups.

Table 3.5: BMI group range of motion means and standard deviations and inter-group mean differences for the lower body (hip, knee, and ankle) joint motions.

Joint	Motion		Normal-weight group (°)	Pre-obese group (°)	Obese group (°)	*p*-value	Mean difference (°) (Pairwise comparison *p*-value)		
							Pre-obese – Normal-weight	Obese – Pre-obese	Obese – Normal-weight
Hip	Extension	Left	17.9 ± 6.7 (A)	15.6 ± 6.8 (B)	14.4 ± 7.5 (B)	**.002***	-2.3 (**.044***)	-1.2 (.481)	-3.5 (**.005***)
		Right	18.2 ± 5.8 (A)	15.3 ± 6.9 (B)	14.2 ± 7.0 (B)	**< .001***	-2.9 (**.003***)	-1.1 (.619)	-4.0 (**.001***)
	Flexion	Left	133.7 ± 8.2 (A)	128.2 ± 7.7 (B)	126.1 ± 7.4 (B)	**< .001***	-5.5 (**< .001***)	-2.1 (.450)	-7.6 (**< .001***)
		Right	134.0 ± 8.0 (A)	128.6 ± 8.1 (B)	126.1 ± 8.1 (B)	**< .001***	-5.4 (**< .001***)	-2.5 (.139)	-7.9 (**< .001***)
Knee	Extension	Left	1.5 ± 2.9	0.9 ± 2.6	1.0 ± 2.4	.402	-0.6	0.1	-0.5
		Right	1.4 ± 2.9	0.7 ± 2.9	1.0 ± 2.3	.153	-0.7	0.3	-0.4
	Flexion	Left	141.6 ± 5.9 (A)	135.3 ± 5.7 (B)	130.1 ± 5.8 (C)	**< .001***	-6.3 (**< .001***)	-5.2 (**< .001***)	-11.5 (**< .001***)
		Right	142.4 ± 6.6 (A)	135.2 ± 6.1 (B)	130.4 ± 6.2 (C)	**< .001***	-7.2 (**< .001***)	-4.8 (**< .001***)	-12.0 (**< .001***)
Ankle	Dorsiflexion	Left	13.1 ± 5.5	11.7 ± 6.1	12.3 ± 6.0	.108	-1.4	0.6	-0.8
		Right	13.3 ± 6.0	11.7 ± 5.7	12.6 ± 6.0	.101	-1.6	0.9	-0.7
	Plantarflexion	Left	59.1 ± 9.2 (A)	53.2 ± 9.5 (B)	52.8 ± 9.2 (B)	**< .001***	-5.9 (**< .001***)	-0.4 (1.000)	-6.3 (**.012***)
		Right	59.7 ± 9.6 (A)	53.6 ± 9.3 (B)	51.9 ±10.2 (B)	**< .001***	-6.1 (**< .001***)	-1.7 (1.000)	-7.8 (**.001***)

Note: Different alphabet characters (A, B, and C) indicate significant mean RoM differences between pairwise comparisons. *Indicates significant at the .05 level.

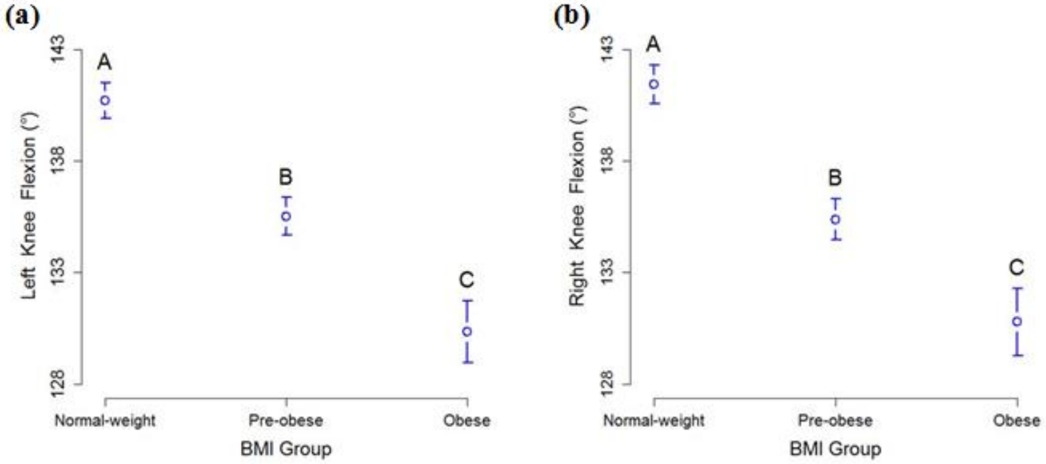

Figure 3.3: BMI group mean RoM values and 95% confidence intervals for the knee flexion: (a) left knee flexion and (b) right knee flexion.

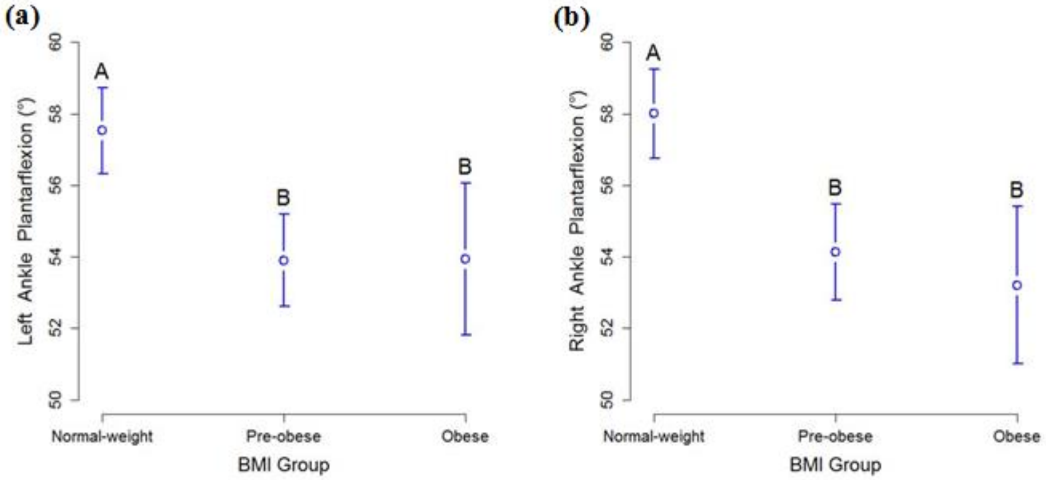

Figure 3.4: BMI group mean RoM values and 95% confidence intervals for the ankle plantarflexion: (a) left ankle plantarflexion and (b) right ankle plantarflexion.

3.4 Discussion

Joint RoM was found to decrease with increasing age for fifteen joint motions as shown in Table 3.2. This finding is congruent with multiple previous studies (Allander et al., 1974; Boone and Azen, 1979; Buckwalter and DiNubile, 1997; Doriot and Wang, 2006; Grimston et al., 1993; James and Parker, 1989; McGill, Yingling, and Peach, 1999; Roach and Miles 1991; Sforza et al., 2002; Soucie et al., 2011; Stubbs, Fernandez, and Glenn, 1993). The observed age-RoM relationships are thought to reflect age-associated functional changes in the musculoskeletal tissues: losses in the resilience of cartilage (Freemont and Hoyland, 2007), reduced elasticity of ligaments (Barros et al., 2002; Sargon, Doral, and Atay, 2004), and fat redistribution (Toth and Tchernof, 2000).

As for the gender effects on RoM, the female group was found to have significantly larger RoM means than the male for eighteen out of the twenty-two joint motions (Table 3.3). The observations are consistent with the finding from previous studies that women are generally more flexible than men for most body joint motions (Araújo, 2004; Chung and Wang, 2009; Doriot and Wang, 2006; Hoffman, 2014; James and Parker, 1989; Soucie et al., 2011). The gender differences have been linked with human sex hormones. Female sex hormones, such as estrogen, progesterone, relaxin and oxytocin, have been reported to increase the laxity of connective tissues in the musculoskeletal systems (Alter, 2004; Dehghan et al., 2014; Fouladi, 2012; Reese and Casey, 2015). Increased laxity of connective tissues would increase body flexibility. On the other hand, testosterone, a male sex hormone, increases muscle mass (Dehm and Tindall, 2007; Mooradian, Morley, and Korenman, 1987; Rahman and Christian, 2007; Reese and Casey, 2015). Increased muscle mass could reduce joint range of motion because affected muscles occupy more space between the adjacent body segments of a joint and thereby limit the inter-segmental rotation more.

The RoM reductions associated with pre-obesity and obesity, which were observed for some of the body joint motions examined (Tables 3.4 and 3.5, Figures 3.1–3.4), are thought to have resulted from the excess fat in the pre-obese or obese body (Park et al., 2010). Inter-segmental rotations at body joints would be mechanically hindered by such extra fat (Chaffin, Anderson, and Martin, 2006; Escalante et al., 1999a,b; Gilleard and Smith, 2007; Laubuch, 1969). The observed RoM reductions may also reflect the effects of muscle mass change – an increase in BMI could result from muscle mass increase as well as increased fat mass.

Decreased physical activity might also be a possible contributor to the observed pre-obesity- and obesity-associated RoM reductions apart from excess fat and muscle mass increases (Park et al., 2010). Pre-obesity and obesity are commonly associated with insufficient physical activity in daily life (Buckwalter and DiNubile, 1997; Doll, Petersen, and Stewart-Brown, 2000; Han et al., 1998; Jebb and Moore, 1999; Kaplan et al., 2003; Kottke and Anderson, 1965; Kvaavik, Tell, and Klepp, 2003; Larsson and Mattsson, 2001; Yamakawa et al., 2004). Prolonged immobilization is known to proliferate fibro-fatty connective tissues and cause fibrous adhesions into joint space (Farmer and James, 2001); therefore, physical inactivity can reduce body flexibility (Joao et al., 2014).

One observation from the current study results was, again, that: RoM reductions associated with pre-obesity and obesity were found for only part of the joint motions examined (Tables 3.4 and 3.5, Figures 3.1–3.4). This non-uniformity or the motion-specific nature of pre-obesity/obesity effects has been linked with the fat accumulation and distribution pattern of the human body (Park et al., 2010). Fat accumulation occurs non-uniformly across different body regions when people become obese (Arner, 1997) – some areas, such as the abdomen, buttock, and thigh, in the human body tend to deposit fat more easily than others. Therefore, the level of mechanical interference and hindrance by excess fat would differ between joint areas and joint motions (Park et al., 2010). The pre-obesity- and obesity- associated RoM reductions observed for hip extension, hip flexion and knee flexion (Table 3.5, Figures 3.2 and 3.3) in the current study may be associated with the aforementioned fat deposit sites (Arner, 1997).

The observed non-uniformity of the obesity and pre-obesity effects on joint RoM may also be partially attributed to the anatomical structure of the human body and how it constrains human motions (Park et al., 2010). For elbow flexion (Table 3.4, Figure 3.1), the fat deposit in the forearm and upper arm areas obstructs the movement. However, for elbow extension (Table 3.4), no such obstructions occur. The asymmetry found for the knee flexion-extension pair (Table 3.5, Figure 3.3) may be accounted for similarly in terms of the human anatomical structure.

The non-uniformity of pre-obesity and obesity effects observed for the elbow pronation-supination (Table 3.4, Figure 3.1) and ankle dorsiflexion-plantarflexion (Table 3.5, Figure 3.4) motion pairs is interesting. The three BMI groups did not show significantly different mean RoM differences for elbow pronation and ankle dorsiflexion; however, the pre-obese and obese groups had significantly smaller RoM means than the normal-weight for elbow supination and ankle plantarflexion. While it is not entirely clear what gave rise to these asymmetries, some conjectures may be offered for future research.

As for the asymmetry found for the elbow pronation-supination movement pair (Table 3.4, Figure 3.1), the major muscles involved in elbow pronation are the pronator teres and pronator quadratus; and, those in elbow supination are the supinator and biceps brachii (O'Rahilly et al., 2008). The biceps brachii is a two-joint muscle spanning across both the shoulder and elbow joints while the other pronator and supinator muscles are mono-articular muscles. One possible explanation for the pre-obesity- and obesity-associated RoM reductions for elbow supination is that: compared with the normal-weight condition, pre-obesity and obesity increased the shoulder abduction angle due to the fat tissues in the torso and upper arm areas, and such an increase in the shoulder abduction angle changed the length of the biceps brachii to eventually affect the joint RoM for elbow supination. The lengths of the elbow pronator muscles, on the other hand, are not affected by the shoulder abduction angle.

The asymmetry found for the ankle dorsiflexion-plantarflexion pair (Table 3.5, Figure 3.4) may be attributed to the soft tissues distribution characteristics of the leg. Anatomically, the ankle dorsiflexors are located in the anterior region of the leg; and, the ankle plantarflexors are in the posterior part of the leg (O'Rahilly et al., 2008). The posterior part of the lower leg has more soft tissues than the anterior – there are more muscles (including the ankle plantarflexors) in the posterior compartment and these posterior muscles are larger in size (O'Rahilly et al., 2008); also, the posterior part of the leg contains more subcutaneous fat. Thus, an increase in BMI would differently affect the two areas of the lower leg. It would lead to a relatively larger increase in mass and volume for the tissues in the posterior part than the anterior. As a result, passive ankle plantarflexion may be subject to relatively larger resistances from the compression of the soft tissues occupying the space around the ankle joint than dorsiflexion.

The observed pre-obesity- and obesity-associated RoM reductions for ankle plantarflexion (Table 3.5, Figure 3.4) may need to be studied in connection with the obesity-associated reduction in ankle plantarflexion during walking (Del Porto et al., 2012; Hortobágyi et al., 2011; Hyun and Ryew, 2016; Lyytinen et al., 2014; Spyropoulos et al., 1991) and the obesity-related foot morphological changes, such as higher percentage of flatfoot, smaller footprint angle, greater Chippaux-Smirak index, and higher plantar pressure (Chen, Chung, and Wang, 2009; Dowling, Steele, and Baur, 2001; Dowling, Steele, and Baur, 2004; Jimenez-Ormeno et al., 2013; Mickle, Steele, and Munro, 2006; Morrison et al., 2007; Riddiford-Harland, Steele, and Storlien, 2000; Villarroya et al., 2008; Villarroya et al., 2009; Wozniacka, Bac, and Matusik, 2015). Again, the ideas above are only conjectures at this time and require further investigation.

One notable observation from the current study results is the effects of pre-obesity ($25kg/m^2 \leq BMI < 30kg/m^2$). The pre-obese group, along with the obese, showed significantly smaller RoM means than the normal-weight for many joint motions (Tables 3.4 and 3.5, Figures 3.1–3.4). These "pre-obesity-associated reductions in joint RoMs" were not previously reported as past studies on the BMI- or obesity-related joint RoM changes did not consider the pre-obese category (Escalante et al., 1999a,b; Joao et al., 2014; Park et al., 2010).

Relatedly, another interesting observation was that the pre-obese and obese groups did not show significant mean RoM differences for most of the body joint motions considered (Tables 3.4 and 3.5, Figures 3.1–3.4). The only exception was knee flexion (Table 3.5, Figure 3.3) – for knee flexion, the obese group had significantly smaller RoM means than the pre-obese group.

The absence of significant mean RoM differences between the pre-obese and obese groups, found for most of the joint motions, seems to be attributed to the large variability in the RoM data for the obese group (Figures 3.1, 3.2, and 3.4). It may be worth noting that the obese group in this study consisted of individuals classified as Class-I obese ($30kg/m^2 \leq BMI < 35kg/m^2$). A comparison of a more severely obese group against the pre-obese may reveal statistically significant mean RoM differences.

It is not clear why joint RoM, with BMI increasing from pre-obesity to obesity, decreased more markedly for knee flexion than for the other joint motions. Perhaps, it is because knee flexion is obstructed by two fleshy parts of the leg, that is, the posterior thigh and calf areas. Also, weight gain has been shown to increase mechanical stresses on the knee joints (Griffin and Guilak, 2005; Harding et al., 2012; Russell and Hamill, 2010) and reduce knee flexion during walking (Hora et al., 2012). These might be related to the observation for knee flexion.

The results of the current study (Tables 3.4 and 3.5) are largely in agreement with the findings from the previous studies: obesity-associated RoM reductions for elbow flexion (Escalante et al., 1999a), hip flexion (Escalante et al., 1999b; Joao et al., 2014) and knee flexion (Escalante et al., 1999b; Park et al., 2010; Joao et al., 2014), and absence of such RoM reductions for shoulder flexion (Escalante et al., 1999a; Park et al., 2010) and ankle dorsiflexion (Park et al., 2010). Some discrepancies were also found between the current and previous study results – Park et al. (2010) reported a lack of significant mean RoM differences between a severely obese and a normal-weight group for elbow flexion and ankle plantarflexion while the current study identified significant inter-group mean RoM differences (Tables 3.4 and 3.5). These discrepancies may be attributed to the differences in the study protocol, especially, those in the measurement method (passive, active), the choice of obesity categories (class I obese, class III obese), and gender composition (both genders, only males).

Chapter 4

Obesity Effects on Executive Functions immediately after Manual Load Lifting/Lowering Task

4.1 Introduction

In many daily life and work activities, people perform cognitive tasks as well as physical tasks. The physical and cognitive tasks are conducted immediately or concurrently. For example, in case of factory workers, they search information on computers immediately after lifting and carrying goods. Similarly, in case of daily life, people organize and schedule their daily activities or read newspapers and magazines immediately after sweeping, vacuuming, washing dishes, doing laundry, or cleaning bathrooms. Bus or truck drivers follow a planned route according to a time schedule during driving. Also, they obey traffic signals and signs during driving. In case of firefighters, they operate the nozzle at appropriate pressure and flow, maintain situational awareness, and find out optimum rescue route immediately after/during extinguishing fires. Office workers plan and organize work activities immediately after paper shredding, office cleaning, packing, or moving some materials. As part of efforts to enhance knowledge on the relationship between physical and cognitive tasks, much research has been conducted to examine physical loading effects on cognitive performance. As mentioned in Chapter 2.2, physical loading effects on cognitive performance still remain equivocal despite a substantial number of investigations in the area.

The obesity effects on physical and cognitive performance are important research topics as a significant proportion of the workforce in many countries are obese

(Finkelstein et al., 2012; World Health Organization 2021a). According to the World Health Organization (2021a), the number of obese people has nearly tripled from 1975 to 2016. It is projected that prevalence of obesity will increase continually in the near future (Finkelstein et al., 2012). As part of efforts to understand the obesity-associated changes in physical and cognitive performance, much research has been conducted to examine obesity effects on physical and cognitive performance. As mentioned in Chapter 2.1, obesity negatively affected diverse physical function and performance, such as muscular strength, joint range of motion, biomechanical stress, postural control, gait speed, 50-meter dash, standing long jump, and pull-ups. This means that obese individuals might experience more exertion or difficulty immediately after/during physical activity. As mentioned in Chapter 2.4, obesity effects on cognitive performance still remain equivocal despite a substantial number of investigations in the area.

Despite previous research efforts, however, research gap still seems to exist concerning the obesity effects on physical and cognitive performance. The previous studies did not consider obesity effects on cognitive performance immediately after/during physical tasks. As mentioned in Chapter 2.2, physical loading affected cognitive performance. Also, as mentioned in Chapter 2.1, obesity negatively affected physical function and performance. Given the two Chapters, compared to normal-weight individuals, obese individuals would have different cognitive performance immediately after/during physical loading.

As an effort towards addressing the research gap, the aim of this chapter was to identify and characterize the obesity effects on cognitive performance immediately after physical task. Executive functions were employed for cognitive performance in this study. Manual load lifting/lowering task was used for physical task.

The main hypotheses of this chapter were as follows:

- H1) Executive functions are improved immediately after a moderate amount of physical loading,

- H2) Immediately after a severe amount of physical loading, executive functions deteriorate,

- H3) Obese and normal-weight individuals do not differ in executive functions without physical loading,

- H4) Immediately after a moderate amount of physical loading, for the normal-weight group, executive functions are significantly improved; however, no such significant improvement is found for the obese group, and

- H5) Immediately after a severe amount of physical loading, for both obese and normal-weight individuals, executive functions deteriorate.

H1 and H2 were based on the observations of Davey (1973) and Basahel (2012) - cognitive performance was improved after or during moderate physical loading; however, after or during severe physical loading, cognitive performance decreased. H3 was based on the finding that there were no associations between obesity and cognitive performance (Gunstad et al., 2007; Kuo et al., 2006; Ward et al., 2005; Wolf et al., 2007). H4 was based on the findings that obesity negatively affected diverse physical function and performance as mentioned in Chapter 2.1. This means that obese individuals might experience more exertion or difficulty immediately after/during physical activity in spite of a moderate amount of physical loading. H5 was based on the finding that after or during severe physical loading, cognitive performance decreased (Davey, 1973; Basahel, 2012). Also, physical loading was known to deteriorate cognitive performance (DiDomenico and Nussbaum, 2011; Lorist et al., 2002; Nibbeling et al., 2014; Smith et al., 2016; Son et al., 2019).

4.2 Research Methods

4.2.1 Participants

Twenty normal-weight and 21 obese male individuals participated in this study. Their age ranged from 19 to 49 years. All of the participants had normal or corrected-to-normal vision in both eyes and normal or mild levels of depression, anxiety, and stress. The depression, anxiety, and stress scale (DASS-21; Lovibond and Lovibond, 1996) was used for a self-report measure of depression, anxiety, and stress. None of them had self-reported current musculoskeletal disorders. Normal-weight participants had body mass index (BMI) between 18.5 and 25kg/m^2. Obese participants belonged to the obesity category of the World Health Organization (2021b) classification (BMI ≥ 30kg/m^2). The participants' age, duration of education, height, body mass, BMI, and waist circumference data are summarized in Table 4.1.

t-tests showed that the two participant groups significantly differed in mean body mass, BMI, and waist circumference ($p<0.001$) but did not in mean age ($p=0.983$), duration of education ($p=0.530$), and height ($p=0.578$).

4.2.2 Manual Load Lifting/Lowering Task

A box with two handles (25cm above the box surface) was used for manual load lifting/lowering task. The box's dimension was 34.5cm (length) × 26cm (width) × 32.5cm (height) (Figure 4.1). Its weight was 1kg in empty status, and, in the experiment, a 2kg weight plate was placed in the box. Thus, the total weight of the box was 3kg.

Participants lifted a 3kg box from the floor to the desk and then lowered it from the desk to the floor. The horizontal (H) and vertical (V) distance between the origin and the destination was 45cm and 70cm, respectively (Figure 4.2). Before the onset of lifting, each participant was standing with feet shoulder-width apart. At a signal indicating the onset of lifting, the participant squatted and grabbed a 3kg box located in the origin. Then, the participant lifted the box and placed it on the desk (the destination). After that, at a signal indicating the onset of lowering, the participant lowered the box from the desk to the floor (the origin) and squatted. After completion of one set of lifting and lowering task, the participant was instructed to stand with feet shoulder-width apart. A visual description of the manual load lifting/lowering task is provided in Figure 4.2. During the lifting/lowering task, a pre-recorded verbal instruction was used.

Physical loading in this study had 3 levels in relation to the number of repetitions (frequency) of the lifting/lowering task for 50 seconds. Level 1 was defined as standing posture for 50s (no lifting and lowering task). Level 2 and 3 were defined as 5 times and 10 times lifting/lowering task for 50 seconds, respectively.

Table 4.1: Summary of the participants' data

Dimensions	**Normal-weight (n=20)**	**Obese (n=21)**
	Mean ± SD	Mean ± SD
Age (years)	27.90 ± 8.22	27.86 ± 4.20
Duration of education (years)	15.53 ± 2.02	15.90 ± 1.81
Height (cm)	175.21 ± 7.74	176.42 ± 6.03
Body mass (kg)	68.32 ± 8.48	105.60 ± 12.13
BMI (kg/m^2)	22.21 ± 1.82	33.89 ± 3.17
Waist circumference (cm)	82.31 ± 4.86	110.65 ± 7.80

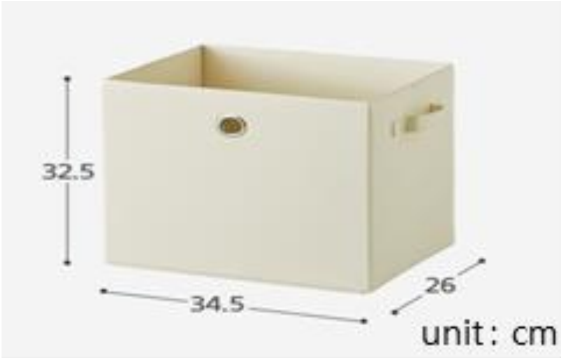

Figure 4.1: The box's dimension

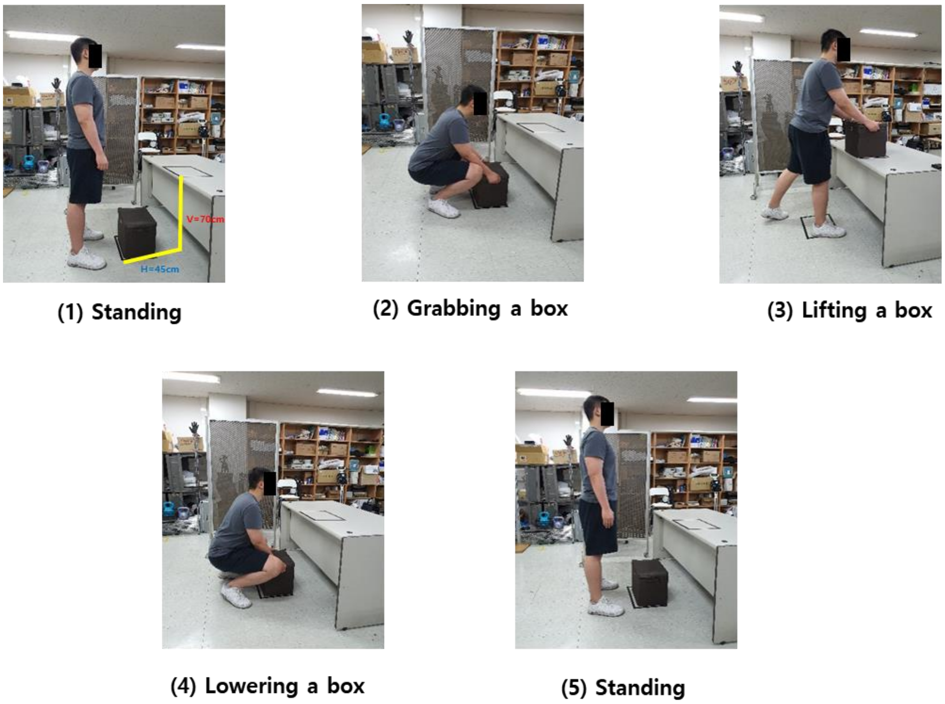

Figure 4.2: A visual description of manual load lifting/lowering task (1 set)

4.2.3 Executive Functions

Three core executive functions, shifting, updating, and inhibition, were employed in this study. The three core executive functions were proposed by Miyake et al. (2000). Number-letter task (Rogers and Monsell, 1995), Letter-memory task (Morris and Jones, 1990), and Stroop task (Stroop, 1935) were used to measure shifting, updating, and inhibition, respectively. The three tasks were adopted from many studies related to the three executive functions (Friedman et al., 2016; Himi et al., 2019; Miyake et al., 2000; Miyake and Friedman, 2012; Strauss, Sherman, and Spreen, 2006). The type and procedure for the three tasks in the current study were based on Miyake et al. (2000), Friedman et al. (2016), and Himi et al. (2019).

Inquisit Lab version 5 (Millisecond Software, Seattle, WA) psychological tool was used to carry out all cognitive tasks (Number-letter task, Letter-memory task, and Stroop task). During the cognitive tasks, a monitor screen (27 inches) was used to display visual instruction and stimulus. Also, wireless membrane numeric key pad (Cosy KP1364WL) was used to input response. The key pad's dimension was 124mm (length) × 82mm (width) × 18mm (height). Its weight was 90g.

Number-letter task (Rogers and Monsell, 1995) was utilized to measure shifting function. A 2 x 2 matrix is presented on the monitor screen. A pair of number-letter (e.g., 3G) or letter-number (e.g., K5) was presented in one of the matrix fields. The stimulus was presented in a clockwise fashion, that is, the presented pair moved in a clockwise pattern to the next quadrant (Figure 4.3). In the presented pair, a number and a letter were chosen at random from the number set and the letter set, respectively. The number set consisted of 4 even numbers (2, 4, 6, 8) and 4 odd numbers (3, 5, 7, 9). The letter set consisted of 4 consonants (G, K, M, R) and 4 vowels (A, E, I, U). The participants were instructed to classify the letter as a consonant or a vowel when the pair appeared in the top quadrants of the matrix, and to classify the number as even or odd when the pair appeared in the bottom quadrants of the matrix. When the pair moved from the top left to the top right quadrant or from the bottom right to the bottom left quadrant, non-switch task occurred; on the other hand, when the pair moved from the top right to the bottom right quadrant or bottom left to the top left quadrant, switch task occurred (Figure 4.3). In the letter task, the participants were instructed to press key "4" on the key pad if the pair included a consonant; but they had to press key "6" if the pair included a vowel. Similarly, in the number task, the participants were instructed to press key "4" if the pair included an even number; but they had to press key "6" if the pair included an odd number. A visual description of Number-letter task is provided in Figure 4.3 - it provides the example of Number-letter when starting at the top left quadrant. Dependent variables were: (1) proportion correct of switch trials (PropCorrect_Switch), (2) proportion correct of nonswitch trials (PropCorrect_Nonswitch), (3) accuracy switch cost (PropCorrect_Switch – PropCorrect_Nonswitch), (4) mean reaction time (latency) of correctly responding to switch trials (MeanRT_Switch), (5) mean reaction time (latency) of correctly responding to nonswitch trials (MeanRT_Nonswitch), and (6) reaction time (latency) switch cost (MeanRT_Switch - MeanRT_Nonswitch).

Letter-memory task (Morris and Jones, 1990) was used to measure updating function. Several letters (5, 7, or 9 letters) from a list of 21 consonants were presented serially for 1250ms per letter on the monitor screen. The sequence of 5, 7, and 9 letters was chosen at random order. After the last letter disappeared, the participants were instructed to rehearse out loud the last four letters in the correct serial order. A visual description of Letter memory task is provided in Figure 4.4 - it provides the example of a series of 5 letters presented. A dependent variable was the number of letters correctly recalled for the current trial, and, the range of possible scores was 0 to 4.

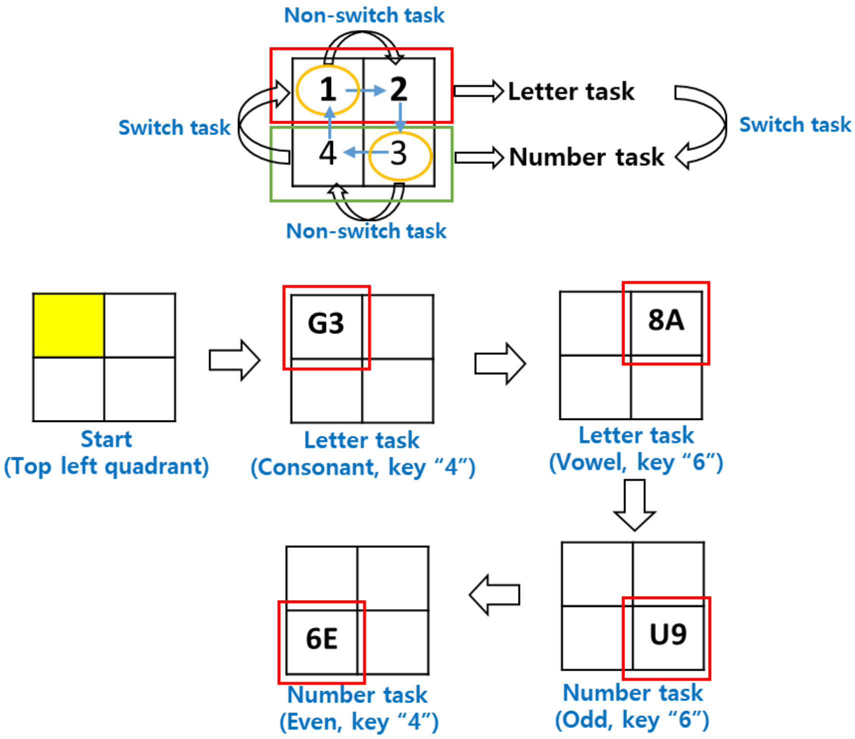

Figure 4.3: A visual description of Number-letter task

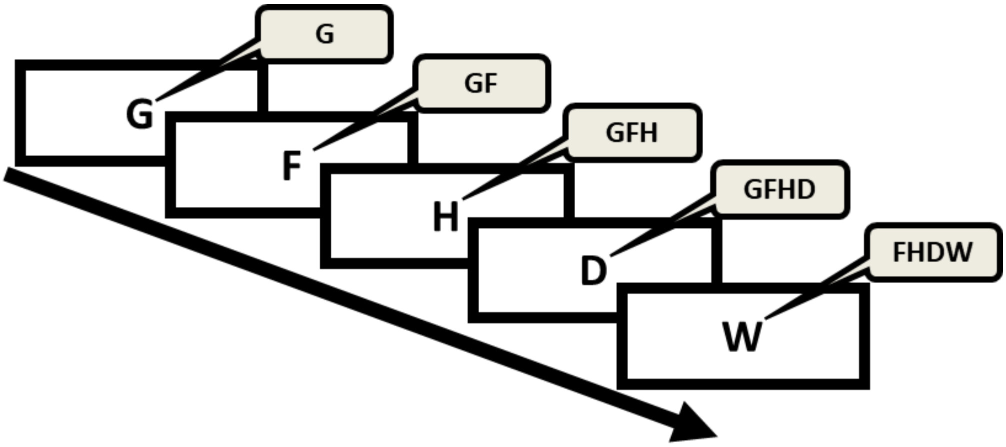

Figure 4.4: A visual description of Letter memory task

Stroop task (Stroop, 1935) were utilized to measure inhibition function. The task consisted of three conditions: control, congruent, and incongruent. In the control condition, a colored rectangle (e.g.,) was presented on the monitor screen. In the congruent condition, a color word written in same color (e.g., GREEN) was presented on the screen; on the other hand, in incongruent condition, a color word written in different color (e.g., BLUE) was presented. Four colors (red, green, blue, black) were used in the three conditions. The sequence of the three conditions (control, congruent, and incongruent) were presented at random order, and, four colors were also randomly sampled. During the task, the participants were asked to indicate color of a stimulus (not its meaning) by pressing appropriate button on the key pad. The keys "0", "2", "5" and "8" were used for red, green, blue, and black response button, respectively. Dependent variables were: (1) overall proportion correct of all trials (congruent, incongruent, control), (2) proportion correct of congruent trials, (3) proportion correct of incongruent trials, (4) proportion correct of control trials, (5) overall mean reaction time (latency) of all correct trials (congruent, incongruent, control), (6) mean reaction time (latency) of all correct congruent trials, (7) mean reaction time (latency) of all correct incongruent trials, (8) mean reaction time (latency) of all correct control trials

4.2.4 Subjective Ratings and Heart Rate

The participants were asked to verbally indicate subjective ratings of perceived exertion, physical discomfort, and mental workload after each task trial. The Borg CR 10 scale (Borg, 1982) was adopted, and, the scale (Table 4.2) was presented on the screen so that they could easily respond.

Heart rate was measured right before and after each task trial using Samsung Galaxy fit. Then, delta heart rate (ΔHR) was calculated as follows: ΔHR = HR (after trial) – HR (before trial).

Table 4.2: Borg CR 10 scale

Rating	Description
0	Nothing at all
0.5	Extremely weak (just noticeable)
1	Very weak
2	Weak
3	Moderate
4	Somewhat strong
5	Strong (Heavy)
6	
7	Very strong
8	
9	
10	Extremely strong (Maximal)

4.2.5 Experimental Procedure

Prior to the experimental trials, the study purpose and procedure were fully explained to the participants. The research protocol was reviewed and approved by Seoul National University Institutional Review Board. Each participant signed a written consent and changed into a short sleeve shirt, short pants, and athletic shoes. The participant was asked his age and duration of education. The body mass, height, and waist circumference were measured. The depression, anxiety, and stress scale (DASS-21; Lovibond and Lovibond, 1996) was used for a self-report measure of depression, anxiety, and stress. The training session was conducted for 30 minutes to familiarize the participants with experimental tasks.

In the experimental trials, one trial consisted of three repeats of a combination of physical and cognitive tasks, that is, three repeated alternations between physical and cognitive tasks. One combination comprised 50 seconds of physical task and 50 seconds of cognitive task; thus, one trial lasted for 300 seconds (5 minutes). Each participant conducted 9 experimental trials (9 = 3 physical loading levels × 3 cognitive tasks). Physical loading levels consisted of 1, 2, and 3, and, cognitive tasks comprised Number-letter task, Letter-memory task, and Stroop task. The order of 9 trials was randomized for each participant. A minimum of 20 minutes of rest was given between trials to minimize the effect of fatigue. After each trial, the participants were asked to verbally indicate subjective ratings of perceived exertion, physical discomfort, and mental workload. The Borg CR 10 scale (Borg, 1982) was adopted. Heart rate was measured right before and after each trial using Samsung Galaxy fit. Then, delta heart rate (ΔHR) was calculated as follows: $\Delta HR = HR$ (after trial) – HR (before trial).

4.2.6 Statistical Analyses

In this study, independent variables were BMI groups [Normal-weight ($18.5 kg/m^2 \leq BMI < 25 kg/m^2$), obese ($BMI \geq 30 kg/m^2$)] and physical loading levels (1, 2, 3). Dependent variables were scores of three cognitive tasks (Number-letter task, Letter memory task, and Stroop task), subjective ratings (perceived exertion, physical discomfort, and mental workload), and delta heart rate (ΔHR).

A series of two-way mixed analyses of variance (ANOVAs) were performed to test for effects of physical loading level and obesity on cognitive performance. In the ANOVAs, within subjects were physical loading levels, and, between subjects were BMI groups. To assess the sphericity, Mauchly's test was conducted. If the sphericity was violated, the degrees of freedom were corrected using Greenhouse-Geisser and Huynh-Feldt corrections (Greenhouse and Geisser, 1959; Huynh and Feldt, 1976) - the Greenhouse-Geisser correction was adopted if the estimate of sphericity (ε) was less than 0.75; otherwise, the Huynh-Feldt correction was employed (Verma, 2015). Pairwise comparisons (post-hoc tests) were conducted in the significant ANOVA results. The Bonferroni adjustment was used for the pairwise comparisons. Statistical Package for the Social Sciences (SPSS) Statistical version 26.0 (SPSS Inc., Chicago, IL) was used to carry out all statistical analyses. The α-level was set at 0.05 for all statistical analyses.

4.3 Results

4.3.1 Number-Letter Task

The ANOVAs found that physical loading significantly affected 3 out of 6 Number-letter task scores, and, significant interaction effects between physical loading and BMI were identified for the three variables (Table 4.3): (1) mean reaction time (latency) of correctly responding to switch trials (MeanRT_Switch), (2) mean reaction time (latency) of correctly responding to nonswitch trials (MeanRT_Nonswitch), and (3) reaction time (latency) switch cost (RT_Switchcost). No significant effects of physical loading and interaction (physical loading * BMI) were found for the rest of the Number-letter task scores (Tables 4.3 and 4.4): (1) proportion correct of switch trials (PropCorrect_Switch), (2) proportion correct of nonswitch trials (PropCorrect_Nonswitch), and (3) accuracy switch cost (ACC_Switchcost). No main effects of BMI were found for all of the Number-letter task scores (Table 4.3).

As for the physical loading effects on the MeanRT_Switch, MeanRT_Nonswitch, and RT_Switchcost (Tables 4.3 and 4.5, Figure 4.5), it was found that the three variables slightly (not significantly) decreased between physical loading level 1 and 2; on the other hand, they significantly increased between physical loading level 2 and 3.

Regarding the interaction effects between physical loading and BMI on the MeanRT_Switch, MeanRT_Nonswitch, and RT_Switchcost (Tables 4.3 and 4.5, Figure 4.5), it was found that there were different patterns of the physical loading effects on the Number-letter task scores between the BMI groups – for the normal-weight group, the mean reaction time of switch and non-switch trials significantly decreased between physical loading level 1 and 2; however, no such significant decrease was found for the obese group. Also, for the obese group, the mean reaction time of switch and non-switch trials and reaction time switch cost significantly increased between physical loading level 1 and 3; however, no such significant increase was found for the normal-weight group.

Table 4.3: Tests of within and between subjects effects for Number-letter task scores

	P-value		
	Test of within subject effect		Test of between subject effect
	Physical loading	Physical loading * BMI	BMI group
PropCorrect_Switch	.836	.921	.456
PropCorrect_Nonswitch	.753	.861	.348
ACC_Switchcost	.986	.893	.639
MeanRT_Switch	**< .001***	**.010***	.266
MeanRT_Nonswitch	**< .001***	**.019***	.536
RT_Switchcost	**< .001***	**.044***	.193

*Indicates significant at the .05 level.

Table 4.4: Mean, SD, and mean difference for PropCorrect_Switch, PropCorrect_Nonswitch, and ACC_Switchcost

		Mean ± SD				Mean difference		
		PL1	PL2	PL3	Total	PL2– PL1	PL3 – PL2	PL3 – PL1
PropCorrect _Switch (%)	T	88.59±8.27	88.43±6.65	88.10±8.47	88.37±7.78	-.16	-.33	-.49
	N	89.52±4.53	89.09±5.90	89.09±4.97	89.23±5.08	-.43	0	-.43
	O	87.70±10.75	87.79±7.39	87.17±10.88	87.56±9.65	.09	-.62	-.53
PropCorrect _Nonswitch (%)	T	92.80±8.44	92.80±7.61	92.43±6.72	92.68±7.56	0	-.37	-.37
	N	94.04±6.17	93.90±5.08	93.37±4.31	93.77±5.16	-.14	-.53	-.67
	O	91.62±10.17	91.76±9.43	91.53±8.43	91.64±9.22	.14	-.23	-.09
ACC _Switchcost (%)	T	-4.21±4.67	-4.37±4.39	-4.33±5.21	-4.30±4.73	-.16	.04	-.12
	N	-4.52±4.05	-4.81±4.22	-4.28±4.86	-4.54±4.32	-.29	.53	.24
	O	-3.92±5.28	-3.97±4.62	-4.36±5.65	-4.08±5.12	-.05	-.39	-.44

‘PL’, 'T', 'N’, and 'O’ denote physical loading, total, normal-weight, and obese, respectively.

Table 4.5: Mean, SD, mean difference, and pairwise comparison p-value for MeanRT_Switch, MeanRT_Nonswitch, and RT_Switchcost

		Mean ± SD				Mean difference (Pairwise comparison p-value)		
		PL1	PL2	PL3	Total	PL2– PL1	PL3 – PL2	PL3 – PL1
MeanRT _Switch (ms)	T	1034±322	1002±326	1162±412	1066±359	-32 (.292)	160 **(< .001*)**	128 **(< .001*)**
	N	1012±279	924±220	1075±302	1003±272	-88 **(.011*)**	151 **(< .001*)**	63 (.269)
	O	1055±363	1075±393	1244±488	1125±420	20 (1.00)	169 **(< .001*)**	189 **(< .001*)**
MeanRT _Nonswitch (ms)	T	794±221	777±225	852±268	807±239	-17 (.274)	75 **(< .001*)**	58 **(<.001*)**
	N	788±163	751±141	813±165	784±156	-37 **(.034*)**	62 **(< .001*)**	25 (.567)
	O	799±269	803±285	889±339	830±297	4 (1.000)	86 **(< .001*)**	90 **(<.001*)**
RT _Switchcost (ms)	T	240±188	224±169	310±215	258±193	-16 (.783)	86 **(< .001*)**	70 **(< .001*)**
	N	224±171	173±128	262±183	220±164	-51 (.062)	89 **(< .001*)**	38 (.289)
	O	256±205	273±191	356±237	295±213	17 (1.00)	83 **(< .001*)**	100 **(< .001*)**

*Indicates significant at the .05 level. ‘PL’, 'T', 'N’, and 'O’ denote physical loading, total, normal-weight, and obese, respectively.

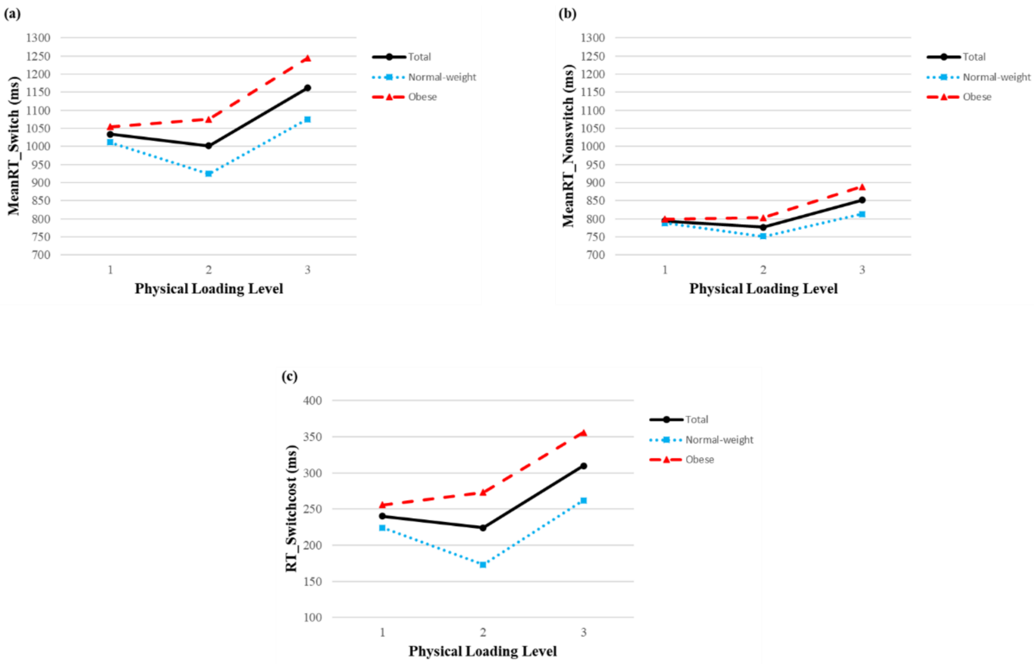

Figure 4.5: Line graphs of Number-letter task scores: (a) MeanRT_Switch, (b) MeanRT_Nonswitch, and (c) RT_Switchcost

4.3.2 Letter Memory Task

The ANOVAs revealed that physical loading significantly affected Letter memory task score, and, a significant interaction effect between physical loading and BMI was identified (Tables 4.6 and 4.7). No main effect of BMI was found for the Letter memory task score (Table 4.6).

As for the physical loading effect on the Letter memory task score (Tables 4.6 and 4.7, Figure 4.6), the score significantly increased between physical loading level 1 and 2; on the other hand, the score significantly decreased between physical loading level 2 and 3.

Regarding the interaction effect between physical loading and BMI on the Letter memory task score (Tables 4.6 and 4.7, Figure 4.6), there were different patterns of the physical loading effect on the Letter memory task score between the BMI groups – for the normal-weight group, the score significantly increased between physical loading level 1 and 2; however, no such significant increase was found for the obese group.

Table 4.6: Tests of within and between subjects effects for Letter memory task score

	P-value		
	Test of within subject effect		Test of between subject effect
	Physical loading	Physical loading * BMI	BMI group
LM score	**< .001***	**< .001***	.255

*Indicates significant at the .05 level. 'LM' denotes Letter memory.

Table 4.7: Mean, SD, mean difference, and pairwise comparison p-value for Letter memory task score

		Mean ± SD				Mean difference (Pairwise comparison p-value)		
		PL1	PL2	PL3	Total	PL2–PL1	PL3 – PL2	PL3 – PL1
LM Score (0~4)	T	3.61± .33	3.71± .30	3.36 ± .37	3.56± .36	.10 **(< .001*)**	–.35 **(< .001*)**	–.25 **(< .001*)**
	N	3.60± .24	3.81± .19	3.45± .24	3.62± .26	.21 **(< .001*)**	-.36 **(< .001*)**	-.15 **(< .001*)**
	O	3.61± .40	3.63± .36	3.28± .44	3.50± .43	.02 (1.000)	-.35 **(< .001*)**	-.33 **(< .001*)**

*Indicates significant at the .05 level. 'PL', 'T', 'N', and 'O' denote physical loading, total, normal-weight, and obese, respectively.

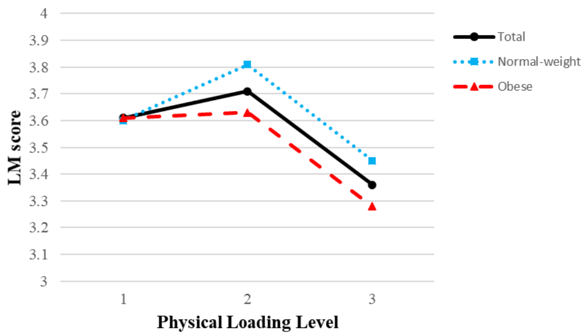

Figure 4.6: Line graph of Letter memory task score

4.3.3 Stroop Task

As can be seen from Table 4.8, physical loading significantly affected 4 out of 8 Stroop task scores, and, significant interaction effects between physical loading and BMI were identified for the four variables: (1) overall mean reaction time (latency) of all correct trials (MeanRT), (2) mean reaction time (latency) of all correct congruent trials (MeanRT_Congruent), (3) mean reaction time (latency) of all correct incongruent trials (MeanRT_Incongruent), and (4) mean reaction time (latency) of all correct control trials (MeanRT_Control). No significant effects of physical loading and interaction (physical loading * BMI group) were found for the rest of the Stroop task scores (Tables 4.8 and 4.9): (1) overall proportion correct of all trials (PropCorrect), (2) proportion correct of congruent trials (PropCorrect_Congruent), (3) proportion correct of incongruent trials (PropCorrect_Incongruent), and (4) proportion correct of control trials (PropCorrect_Control). No main effects of BMI were found for all of the Stroop task scores (Table 4.8).

Regarding the physical loading effects on the MeanRT, MeanRT_Congruent, MeanRT_Incongruent, and MeanRT_Control (Tables 4.8 and 4.10, Figure 4.7), it was found that the four variables slightly (not significantly) decreased between physical loading level 1 and 2; on the other hand, they significantly increased between physical loading level 2 and 3.

As for the interaction effects between physical loading and BMI on the MeanRT, MeanRT_Congruent, MeanRT_Incongruent, and MeanRT_Control (Tables 4.8 and 4.10, Figure 4.7), it was found that there were different patterns of the physical loading effects on the Stroop task scores between the BMI groups – for the normal-weight group, the four variables significantly decreased between physical loading level 1 and 2; on the other hand, for the obese group, MeanRT and MeanRT_Congruent significantly increased between physical loading level 1 and 2, and, MeanRT_Incongruent and MeanRT_Control slightly (not significantly) increased between physical loading level 1 and 2.

Table 4.8: Tests of within and between subjects effects for Stroop task scores

	P-value		
	Test of within subject effect		Test of between subject effect
	Physical loading	Physical loading * BMI	BMI group
PropCorrect	.142	.373	.508
PropCorrect_Congruent	.170	.660	.560
PropCorrect_Incongruent	.899	.747	.195
PropCorrect_Control	.070	.064	.500
MeanRT	**< .001***	**.001***	.469
MeanRT_Congruent	**< .001***	**< .001***	.325
MeanRT_Incongruent	**< .001***	**.005***	.589
MeanRT_Control	**< .001***	**.006***	.499

*Indicates significant at the .05 level.

Table 4.9: Mean, SD, and mean difference for PropCorrect, PropCorrect_Congruent, PropCorrect_Incongruent, and PropCorrect_Control

		Mean ± SD				Mean difference		
		PL1	PL2	PL3	Total	PL2–PL1	PL3–PL2	PL3–PL1
PropCorrect (%)	T	92.41±3.70	91.48±5.30	92.20±3.37	92.03±4.19	-.93	.72	-.21
	N	93.19±3.23	91.84±4.47	92.29±3.61	92.44±3.78	-1.35	.45	-.90
	O	91.67±4.03	91.13±6.07	92.12±3.22	91.64±4.55	-.54	.99	.45
PropCorrect_Congruent (%)	T	94.04±3.83	93.14±5.20	94.43±3.01	93.87±4.12	-.90	1.29	.39
	N	94.72±3.93	93.22±3.99	94.57±3.00	94.17±3.67	-1.50	1.35	-.15
	O	93.39±3.71	93.05±6.24	94.29±3.08	93.57±4.51	-.34	1.24	.90
PropCorrect_Incongruent (%)	T	89.02±6.29	88.73±8.65	89.01±6.06	88.92±7.04	-.29	.28	-.01
	N	90.55±4.82	89.71±7.69	90.51±5.20	90.25±5.95	-.84	.80	-.04
	O	87.57±7.24	87.81±9.58	87.59±6.59	87.66±7.78	.24	-.22	.02
PropCorrect_Control (%)	T	94.17±4.07	92.57±4.75	93.17±4.83	93.30±4.57	-1.60	.60	-1.00
	N	94.31±4.60	92.60±4.46	91.78±5.15	92.90±4.78	-1.71	-.82	-2.53
	O	94.04±3.60	92.54±5.12	94.49±4.20	93.69±4.36	-1.50	1.95	.45

‘PL’, 'T', 'N’, and 'O’ denote physical loading, total, normal-weight, and obese, respectively.

Table 4.10: Mean, SD, mean difference, and pairwise comparison p-value for MeanRT, MeanRT_Congruent, MeanRT_Incongruent, and MeanRT_Control

		Mean ± SD				Mean difference (Pairwise comparison p-value)		
		PL1	PL2	PL3	Total	PL2–PL1	PL3 – PL2	PL3 – PL1
MeanRT (ms)	T	741±153	734±152	779±164	751±157	-7 (.081)	45 **(< .001*)**	38 **(< .001*)**
	N	736±97	704±86	760±114	733±100	-32 **(< .001*)**	56 **(< .001*)**	24 **(.009*)**
	O	746±195	762±194	798±202	769±195	16 **(.010*)**	36 **(.001*)**	52 **(< .001*)**
MeanRT_ Congruent (ms)	T	703±138	701±141	733±146	713±141	-2 (1.000)	32 **(< .001*)**	30 **(< .001*)**
	N	693±75	672±71	706±82	690±76	-21 **(.001*)**	34 **(< .001*)**	13 (.153)
	O	714±180	729±183	759±186	734±181	15 **(.010*)**	30 **(< .001*)**	45 **(< .001*)**
MeanRT_ Incongruent (ms)	T	806±189	796±185	858±206	820±194	-10 (.196)	62 **(< .001*)**	52 **(< .001*)**
	N	803±135	763±121	844±158	803±140	-40 **(< .001*)**	81 **(< .001*)**	41 **(.001*)**
	O	809±232	827±229	872±247	836±234	18 (.077)	45 **(.007*)**	63 **(<.001*)**
MeanRT_ Control (ms)	T	719±146	708±143	752±156	726±148	-11 (.076)	44 **(< .001*)**	33 **(< .001*)**
	N	717±97	680±80	733±117	710±100	-37 **(< .001*)**	53 **(< .001*)**	16 (.263)
	O	721±184	734±183	770±186	741±182	13 (.229)	36 **(.014*)**	49 **(< .001*)**

*Indicates significant at the .05 level. ‘PL’, 'T', 'N', and 'O’ denote physical loading, total, normal-weight, and obese, respectively.

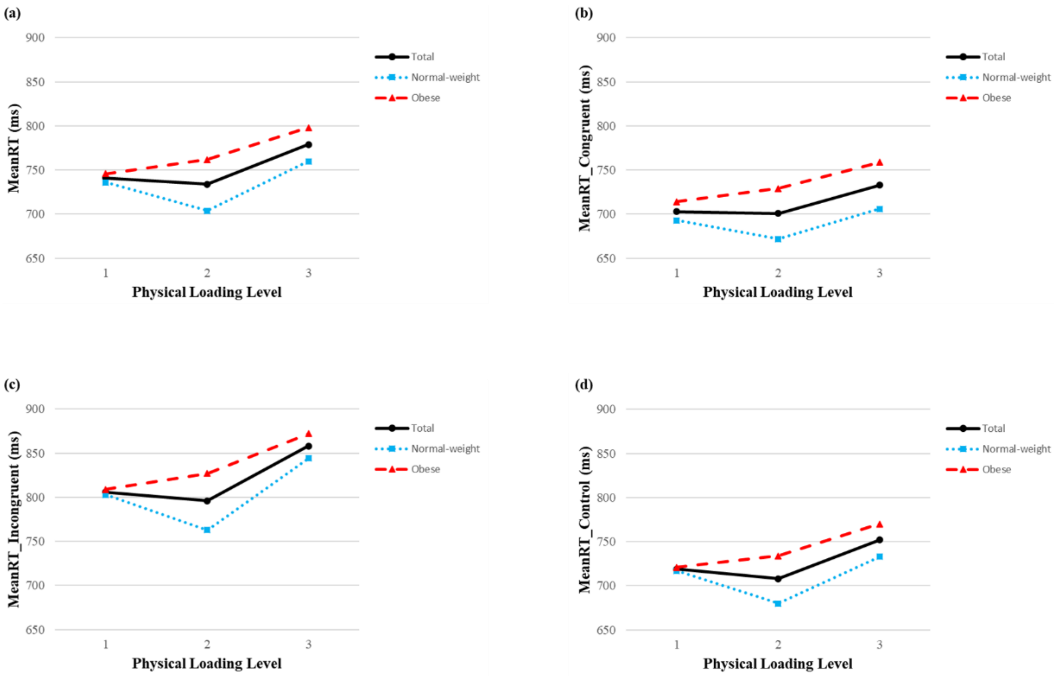

Figure 4.7: Line graphs of Stroop task scores: (a) MeanRT, (b) MeanRT_Congruent, (c) MeanRT_Incongruent, and (d) MeanRT_Control

4.3.4 ΔHeart Rate (ΔHR) and Subjective Ratings

The ANOVAs found that physical loading significantly affected delta heart rate (ΔHR), the perceived exertion (PE), physical discomfort (PD), and mental workload (MW) variables. As for the physical loading effects on the ΔHR, PE, PD, and MW variables, they increased as physical loading increased. No significant effects of BMI and interaction (physical loading * BMI) were found for the ΔHR, PE, PD, and MW variables.

4.4 Discussion

The current study empirically examined the obesity effects on cognitive performance immediately after physical task. Manual load lifting/lowering task was employed for the physical task. In the physical task, three levels of physical loading were used: (1) Level 1: standing posture for 50s (no lifting and lowering task). (2) Level 2: 5 times lifting/lowering task for 50 seconds. (3) Level 3: 10 times lifting/lowering task for 50 seconds. Obesity had two groups based on the BMI [Normal-weight ($18.5kg/m^2 \leq BMI < 25kg/m^2$), obese ($BMI \geq 30kg/m^2$)]. In the cognitive task, three core executive functions (shifting, updating, and inhibition) were employed. To measure shifting, updating, and inhibition, Number-letter task, Letter-memory task, and Stroop task were used, respectively. One trial consisted of three repeats of a combination of physical and cognitive tasks, that is, three repeated alternations between physical and cognitive tasks. After each trial, subjective ratings of perceived exertion, physical discomfort, and mental workload were conducted. Heart rate was measured right before and after each trial.

The main objective of the current study was to identify and characterize the obesity effects on executive functions immediately after physical loading. A series of two-way mixed analyses of variance (ANOVAs) were performed. The ANOVAs found significant effects of physical loading and interaction (physical loading*BMI) on executive functions (Tables 4.3-4.10, Figures 4.5-4.7). There were no main effects of BMI on executive functions (Tables 4.3, 4.6, 4.8). Main findings were as follows:

- Executive functions were slightly improved immediately after a moderate amount of physical loading (between physical loading level 1 and 2).

- Immediately after a severe amount of physical loading (between physical loading level 2 and 3), performance of executive functions generally deteriorated.

- In the significant interaction effects between physical loading and BMI, there were different patterns of the physical loading effects on executive functions between normal-weight and obese groups.

  - Obese and normal-weight groups did not differ in executive functions for physical loading level 1.

  - For the normal-weight group, executive functions were significantly improved immediately after a moderate amount of physical loading (between physical loading level 1 and 2); however, no such significant improvement was found for the obese group.

  - Immediately after a severe amount of physical loading (between physical loading level 2 and 3), for both obese and normal-weight individuals, performance of executive functions generally deteriorated.

- In the task scores of Number-letter and Stroop, contrary to the scores of reaction time, no significant effects of physical loading and interaction (physical loading*BMI) were found for the proportion correct (accuracy rate).

The observed physical loading effects on improvement and deterioration of executive functions (Tables 4.3-4.10, Figures 4.5-4.7) could be explained in terms of the relationship between arousal and cognitive performance, that is, Yerkes-Dodson law (Yerkes and Dodson, 1908). Multiple research studies referred to the relationship between arousal and cognitive performance as an inverted U relationship (Brisswalter et al., 1997; Chmura, Nazar, and Kaciuba-Uścilko, 1994; Davey, 1973; Levitt and Gutin, 1971; Martens and Landers, 1970; Reilly and Smith, 1986; Salmela and Ndoye, 1986; Sonstroem and Bernardo, 1982). These studies demonstrated that cognitive performance was improved as exercise-induced arousal increased, and, the cognitive performance deteriorated as the arousal levels reached maximal levels. In the current study, the level of arousal was measured by delta heart rate and ratings of perceived exertion and mental workload – delta heart rate and ratings of perceived exertion and mental workload were found to increase as physical loading increased. Therefore, the increased arousal could affect executive functions as the inverted U relationship.

The effects of negative emotions on scope of attention and working memory may also be a possible contributor to the observed physical loading effects on executive functions, especially for the severe amount of physical loading effects. Executive functions include various basic cognitive processes such as attentional control, working memory, cognitive inhibition, and cognitive flexibility (Chan et al., 2008; Diamond, 2013). Multiple previous studies demonstrated that negative emotions, such as anxiety and anger, could narrow the scope of attention (Easterbrook, 1959; Fredrickson and Branigan, 2005; Strauss and Allen, 2006). Also, such negative emotions could degrade working memory (Berkun, 1964; Davies and Parasuraman, 1982; Wachtel, 1968; Wickens et al., 2013). King and Emmons (1991) and Fergus, Bardeen, and Orcutt (2015) found that physical discomfort generally correlated with anxiety. Son et al. (2019) mentioned that perceived physical discomfort increased with increasing backpack weight, and, working memory task performance decreased with increasing physical discomfort. In the current study, perceived physical discomfort increased with increasing physical loading. For the physical loading level 2, the physical discomfort ratings were about 2 on the Borg CR 10 scale indicating weak feeling of discomfort; however, for the physical loading level 3, the discomfort ratings were above 4 on the Borg CR 10 scale indicating somewhat strong feeling of discomfort. From the changes associated with increased physical loading, the severe amount of physical loading (level 3) may cause negative emotions, and, the negative emotions could narrow scope of attention and degrade working memory; therefore, immediately after the severe amount of physical loading, performance of executive functions may also decrease.

The interaction effects between physical loading and BMI (Tables 4.3-4.10, Figures 4.5-4.7), which were observed different patterns of the physical loading effects on executive functions between normal-weight and obese groups, may be attributed to the excess fat in the obese body. Excess fat would hinder inter-segmental rotations at body joints (Chaffin, Anderson, and Martin, 2006; Escalante et al., 1999a,b; Gilleard and Smith, 2007; Laubuch, 1969), and, decrease joint range of motion (Escalante et al., 1999a,b; Joao et al., 2014; Park et al., 2010); thus, the obese individuals may experience more exertion or difficulty immediately after physical activity, such as lifting box, squat, and stoop. In the current study, the physical task consisted of repeated manual load lifting/lowering task. Also, the experimental trials consisted of repeated alternations between physical and cognitive tasks. Therefore, the obese individuals may experience more exertion or difficulty in manual load lifting/lowering task despite a moderate amount of physical loading. From the changes associated with excess fat, the obese group may not have significant improvement of executive functions between physical loading level 1 and 2. Note that for the normal-weight group, executive functions were significantly improved between physical loading level 1 and 2; however, no such significant improvement was found for the obese group.

Difference between obese and normal-weight individuals in low back biomechanical stresses during manual load lifting might also be a possible contributor to the the interaction effects between physical loading and BMI. Compared to the normal-weight individuals, obese individuals have larger compression forces and external moments at L5/S1 disc during manual load lifting (Corbeil et al., 2019; Singh et al., 2015). For the obese group, the larger compression forces and external moments at L5/S1 could cause more exertion or difficulty in lifting task in spite of a moderate amount of physical loading; therefore, compared to the normal-weight group, the performance of executive functions may not be improved between physical loading level 1 and 2 for the obese group.

The observed different patterns of the physical loading effects on executive functions between normal-weight and obese groups might have been linked with lower body-mass normalized muscular strength and poor physical performance (balance, gait speed, 50-meter dash, standing long jump, and pull-ups) for the obese individuals (Blimkie, Sale, and Bar-Or, 1990; Cavuoto and Nussbaum, 2013; De Stefano et al., 2015; Du, Zhu, and Jiao, 2017; Houston et al., 2007; Hulens et al., 2001; Kitagawa and Miyashita (1978), Koushyar et al., 2017; Miyatake et al., 2000; Tomlinson et al., 2016). The lower body-mass normalized muscular strength and poor physical performance could cause more exertion or difficulty in lifting task for the obese group despite a moderate amount of physical loading; therefore, compared to the normal-weight group, the improvement of executive functions may not occur between physical loading level 1 and 2 for the obese group.

The observed non-uniformity of the scores of reaction time and proportion correct in the Number-letter and Stroop tasks, that is, no significant effects of physical loading and interaction (physical loading*BMI) for the proportion correct (accuracy rate) contrary to the scores of reaction time, may be attributed to the instructions for the cognitive task in the current study. In the Number-letter and Stroop tasks, the participants were instructed to answer as correctly as possible during 50 seconds; thus, physical loading and interaction effects on cognitive performance may more pronounced for the scores of reaction time rather than the proportion correct.

Chapter 5

Obesity Effects on Executive Functions during Postural Holding Task

5.1 Introduction

In many daily life and work activities, people perform cognitive tasks as well as postural holding tasks. The postural holding and cognitive tasks are conducted concurrently. For example, in case of factory workers, they monitor screens with maintaining various postures, such as sitting, standing, reaching, kneeling, or twisting postures. Similarly, in case of daily life, people search information on mobile phones with sitting on couches or chairs, lying on bed, or standing on the floor. Bus or truck drivers follow a planned route according to a time schedule during driving. Also, they obey traffic signals and signs during driving. The driving postures consist of sitting, reaching, holding, or twisting. In case of firefighters, they operate the nozzle at appropriate pressure and flow, maintain situational awareness, and find out optimum rescue route during extinguishing fires. During the extinguishing fires, they maintain various postures, such as standing, holding, squatting, kneeling, or twisting. Office workers make a report with prolonged sitting postures or make a presentation with prolonged standing postures. In case of doctors, they perform a surgery with prolonged standing, twisting, holding, or stooping postures. The performing a surgery is highly complex and mentally demanding task, and, it related to several cognitive functions and processes, such as perception, attention, and deliberate thinking (Marquardt et al., 2015). As part of efforts to enhance knowledge on the relationship between postural holding and cognitive tasks, much research has been conducted to examine postural loading effects on cognitive performance. As mentioned in Chapter 2.3, some studies found that postural loading adversely affected cognitive performance. However, some studies reported that postural loading did not affect cognitive performance. Postural loading effects on cognitive performance still remain equivocal despite a substantial number of investigations in the area.

The obesity effects on postural control and cognitive performance are important research topics as a significant proportion of the workforce in many countries are obese (Finkelstein et al., 2012; World Health Organization, 2021a). According to the World Health Organization (2021a), the number of obese people has nearly tripled from 1975 to 2016. It is projected that prevalence of obesity will increase continually in the near future (Finkelstein et al., 2012). As part of efforts to understand the obesity-associated changes in postural control and cognitive performance, much research has been conducted to examine obesity effects on postural control and cognitive performance. As mentioned in Chapter 2.1, obesity was associated with increased postural sway, that is, obesity adversely affected postural control (Hue et al., 2007; Kejonen et al., 2003; McGraw et al., 2000; Singh et al., 2009; Teasdale et al., 2007). This means that obese individuals might experience more exertion or difficulty during postural holding task. As mentioned in Chapter 2.4, obesity effects on cognitive performance still remain equivocal despite a substantial number of investigations in the area.

Despite previous research efforts, however, research gap still seems to exist concerning the obesity effects on postural control and cognitive performance. The previous studies did not consider obesity effects on cognitive performance during postural holding tasks. As mentioned in Chapter 2.3, postural loading adversely affected cognitive performance. Also, as mentioned in Chapter 2.1, obesity negatively affected postural control. Given the two Chapters, compared to normal-weight individuals, obese individuals would have different cognitive performance during postural holding tasks.

As an effort towards addressing the research gap, the aim of this chapter was to identify and characterize the obesity effects on cognitive performance during postural holding task. Executive functions were employed for cognitive performance in this study. Three kinds of postures based on the Ovako Working Posture Analyzing System (OWAS) proposed by Karhu, Kansi, and Kuorinka (1977) were used for postural holding task.

The main hypotheses of this chapter were as follows:

- H1) Executive functions deteriorate as postural loading increases,
- H2) Obese and normal-weight individuals do not differ in executive functions without postural loading,
- H3) During a moderate amount of postural loading, for the obese group, executive functions significantly deteriorate; however, no such significant deterioration is found for the normal-weight group, and
- H4) During a severe amount of postural loading, for both obese and normal-weight individuals, executive functions significantly deteriorate; however, the deterioration of executive functions is more pronounced for the obese group.

H1 was based on the observations that postural loading adversely affected cognitive performance (Kang, Lee, and Jin, 2021; Kerr et al., 1985; Son, 2018; Stephenson et al., 2020). H2 was based on the finding that there were no associations between obesity and cognitive performance (Gunstad et al., 2007; Kuo et al., 2006; Ward et al., 2005; Wolf et al., 2007). H3 was based on the findings that obesity was associated with increased postural sway, that is, obesity adversely affected postural control (Hue et al., 2007; Kejonen et al., 2003; McGraw et al., 2000; Singh et al., 2009; Teasdale et al., 2007). This means that obese individuals might experience more exertion or difficulty during postural holding task in spite of a moderate amount of postural loading. H4 was based on the finding that postural loading adversely affected cognitive performance (Kang, Lee, and Jin, 2021; Kerr et al., 1985; Son, 2018; Stephenson et al., 2020). Also, obesity was known to decrease postural control (Hue et al., 2007; Kejonen et al., 2003; McGraw et al., 2000; Singh et al., 2009; Teasdale et al., 2007).

5.2 Research Methods

5.2.1 Participants

Twenty-one normal-weight and 21 obese male individuals participated in this study. Their age ranged from 19 to 49 years. All of the participants had normal or corrected-to-normal vision in both eyes and normal or mild levels of depression, anxiety, and stress. The depression, anxiety, and stress scale (DASS-21; Lovibond and Lovibond, 1996) was used for a self-report measure of depression, anxiety, and stress. None of them had self-reported current musculoskeletal disorders. Normal-weight participants had body mass index (BMI) between 18.5 and 25kg/m^2. Obese participants belonged to the obesity category of the World Health Organization (2021b) classification (BMI $\geq$ 30kg/m^2). The participants' age, duration of education, height, body mass, BMI, and waist circumference data are summarized in Table 5.1.

t-tests showed that the two participant groups significantly differed in mean body mass, BMI, and waist circumference ($p<0.001$) but did not in mean age ($p=0.943$), duration of education ($p=0.545$), and height ($p=0.796$).

5.2.2 Postural Holding Task

In this study, three kinds of postures were employed for postural holding task. During the postural holding task, a force plate (Model 4060-07, Bertec Corp.) was used. The postures had different postural loading levels; and, the loading levels were based on the Ovako Working Posture Analyzing System (OWAS) proposed by Karhu, Kansi, and Kuorinka (1977), which is a widely used method for evaluating working postures. The postural loading levels were defined as follows: (1) Level 1: standing with feet shoulder-width apart for 120 seconds, (2) Level 2: standing with 120 degrees of knee bend and straight upper body for 120 seconds, and (3) Level 3: standing with 120 degrees of knee bend, 30 degrees of left rotation of upper body, and both arms above shoulder level (120 degrees) for 120 seconds. The loading levels 1, 2, and 3 corresponded to the OWAS class 1 (normal postures which do not need any special attention, except in some special cases), class 2 (postures must be considered during the next regular check of working methods), and class 4 (postures need immediate consideration), respectively. A visual description of the postural loading levels is provided in Figure 5.1. During the postural holding task, each participant was instructed to maintain the postures on the force plate. A pre-recorded verbal instruction was used during the task.

Table 5.1: Summary of the participants' data

Dimensions	**Normal-weight (n=21)**	**Obese (n=21)**
	Mean ± SD	Mean ± SD
Age (years)	27.71 ± 8.07	27.86 ± 4.20
Duration of education (years)	15.55 ± 1.97	15.90 ± 1.81
Height (cm)	175.86 ± 7.85	176.42 ± 6.03
Body mass (kg)	69.22 ± 8.44	105.60 ± 12.13
BMI (kg/m^2)	22.33 ± 1.73	33.89 ± 3.17
Waist circumference (cm)	82.79 ± 4.82	110.65 ± 7.80

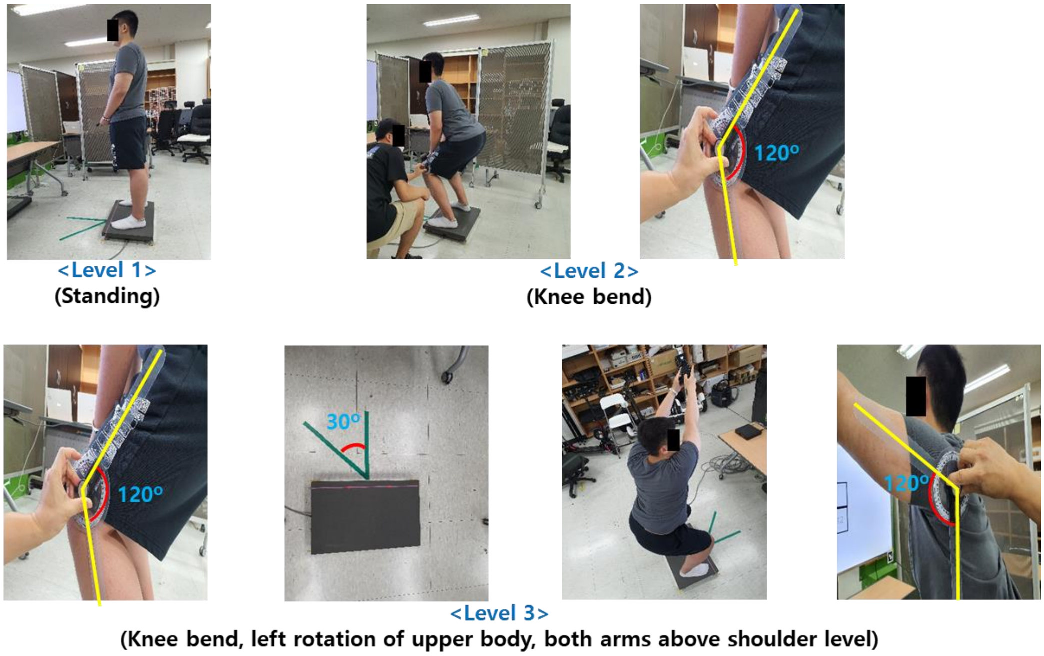

Figure 5.1: A visual description of postural loading levels

5.2.3 Postural Sway Measures

Three kinds of postural sway measures, sway area, sway path, and sway maximal amplitude, were employed in this study. The three measures have been widely used in a variety of studies (Baratto, Morasso, and Spada, 2002; Błaszczyk et al., 2007; Diener et al., 1984; Martinez-Mendez, Sekine, and Tamura, 2012; Panjan and Sarabon, 2010; Raper and Soames, 1991; Son et al., 2019; Stylianou et al., 2011; Verbecque, Vereeck, and Hallemans, 2016). For obtaining postural sway data, the center of pressure (CoP) signals were collected at a sampling frequency of 100 Hz using a force plate. The definition of postural sway measures was based on Baratto, Morasso, and Spada (2002) and Panjan and Sarabon (2010). A detailed description of the postural sway measures was as follows: (1) sway area: the time integral of the area swept by the CoP trajectory with respect to platform center (unit: mm^2), (2) sway path: the length of the trajectory of the CoP sway (unit: mm), (3) sway maximal amplitude_ML: the amplitude between the two most distant samples of CoP sway in medio-lateral (ML) direction (unit: mm), and (4) sway maximal amplitude_AP: the amplitude between the two most distant samples of CoP sway in anterior-posterior (AP) direction (unit: mm).

5.2.4 Executive Functions

As in Chapter 4, three core executive functions, shifting, updating, and inhibition, were employed in this study. Number-letter task (Rogers and Monsell, 1995), Letter-memory task (Morris and Jones, 1990), and Stroop task (Stroop, 1935) were used to measure shifting, updating, and inhibition, respectively. Inquisit Lab version 5 (Millisecond Software, Seattle, WA) psychological tool was used to carry out all cognitive tasks (Number-letter task, Letter-memory task, and Stroop task). During the cognitive tasks, a monitor screen (27 inches) was used to display visual instruction and stimulus. Also, wireless membrane numeric key pad (Cosy KP1364WL) was used to input response. The key pad's dimension was 124mm (length) × 82mm (width) × 18mm (height). Its weight was 90g.

5.2.5 Subjective Ratings and Heart Rate

As in Chapter 4, the participants were asked to verbally indicate subjective ratings of perceived exertion, physical discomfort, and mental workload after each task trial in this study. The Borg CR 10 scale (Borg, 1982) was adopted, and, the scale was presented on the screen so that they could easily respond. Heart rate was measured right before and after each task trial using Samsung Galaxy fit. Then, delta heart rate (ΔHR) was calculated as follows: $\Delta HR = HR\ (\text{after trial}) - HR\ (\text{before trial})$.

5.2.6 Experimental Procedure

Prior to the experimental trials, the study purpose and procedure were fully explained to the participants. The research protocol was reviewed and approved by Seoul National University Institutional Review Board. Each participant signed a written consent and changed into a short sleeve shirt, short pants, and athletic shoes. The participant was asked his age and duration of education. The body mass, height, and waist circumference were measured. The depression, anxiety, and stress scale (DASS-21; Lovibond and Lovibond, 1996) was used for a self-report measure of depression, anxiety, and stress. The training session was conducted for 30 minutes to familiarize the participants with experimental tasks.

In the experimental trials, one trial consisted 30 seconds of postural holding task and 90 seconds of concurrent postural holding and cognitive tasks; thus, one trial lasted for 120 seconds (2 minutes). Each participant conducted 9 experimental trials (9 = 3 postural loading levels × 3 cognitive tasks). Postural loading levels consisted of 1, 2, and 3, and, cognitive tasks comprised Number-letter task, Letter-memory task, and Stroop task. The order of 9 trials was randomized for each participant. During the concurrent postural holding and cognitive tasks, the center of pressure (CoP) signals were recorded at a sampling frequency of 100 Hz using a force plate. A minimum of 20 minutes of rest was given between trials to minimize the effect of fatigue. After each trial, the participants were asked to verbally indicate subjective ratings of perceived exertion, physical discomfort, and mental workload. The Borg CR 10 scale (Borg, 1982) was adopted. Heart rate was measured right before and after each trial using Samsung Galaxy fit. Then, delta heart rate (ΔHR) was calculated as follows: $\Delta HR = HR \text{ (after trial)} - HR \text{ (before trial)}$.

5.2.7 Statistical Analyses

In this study, independent variables were BMI groups [Normal-weight ($18.5kg/m^2 \leq BMI < 25kg/m^2$), obese ($BMI \geq 30kg/m^2$)] and postural loading levels (1, 2, 3). Dependent variables were scores of three cognitive tasks (Number-letter task, Letter memory task, Stroop task), postural sway data (sway area, sway path, sway maximal amplitude_ML, sway maximal amplitude_AP), subjective ratings (perceived exertion, physical discomfort, and mental workload), and delta heart rate (ΔHR).

A series of two-way mixed analyses of variance (ANOVAs) were performed to test for effects of postural loading level and obesity on cognitive performance. In the ANOVAs, within subjects were postural loading levels, and, between subjects were BMI groups. To assess the sphericity, Mauchly's test was conducted. If the sphericity was violated, the degrees of freedom were corrected using Greenhouse-Geisser and Huynh-Feldt corrections (Greenhouse and Geisser, 1959; Huynh and Feldt, 1976) - the Greenhouse-Geisser correction was adopted if the estimate of sphericity (ε) was less than 0.75; otherwise, the Huynh-Feldt correction was employed (Verma, 2015). Pairwise comparisons (post-hoc tests) were conducted in the significant ANOVA results. The Bonferroni adjustment was used for the pairwise comparisons. Statistical Package for the Social Sciences (SPSS) Statistical version 26.0 (SPSS Inc., Chicago, IL) was used to carry out all statistical analyses. The α-level was set at 0.05 for all statistical analyses.

5.3 Results

5.3.1 Number-Letter Task

The ANOVAs revealed that postural loading significantly affected 3 out of 6 Number-letter task scores (Table 5.2): (1) mean reaction time (latency) of correctly responding to switch trials (MeanRT_Switch), (2) mean reaction time (latency) of correctly responding to nonswitch trials (MeanRT_Nonswitch), and (3) reaction time (latency) switch cost (RT_Switchcost). Among the three variables, significant interaction effects between postural loading and BMI were identified for the two variables (Table 5.2): (1) MeanRT_Switch and (2) RT_Switchcost. No significant effects of postural loading and interaction (postural loading * BMI) were found for the rest of the Number-letter task scores (Tables 5.2 and 5.3): (1) proportion correct of switch trials (PropCorrect_Switch), (2) proportion correct of nonswitch trials (PropCorrect_Nonswitch), and (3) accuracy switch cost (ACC_Switchcost). No main effects of BMI were found for all of the Number-letter task scores (Table 5.2).

Regarding the postural loading effects on the MeanRT_Switch, MeanRT_Nonswitch, and RT_Switchcost (Tables 5.2 and 5.4, Figure 5.2), the three variables increased as postural loading increased. Among the three variables, MeanRT_Switch significantly increased between postural loading level 1 and 2; however, MeanRT_Nonswitch and RT_Switchcost slightly (not significantly) increased between two levels. All the three variables significantly increased between postural loading level 2 and 3.

As for the interaction effects between postural loading and BMI on the MeanRT_Switch and RT_Switchcost (Tables 5.2 and 5.4, Figure 5.2), it was found that there were different patterns of the postural loading effects on the Number-letter task scores between the BMI groups – for the obese group, the MeanRT_Switch and RT_Switchcost significantly increased between postural loading level 1 and 2; however, no such significant increase was found for the normal-weight group. Also, for the obese group, the RT_Switchcost significantly increased between postural loading level 2 and 3; however, no such significant increase was found for the normal-weight group.

Table 5.2: Tests of within and between subjects effects for Number-letter task scores

	P-value		
	Test of within subject effect		Test of between subject effect
	Postural loading	Postural loading * BMI	BMI group
PropCorrect_Switch	.946	.969	.919
PropCorrect_Nonswitch	.923	.979	.152
ACC_Switchcost	.996	.976	.074
MeanRT_Switch	**< .001***	**.001***	.145
MeanRT_Nonswitch	**< .001***	.145	.479
RT_Switchcost	**< .001***	**.005***	.157

*Indicates significant at the .05 level.

Table 5.3: Mean, SD, and mean difference for PropCorrect_Switch, PropCorrect_Nonswitch, and ACC_Switchcost

		Mean ± SD				Mean difference		
		PL1	PL2	PL3	Total	PL2–PL1	PL3–PL2	PL3–PL1
PropCorrect_Switch (%)	T	90.37±7.98	90.59±7.01	90.29±6.11	90.42±7.02	.22	-.30	-.08
	N	90.35±9.24	90.80±8.47	90.37±6.52	90.51±8.03	.45	-.43	.02
	O	90.38±6.73	90.37±5.38	90.20±5.83	90.32±5.91	-.01	-.17	-.18
PropCorrect_Nonswitch (%)	T	93.05±7.44	93.19±6.55	92.86±5.57	93.04±6.52	.14	-.33	-.19
	N	94.25±8.03	94.42±7.45	94.22±5.46	94.30±6.95	.17	-.20	-.03
	O	91.85±6.78	91.97±5.42	91.51±5.48	91.78±5.83	.12	-.46	-.34
ACC_Switchcost (%)	T	-2.68±6.91	-2.60±5.16	-2.57±6.40	-2.62±6.15	.08	.03	.11
	N	-3.90±7.90	-3.62±4.15	-3.85±5.25	-3.79±5.88	.28	-.23	.05
	O	-1.47±5.69	-1.60±5.94	-1.31±7.28	-1.46±6.24	-.13	.29	.16

‘PL’, 'T', 'N’, and 'O’ denote postural loading, total, normal-weight, and obese, respectively.

Table 5.4: Mean, SD, mean difference, and pairwise comparison p-value for MeanRT_Switch, MeanRT_Nonswitch, and RT_Switchcost

		Mean ± SD				Mean difference (Pairwise comparison p-value)		
		PL1	PL2	PL3	Total	PL2–PL1	PL3 – PL2	PL3 – PL1
MeanRT_Switch (ms)	T	1275±390	1313±403	1491±473	1360±430	38 **(.014*)**	178 **(< .001*)**	216 **(< .001*)**
	N	1223±362	1228±379	1346±404	1286±380	5 (1.000)	118 **(.002*)**	123 **(.002*)**
	O	1328±418	1397±416	1635±502	1454±460	69 **(.001*)**	238 **(< .001*)**	307 **(< .001*)**
MeanRT_Nonswitch (ms)	T	873±240	887±246	974±274	911±256	14 (.262)	87 **(< .001*)**	101 **(< .001*)**
	N	856±170	860±184	934±207	883±188	4	74	78
	O	890±297	913±299	1014±328	939±308	23	101	124
RT_Switchcost (ms)	T	402±300	426±297	517±331	449±311	24 (.150)	91 **(< .001*)**	115 **(< .001*)**
	N	367±243	368±242	413±278	382±252	1 (1.000)	45 (.371)	46 (.495)
	O	438±350	485±339	621±353	515±351	47 **(.023*)**	136 **(< .001*)**	183 **(<. 001*)**

*Indicates significant at the .05 level. ‘PL’, 'T', 'N’, and 'O’ denote postural loading, total, normal-weight, and obese, respectively.

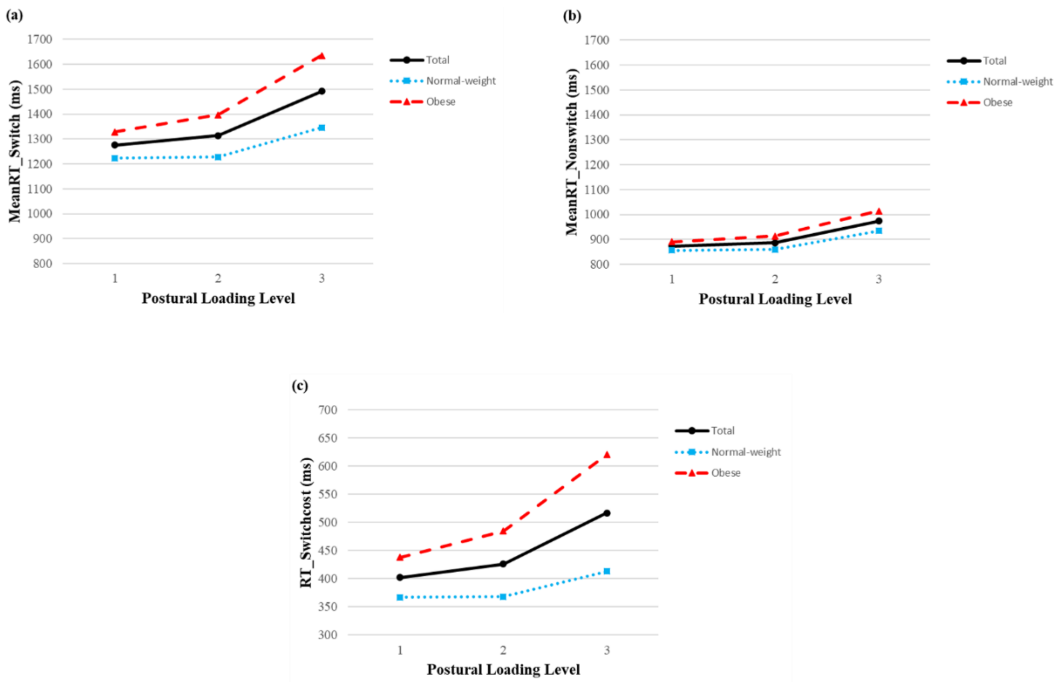

Figure 5.2: Line graphs of Number-letter task scores: (a) MeanRT_Switch, (b) MeanRT_Nonswitch, and (c) RT_Switchcost

5.3.2 Letter Memory Task

The ANOVAs found that postural loading significantly affected Letter memory task score, and, a significant interaction effect between postural loading and BMI was identified (Tables 5.5 and 5.6). No main effect of BMI was found for the Letter memory task score (Table 5.5).

As for the postural loading effect on the Letter memory task score (Tables 5.5 and 5.6, Figure 5. 3), the score significantly decreased as postural loading increased.

Regarding the interaction effect between postural loading and BMI on the Letter memory task score (Tables 5.5 and 5.6, Figure 5.3), there were different patterns of the postural loading effect on the Letter memory task score between the BMI groups – for the obese group, the score significantly decreased between postural loading level 1 and 2; however, no such significant decrease was found for the normal-weight group.

Table 5.5: Tests of within and between subjects effects for Letter memory task score

	P-value		
	Test of within subject effect		Test of between subject effect
	Postural loading	Postural loading * BMI	BMI group
LM score	**< .001***	**.001***	.154

*Indicates significant at the .05 level. 'LM' denotes Letter memory.

Table 5.6: Mean, SD, mean difference, and pairwise comparison p-value for Letter memory task score

		Mean ± SD				Mean difference (Pairwise comparison p-value)		
		PL1	PL2	PL3	Total	PL2–PL1	PL3 – PL2	PL3 – PL1
LM Score (0~4)	T	3.49± .38	3.30± .40	2.98± .41	3.26± .45	-.19 **(< .001*)**	-.32 **(< .001*)**	-.51 **(< .001*)**
	N	3.48± .33	3.42± .37	3.11± .37	3.34± .39	-.06 (.990)	-.31 **(< .001*)**	-.37 **(< .001*)**
	O	3.50± .43	3.18± .41	2.84± .42	3.18± .49	-.32 **(< .001*)**	-.34 **(< .001*)**	-.66 **(< .001*)**

*Indicates significant at the .05 level. 'PL', 'T', 'N', and 'O' denote postural loading, total, normal-weight, and obese, respectively.

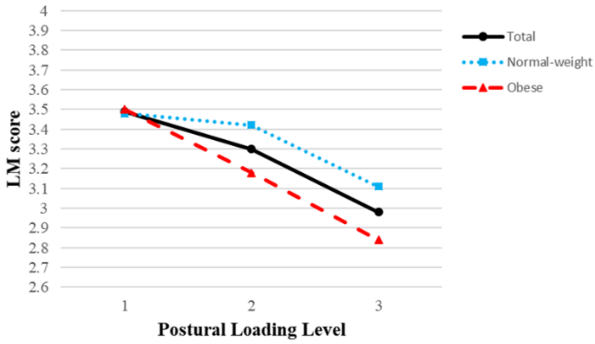

Figure 5.3: Line graph of Letter memory task score

5.3.3 Stroop Task

As can be seen from Table 5.7, postural loading significantly affected 4 out of 8 Stroop task scores: (1) overall mean reaction time (latency) of all correct trials (MeanRT), (2) mean reaction time (latency) of all correct congruent trials (MeanRT_Congruent), (3) mean reaction time (latency) of all correct incongruent trials (MeanRT_Incongruent), and (4) mean reaction time (latency) of all correct control trials (MeanRT_Control). Among the four variables, significant interaction effects between postural loading and BMI were identified for the three variables (Table 5.7): (1) MeanRT, (2) MeanRT_Incongruent, and (3) MeanRT_Control. No significant effects of postural loading and interaction (postural loading * BMI) were found for the rest of the Stroop task scores (Tables 5.7 and 5.8): (1) overall proportion correct of all trials (PropCorrect), (2) proportion correct of congruent trials (PropCorrect_Congruent), (3) proportion correct of incongruent trials (PropCorrect_Incongruent), and (4) proportion correct of control trials (PropCorrect_Control). No main effects of BMI were found for all of the Stroop task scores (Table 5.7).

Regarding the postural loading effects on the MeanRT, MeanRT_Congruent, MeanRT_Incongruent, and MeanRT_Control (Tables 5.7 and 5.9, Figure 5.4), the four variables significantly increased as postural loading increased.

As for the interaction effects between postural loading and BMI on the MeanRT, MeanRT_Incongruent, and MeanRT_Control (Tables 5.7 and 5.9, Figure 5.4), it was found that there were different patterns of the postural loading effects on the Stroop task scores between the BMI groups – for the obese group, the three variables significantly increased between postural loading level 1 and 2; however, no such significant increase was found for the normal-weight group.

Table 5.7: Tests of within and between subjects effects for Stroop task scores

	P-value		
	Test of within subject effect		Test of between subject effect
	Postural loading	Postural loading * BMI	BMI group
PropCorrect	.864	.301	.637
PropCorrect_Congruent	.085	.666	.605
PropCorrect_Incongruent	.259	.673	.846
PropCorrect_Control	.636	.351	.594
MeanRT	**< .001***	**.037***	.746
MeanRT_Congruent	**< .001***	.206	.803
MeanRT_Incongruent	**< .001***	**.038***	.754
MeanRT_Control	**< .001***	**.013***	.721

*Indicates significant at the .05 level.

Table 5.8: Mean, SD, and mean difference for PropCorrect, PropCorrect_Congruent, PropCorrect_Incongruent, and PropCorrect_Control

		Mean ± SD				Mean difference		
		PL1	PL2	PL3	Total	PL2–PL1	PL3–PL2	PL3–PL1
PropCorrect (%)	T	93.42±3.93	93.11±3.64	93.24±4.02	93.26±3.84	-.31	.13	-.18
	N	93.70±4.85	92.49±4.11	92.87±4.39	93.02±4.42	-1.21	.38	-.83
	O	93.15±2.83	93.72±3.09	93.60±3.68	93.49±3.18	.57	-.12	.45
PropCorrect_Congruent (%)	T	93.08±4.85	94.38±3.72	95.10±4.73	94.19±4.50	1.30	.72	2.02
	N	93.31±5.54	93.96±4.56	94.57±4.01	93.95±4.70	.65	.61	1.26
	O	92.86±4.79	94.79±2.68	95.62±5.40	94.42±4.33	1.93	.83	2.76
PropCorrect_Incongruent (%)	T	92.11±6.79	90.54±6.77	90.28±8.70	90.98±7.46	-1.57	-.26	-1.83
	N	92.54±7.51	90.12±6.98	89.73±9.85	90.79±8.17	-2.42	-.39	-2.81
	O	91.68±6.14	90.97±6.69	90.83±7.58	91.16±6.73	-.71	-.14	-.85
PropCorrect_Control (%)	T	95.08±4.19	94.41±4.82	94.33±4.99	94.61±4.65	-.67	-.08	-.75
	N	95.24±4.90	93.41±5.04	94.31±5.83	94.32±5.25	-1.83	.90	-.93
	O	94.91±3.45	95.41±4.48	94.35±4.12	94.89±4.00	.50	-1.06	-.56

‘PL’, 'T', 'N’, and 'O’ denote postural loading, total, normal-weight, and obese, respectively.

Table 5.9: Mean, SD, mean difference, and pairwise comparison p-value for MeanRT, MeanRT_Congruent, MeanRT_Incongruent, and MeanRT_Control

		Mean ± SD				Mean difference (Pairwise comparison p-value)		
		PL1	PL2	PL3	Total	PL2–PL1	PL3 – PL2	PL3 – PL1
MeanRT (ms)	T	763±167	799±179	858±211	807±189	36 **(< .001*)**	59 **(< .001*)**	95 **(< .001*)**
	N	770±186	781±183	841±215	797±195	11 (.793)	60 **(< .001*)**	71 **(.002*)**
	O	756±150	817±178	876±211	816±185	61 **(< .001*)**	59 **(< .001*)**	120 **(< .001*)**
MeanRT_ Congruent (ms)	T	718±135	742±145	789±164	750±150	24 **(.001*)**	47 **(< .001*)**	71 **(< .001*)**
	N	720±131	730±136	783±164	744±145	10	53	63
	O	717±142	755±155	795±166	756±156	38	40	78
MeanRT_ Incongruent (ms)	T	841±244	894±262	979±305	905±275	53 **(< .001*)**	85 **(< .001*)**	138 **(< .001*)**
	N	852±281	869±275	953±317	891±290	17 (0.521)	84 **(< .001*)**	101 **(.003*)**
	O	829±207	918±252	1006±297	918±261	89 **(< .001*)**	88 **(< .001*)**	177 **(< .001*)**
MeanRT_ Control (ms)	T	733±141	765±158	815±185	771±164	32 **(< .001*)**	50 **(< .001*)**	82 **(< .001*)**
	N	743±160	747±155	797±185	762±167	4 (1.000)	50 **(< .001*)**	54 **(.011*)**
	O	723±122	784±163	833±187	780±163	61 **(< .001*)**	49 **(< .001*)**	110 **(< .001*)**

*Indicates significant at the .05 level. ‘PL’, 'T', 'N', and 'O’ denote postural loading, total, normal-weight, and obese, respectively.

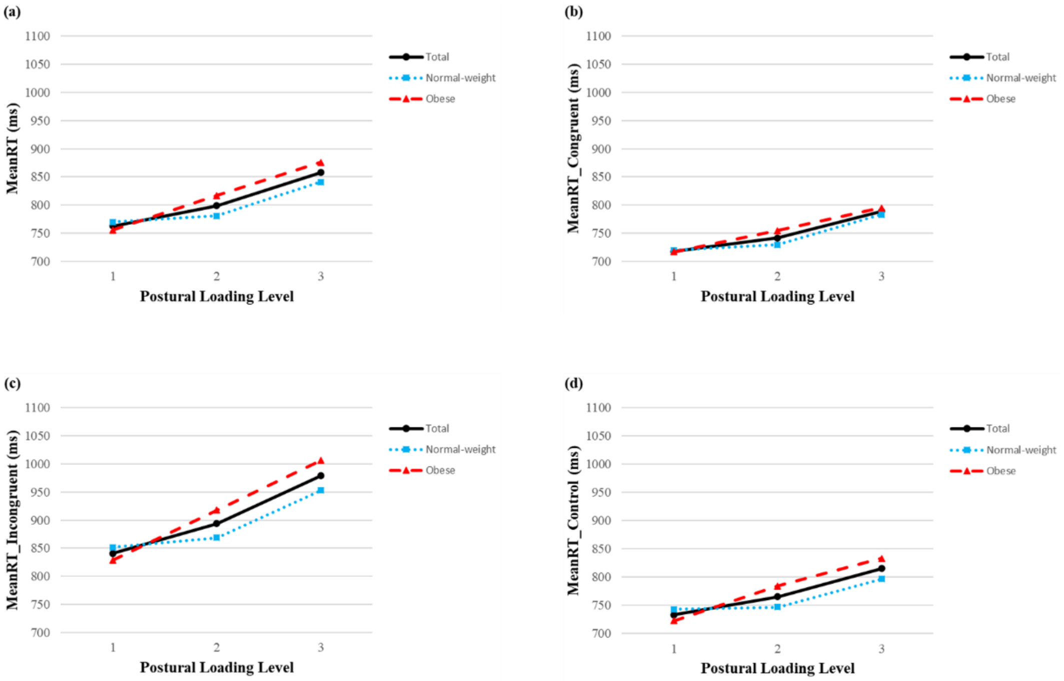

Figure 5.4: Line graphs of Stroop task scores: (a) MeanRT, (b) MeanRT_Congruent, (c) MeanRT_Incongruent, and (d) MeanRT_Control

5.3.4 Postural Sway

The ANOVAs found that postural loading significantly affected all of the postural sway data: (1) Sway Path (SP) (2) Sway Area (SA) (3) Sway Maximal Amplitude_ML (SMA_ML) (4) Sway Maximal Amplitude_AP (SMA_AP). Among the variables, significant interaction effects between postural loading and BMI were identified for the sway path (SP) variables. Significant BMI effects were found for the Sway Maximal Amplitude_AP (SMA_AP) variables.

As for the postural loading effects on the SP, SA, SMA_ML, and SMA_AP variables, they increased as postural loading increased. Regarding the interaction effects between postural loading and BMI on the SP, the postural loading effects on SP were more pronounced for the obese group than the normal-weight group. As for the BMI effects on the SMA_AP, obese group had larger SMA_AP than the normal-weight group.

5.3.5 ΔHeart Rate (ΔHR) and Subjective Ratings

The ANOVAs found that postural loading and BMI significantly affected delta heart rate (ΔHR), the perceived exertion (PE), physical discomfort (PD), and mental workload (MW) variables. As for the postural loading effects on the ΔHR, PE, PD, and MW variables, they increased as postural loading increased. Regarding the BMI effects on the ΔHR, PE, PD, and MW variables, the obese group had larger the ΔHR, PE, PD, and MW variables than the normal-weight group. No significant interaction (postural loading * BMI) effects were found for the ΔHR, PE, PD, and MW variables.

5.4 Discussion

This study empirically investigated the obesity effects on cognitive performance during postural holding task. Three kinds of postures were employed for postural holding task, and, had different postural loading levels (1, 2, and 3) based on the OWAS (Karhu, Kansi, and Kuorinka, 1977) class. During the postural holding task, each participant was instructed to maintain the postures on the force plate, and, the center of pressure (CoP) signals were collected to obtain postural sway data (sway area, sway path, sway maximal amplitude_ML, and sway maximal amplitude_AP). Obesity had two groups based on the BMI [Normal-weight ($18.5kg/m^2 \leq BMI < 25kg/m^2$), obese ($BMI \geq 30kg/m^2$)]. In the cognitive task, three core executive functions (shifting, updating, and inhibition) were employed. To measure shifting, updating, and inhibition, Number-letter task, Letter-memory task, and Stroop task were used, respectively. One trial consisted 30 seconds of postural holding task and 90 seconds of concurrent postural holding and cognitive tasks. After each trial, subjective ratings of perceived exertion, physical discomfort, and mental workload were conducted. Heart rate was measured right before and after each trial.

The main objective of the current study was to identify and characterize the obesity effects on executive functions during postural loading. A series of two-way mixed analyses of variance (ANOVAs) were performed. The ANOVAs found significant effects of postural loading and interaction (postural loading*BMI) on executive functions (Tables 5.2-5.9, Figures 5.2-5.4). There were no main effects of BMI on executive functions (Tables 5.2, 5.5, 5.7). Main findings were as follows:

- Executive functions generally deteriorated as postural loading increased.

- As postural loading increased, deterioration of executive functions became progressively more pronounced, especially between postural loading level 2 and 3.

- In the significant interaction effects between postural loading and BMI, there were different patterns of the postural loading effects on executive functions between normal-weight and obese groups.

  - Obese and normal-weight groups did not differ in executive functions for postural loading level 1.

  - For the obese group, executive functions significantly deteriorated between postural loading level 1 and 2; however, no such significant deterioration was found for the normal-weight group.

  - Between postural loading level 2 and 3, executive functions deteriorated for both the normal-weight and obese groups; however, the deterioration of executive functions was more pronounced for the obese group.

- In the task scores of Number-letter and Stroop, contrary to the scores of reaction time, no significant effects of postural loading and interaction (postural loading*BMI) were found for the proportion correct (accuracy rate).

The observed postural loading effects on deterioration of executive functions (Tables 5.2-5.9, Figures 5.2-5.4) could be explained in terms of the attentional resources. Multiple research studies mentioned that humans have a limited capacity of attentional resources (Chun and Potter, 1995; Shapiro, Raymond, and Arnell, 1994; Ward, Duncan, and Shapiro, 1996; Wickens et al., 2013). People make more mistakes or perform their tasks more slowly when multitasking (Matlin, 2013; Wickens et al., 2013). In the current study, each participant was required to concurrently perform postural holding task and executive functions task. The postural holding task requires postural control, and, such postural control also requires attentional resources (Dault et al., 2001; Palluel, Nougier, and Olivier, 2010). Difficulty of postural control increases with increasing postural loading – the postural sway data (sway path, sway area, and sway maximal amplitude) generally increased as postural loading increased. Also, mental workload increased as postural loading increased. The increased difficulty of postural control and mental workload during postural holding task may reduce attentional resources; therefore, performance of executive functions could deteriorate as postural loading increases.

The effects of negative emotions on scope of attention and working memory may also be a possible contributor to the observed postural loading effects on executive functions. Executive functions include various basic cognitive processes such as attentional control, working memory, cognitive inhibition, and cognitive flexibility (Chan et al., 2008; Diamond, 2013). Multiple previous studies demonstrated that negative emotions, such as anxiety and anger, could narrow the scope of attention (Easterbrook, 1959; Fredrickson and Branigan, 2005; Strauss and Allen, 2006). Also, such negative emotions could degrade working memory (Berkun, 1964; Davies and Parasuraman, 1982; Wachtel, 1968; Wickens et al., 2013). King and Emmons (1991) and Fergus, Bardeen, and Orcutt (2015) found that physical discomfort generally correlated with anxiety. Son (2018) mentioned that perceived physical discomfort increased with increasing postural loading, and, working memory task performance decreased with increasing physical discomfort. In the current study, perceived physical discomfort increased with increasing postural loading - for the postural loading level 2, the physical discomfort ratings were about 4 on the Borg CR 10 scale indicating somewhat strong feeling of discomfort, and, for the postural loading level 3, the discomfort ratings were above 5 on the Borg CR 10 scale indicating strong feeling of discomfort. From the changes associated with increased postural loading, postural loading may cause negative emotions, and, the negative emotions could narrow scope of attention and degrade working memory; therefore, performance of executive functions could deteriorate as postural loading increases.

The interaction effects between postural loading and BMI (Tables 5.2-5.9, Figures 5.2-5.4), which were observed different patterns of the postural loading effects on executive functions between normal-weight and obese groups, may be attributed to the excess fat in the obese body. Excess fat would hinder inter-segmental rotations at body joints (Chaffin, Anderson, and Martin, 2006; Escalante et al., 1999a,b; Gilleard and Smith, 2007; Laubuch, 1969), and, decrease joint range of motion (Escalante et al., 1999a,b; Joao et al., 2014; Park et al., 2010); thus, the obese individuals may experience more exertion or difficulty during postural holding task. In the current study, the postural holding task consisted of three different postures based on OWAS (Karhu, Kansi, and Kuorinka, 1997). Also, the experimental trials consisted of concurrent postural holding and cognitive tasks. Therefore, the obese individuals may experience more exertion or difficulty in postural holding task despite a moderate amount of postural loading. For the postural loading level 2 and 3, compared to the normal-weight group, the obese group had greater postural sway data, delta heart rate, and ratings of perceived exertion, physical discomfort, and mental workload. From the changes associated with excess fat, compared to the normal-weight group, the obese group may have significant deterioration of executive functions between postural loading level 1 and 2. Also, between postural loading level 2 and 3, the deterioration of executive functions may be more pronounced for the obese group.

Difference between obese and normal-weight individuals in postural control during postural holding task might also be a possible contributor to the the interaction effects between postural loading and BMI. Obesity was associated with increased postural sway, that is, obesity adversely affected postural control (Hue et al., 2007; Kejonen et al., 2003; McGraw et al., 2000; Singh et al., 2009; Teasdale et al., 2007). This means that obese individuals might experience more exertion or difficulty during postural holding task in spite of a moderate amount of postural loading. In the current study, for the postural loading level 2 and 3, the obese group had greater postural sway data than the normal-weight group. Therefore, compared to the normal-weight individuals, the obese individuals may have significant deterioration of executive functions between postural loading level 1 and 2. Also, between postural loading level 2 and 3, the deterioration of executive functions may be more pronounced for the obese group.

The observed different patterns of the postural loading effects on executive functions between normal-weight and obese groups might have been linked with lower body-mass normalized muscular strength and poor physical performance (balance, gait speed, 50-meter dash, standing long jump, and pull-ups) for the obese individuals (Blimkie, Sale, and Bar-Or, 1990; Cavuoto and Nussbaum, 2013; De Stefano et al., 2015; Du, Zhu, and Jiao, 2017; Houston et al., 2007; Hulens et al., 2001; Kitagawa and Miyashita 1978; Koushyar et al., 2017; Miyatake et al., 2000; Tomlinson et al., 2016). The lower body-mass normalized muscular strength and poor physical performance could cause more exertion or difficulty in postural holding task for the obese group despite a moderate amount of postural loading. Therefore, compared to the normal-weight group, the obese group may have significant deterioration of executive functions between postural loading level 1 and 2. Also, between postural loading level 2 and 3, the deterioration of executive functions may be more pronounced for the obese group.

The observed non-uniformity of the scores of reaction time and proportion correct in the Number-letter and Stroop tasks, that is, no significant effects of postural loading and interaction (postrual loading*BMI) for the proportion correct (accuracy rate) contrary to the scores of reaction time, may be attributed to the instructions for the cognitive task in the current study. In the Number-letter and Stroop tasks, the participants were instructed to answer as correctly as possible during 90 seconds; thus, postural loading and interaction effects on cognitive performance may more pronounced for the scores of reaction time rather than the proportion correct.

Chapter 6

Conclusion

6.1 Summary

The objective of the current study was to examine the obesity effects on physical and cognitive performance. The dissertation consisted of three major studies in relation to the research objectives. Study 1 examined pre-obesity and obesity effects on joint range of motion. Study 2 investigated obesity effects on executive functions immediately after manual load lifting/lowering task. Study 3 examined obesity effects on executive functions during postural holding task.

In the study 1, the pre-obesity and obesity effects on joint range of motion (RoM) for twenty-two body joint motions were investigated. A publicly available joint RoM dataset was analyzed. Three BMI groups (normal-weight, pre-obese, and obese) were statistically compared in joint RoM. The pre-obese and obese groups were found to have significantly smaller RoM means than the normal-weight for elbow flexion and supination, hip extension and flexion, knee flexion, and ankle plantarflexion. The pre-obese and obese groups exhibited no significant inter-group mean RoM differences except for knee flexion; for knee flexion, the obese group had significantly smaller RoM means than the pre-obese.

In the study 2, the obesity effects on cognitive performance immediately after physical task were examined. Manual load lifting/lowering task was employed for the physical task. In the physical task, three levels of physical loading were used. Obesity had two groups based on the BMI (normal-weight and obese). In the cognitive task, three core executive functions (shifting, updating, and inhibition) were employed. To measure shifting, updating, and inhibition, Number-letter task, Letter-memory task, and Stroop task were used, respectively. One trial consisted of three repeats of a combination of physical and cognitive tasks. After each trial, subjective ratings of perceived exertion, physical discomfort, and mental workload were conducted. Heart rate was measured right before and after each trial. Significant effects of physical loading and interaction (physical loading*BMI) on executive functions were found. Executive functions were slightly improved immediately after a moderate amount of physical loading; however, immediately after a severe amount of physical loading, performance of executive functions generally deteriorated. In the significant interaction effects between physical loading and BMI, there were different patterns of the physical loading effects on executive functions between normal-weight and obese groups. Obese and normal-weight groups did not differ in executive functions for physical loading level 1. Immediately after a moderate amount of physical loading, executive functions were significantly improved for the normal-weight group; however, no such significant improvement was found for the obese group.

In the study 3, the obesity effects on cognitive performance during postural holding task were investigated. Three kinds of postures were employed for postural holding tasks, and, had different postural loading levels (1, 2, and 3) based on the OWAS (Karhu, Kansi, and Kuorinka, 1977) class. During the postural holding task, each participant was instructed to maintain the postures on the force plate, and, the center of pressure (CoP) signals were collected to obtain postural sway data (sway area, sway path, sway maximal amplitude_ML, and sway maximal amplitude_AP). Obesity had two groups based on the BMI (normal-weight and obese). In the cognitive task, three core executive functions (shifting, updating, and inhibition) were employed. To measure shifting, updating, and inhibition, Number-letter task, Letter-memory task, and Stroop task were used, respectively. One trial consisted 30 seconds of postural holding task and 90 seconds of concurrent postural holding and cognitive tasks. After each trial, subjective ratings of perceived exertion, physical discomfort, and mental workload were conducted. Heart rate was measured right before and after each trial. Significant effects of postural loading and interaction (postural loading*BMI) on executive functions were found. Executive functions generally deteriorated as postural loading increased. In the significant interaction effects between postural loading and BMI, there were different patterns of the postural loading effects on executive functions between normal-weight and obese groups. For the obese group, executive functions significantly deteriorated between postural loading level 1 and 2; however, no such significant deterioration was found for the normal-weight group. Between postural loading level 2 and 3, executive functions deteriorated for both the normal-weight and obese groups; however, the deterioration of executive functions was more pronounced for the obese group.

6.2 Implications

This study investigated obesity effects on physical and cognitive performance. In the study 1, pre-obesity and obesity effects on joint range of motion were examined. In the study 2, obesity effects on executive functions immediately after manual load lifting/lowering task were investigated. In the study 3, obesity effects on executive functions during postural holding task were examined. The current study improved our understanding of obesity effects on body flexibility and cognitive performance immediately after or during physical/postural loading, also, contributed to the ergonomics design for obese individuals.

The knowledge provided in the study 1 would be useful for the ergonomics design of work tasks (e.g., lifting, lowering, and other materials handling tasks) and products and systems (e.g., vehicles, workstations, and furniture) for high BMI individuals (BMI≥25kg/m^2). Especially, the effects of pre-obesity identified in this study suggest that considering BMI-related RoM changes in the design of products and systems would benefit not only obese but also pre-obese individuals. The knowledge provided in this study may also guide the development of sophisticated digital human models representing differently sized individuals (Chaffin 2005; Chaffin and Nelson, 2001; Gragg and Yang, 2011).

The findings provided in the study 2 would be helpful to provide the ergonomics guidelines for daily life and work activities. In many daily life and work activities, people perform cognitive tasks as well as physical tasks. The physical and cognitive tasks are conducted immediately or concurrently. In this study, executive functions were improved immediately after a moderate amount of physical loading; however, immediately after a severe amount of physical loading, performance of executive functions generally deteriorated. These findings suggest that physical loading-related cognitive performance changes should be considered in the working environment and daily life. Especially, in the working environment, a severe amount of physical loading needs to be avoided for workforce productivity as well as safety – the workforce productivity may decrease as cognitive performance deteriorates. In the significant interaction effects between physical loading and BMI, this study found that immediately after a moderate amount of physical loading, executive functions were improved for the normal-weight group; however, no such significant improvement was found for the obese group. This means that obese individuals may experience more exertion or difficulty despite a moderate amount of physical loading. These findings suggest that different patterns of the physical loading effects on executive functions between normal-weight and obese groups should be considered in the working environment and daily life. Especially, in the working environment, for obese individuals, moderate as well as severe physical loading needs to be avoided. The knowledge provided in this study may also provide useful guidelines for the improvement of executive functions. Executive functions can be improved by computerized training (Bergman Nutley et al. 2011; Holmes, Gathercole, and Dunning, 2009; Karbach and Kray, 2009; Klingberg et al., 2005, Mackey et al., 2011; Thorell et al., 2009) and physical activities such as martial arts, aerobics, and yoga (Davis et al., 2011; Kamijo et al., 2011; Lake and Hoyt, 2004; Manjunath and Telles 2001). Understanding obesity- and physical loading-related changes in executive functions may be helpful in developing training and physical activities for improving executive functions.

The knowledge in the study 3 would be useful to provide the ergonomics guidelines for daily life and work activities. In many daily life and work activities, people perform cognitive tasks as well as postural holding tasks. The postural holding tasks and cognitive tasks are conducted concurrently. In this study, executive functions generally deteriorated as postural loading increased. This finding suggests that postural loading-related cognitive performance changes should be considered in the working environment and daily life. Especially, in the working environment, moderate as well as severe postural loading needs to be avoided for workforce productivity as well as safety – the workforce productivity may decrease as cognitive performance deteriorates. In the significant interaction effects between postural loading and BMI, this study found that for the obese group, executive functions significantly deteriorated during moderate as well as severe postural loading; however, for the normal-weight group, significant deterioration of cognitive performance were only found in a severe amount of postural loading. Also, during a severe amount of postural loading, the deterioration of executive functions was more pronounced for the obese group. This means that obese individuals may experience more exertion or difficulty during postural loading. These findings suggest that different patterns of the postural loading effects on executive functions between normal-weight and obese groups should be considered in the working environment and daily life. Especially, for obese individuals, moderate as well as severe postural loading needs to be avoided in the working environment. The knowledge provided in this study may also provide useful guidelines for the improvement of executive functions. Executive functions can be improved by computerized training (Bergman Nutley et al. 2011; Holmes, Gathercole, and Dunning, 2009; Karbach and Kray, 2009; Klingberg et al., 2005, Mackey et al., 2011; Thorell et al., 2009) and physical activities such as martial arts, aerobics, and yoga (Davis et al., 2011; Kamijo et al., 2011; Lake and Hoyt, 2004; Manjunath and Telles 2001). Understanding obesity- and postural loading-related changes in executive functions may be helpful in developing training and physical activities for improving executive functions.

6.3 Limitations and Future Works

Some limitations of the current study are described here along with future research ideas. In the study 1, first, this study considered only the Class-I obesity category (30 $kg/m^2 \leq BMI < 35 kg/m^2$); other obesity categories ($BMI \geq 35$ kg/m^2; Class II and III obesity categories) were not examined. Investigating the BMI-associated changes in joint RoM for the entire range of BMI would provide a complete knowledge. Second, this study used the widely used body fat measure, BMI to define pre-obesity and obesity. However, BMI is an indirect measure of body fat and does not differentiate fat and muscle masses. Therefore, a small portion of the individuals in the pre-obese and obese groups, for example, very muscular people, might not be pre-obese/obese in terms of body fat percentage. In future studies, fat mass/percentage measures based on bioelectrical impedance analysis or hydrostatic weighing could be employed instead of BMI. Third, although the current study investigated a variety of joint motions, there are other joint motions that remain to be studied, including the motions at the spine and hand/finger joints. Fourth, the current study identified some asymmetries of pre-obesity and obesity effects on joint RoM for the elbow pronation-supination and ankle dorsiflexion-plantarflexion movement pairs. While this study offered some conjectures concerning the causes of these asymmetries on the basis of the human anatomical characteristics, further studies are needed to verify them. Finally, the current study examined only passive RoM measurements. Future studies may as well examine active RoM data. Both active RoM (Grimston et al., 1993; Park et al., 2010; Roach and Miles, 1991) and passive RoM (Escalante et al., 1999a,b; Joao et al., 2014; Soucie et al., 2011) measurements are used to characterize the body flexibility (Chaffin, Anderson, and Martin, 2006; Kroemer et al. 1997).

In the study 2, manual load lifting lowering task was used for physical task in this study. Other methods for physical task, such as walking, running, or pulling, need to be studied. Also, this study utilized executive functions for cognitive performance. Other cognitive functions, such as attention, memory, perceptual reasoning, or verbal reasoning, need to be studied. Finally, this study considered only males. There are gender differences in cognitive and physical performance – females in general are known to perform better on some cognitive performance such as reading comprehension, initiative, working memory, planning and organization, inhibition, written fluency, and metacognition (Altemeier, Abbott, and Berninger, 2008; Berninger and Fuller, 1992; Lezak et al., 2004; Wierenga et al., 2019; Wolff, et al., 1983). However, males on average perform better on some physical performance such as muscular strength and endurance, handgrip, and standing long jump (Davies, Greenwood, and Jones, 1988; Miller et al., 1993; Vanderburgh et al., 1997). Therefore, comparing the male and female individuals in terms of physical loading-related cognitive performance changes may provide further insights into the physical loading effects on cognitive performance.

In the study 3, first, three kinds of postures based on OWAS (Karhu, Kansi, and Kuorinka, 1977) class was used for postural holding task in this study. Other methods for postural holding task, such as stooping, sitting, or standing on one leg, need to be studied. Second, this study utilized executive functions for cognitive performance. Other cognitive functions, such as attention, memory, perceptual reasoning, or verbal reasoning, need to be studied. Third, this study considered only males. There are gender differences in cognitive and physical performance – females in general are known to perform better on some cognitive performance such as reading comprehension, initiative, working memory, planning and organization, inhibition, written fluency, and metacognition (Altemeier, Abbott, and Berninger, 2008; Berninger and Fuller, 1992; Lezak et al., 2004; Wierenga et al., 2019; Wolff, et al., 1983). However, males on average perform better on some physical performance such as muscular strength and endurance, handgrip, and standing long jump (Davies, Greenwood, and Jones, 1988; Miller et al., 1993; Vanderburgh et al., 1997). Therefore, comparing the male and female individuals in terms of postural loading-related cognitive performance changes may provide further insights into the postural loading effects on cognitive performance. Fourth, this study analyzed only postural sway data for concurrent postural holding and cognitive tasks. Comparing the postural holding only task and the concurrent postural holding-cognitive task in terms of postural loading-related postural sway changes may help identify cognitive task effects on postural control. Finally, a future study is needed to compare a manual load lifting/lowering task and a postural holding task in terms of cognitive performance. Since the two tasks differ in the characteristics of physical exertion and coordination, significant differences between two tasks in cognitive performance are expected.

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Appendix A. Tables for Manual Load Lifting/Lowering Task: ΔHR, PE, PD, and MW

Table A.1: Tests of within and between subjects effects for △Heart Rate（△HR)

	P-value		
	Test of within subject effect		Test of between subject effect
	Physical loading	Physical loading * BMI	BMI group
ΔHR_NL	**< .001***	.882	.240
ΔHR_LM	**< .001***	.111	.573
ΔHR_S	**< .001***	.965	.830

*Indicates significant at the .05 level. ‘NL’, ‘LM’ and ‘S’ denote Number-letter, Letter memory, and Stroop, respectively.

Table A.2: Mean, SD, mean difference, and pairwise comparison p-value for △Heart Rate (△HR)

		Mean ± SD				Mean difference (Pairwise comparison p-value)		
		PL1	PL2	PL3	Total	PL2–PL1	PL3 – PL2	PL3 – PL1
ΔHR_NL (bpm)	T	4.20±5.83	7.24±10.35	19.73±14.84	10.39±12.80	3.04 (.364)	12.49 **(< .001*)**	15.53 **(< .001*)**
	N	3.25±4.05	5.20±10.63	18.45±13.41	8.97±12.08	1.95	13.25	15.20
	O	5.10±7.11	9.19±9.93	20.95±16.32	11.75±13.41	4.09	11.76	15.85
ΔHR_LM (bpm)	T	3.15±8.14	7.51±8.93	21.49±13.05	10.72±12.86	4.36 **(.032*)**	13.98 **(< .001*)**	18.34 **(< .001*)**
	N	4.30±7.10	4.70±9.13	21.05±13.38	10.02±12.75	.40	16.35	16.75
	O	2.05±9.05	10.19±8.05	21.90±13.04	11.38±13.03	8.14	11.71	19.85
ΔHR_S (bpm)	T	3.49±8.66	10.15±9.11	22.95±13.33	12.20±13.26	6.66 **(.003*)**	12.80 **(< .001*)**	19.46 **(< .001*)**
	N	3.50±9.26	9.60±8.53	22.70±11.52	11.93±12.61	6.10	13.10	19.20
	O	3.48±8.29	10.67±9.82	23.19±15.15	12.44±13.95	7.19	12.52	19.71

*Indicates significant at the .05 level. ‘PL’, 'T', 'N’, and 'O’ denote physical loading, total, normal-weight, and obese, respectively.

Table A.3: Tests of within and between subjects effects for perceived exertion (PE)

	P-value		
	Test of within subject effect		Test of between subject effect
	Physical loading	Physical loading * BMI	BMI group
PE_NL	**< .001***	.630	.460
PE_LM	**< .001***	.075	.363
PE_S	**< .001***	.989	.148

*Indicates significant at the .05 level. 'NL', 'LM' and 'S' denote Number-letter, Letter memory, and Stroop, respectively.

Table A.4: Mean, SD, mean difference, and pairwise comparison p-value for perceived exertion (PE)

		Mean ± SD				Mean difference (Pairwise comparison p-value)		
		PL1	PL2	PL3	Total	PL2–PL1	PL3 – PL2	PL3 – PL1
PE_NL	T	.71±.91	2.91±1.41	5.00±1.50	2.87±2.18	2.20 **(< .001*)**	2.09 **(< .001*)**	4.29 **(< .001*)**
	N	.70±1.06	2.68±1.26	4.90±1.52	2.76±2.15	1.98	2.22	4.20
	O	.71±.77	3.14±1.53	5.10±1.51	2.98±2.22	2.43	1.96	4.39
PE_LM	T	.73±.95	2.95±1.20	4.95±1.63	2.88±2.15	2.22 **(< .001*)**	2.00 **(< .001*)**	4.22 **(< .001*)**
	N	.30±.52	2.85±1.18	5.05±1.82	2.73±2.33	2.55	2.20	4.75
	O	1.14±1.09	3.05±1.24	4.86±1.46	3.02±1.98	1.91	1.81	3.72
PE_S	T	.71±.81	2.95±1.24	4.88±1.55	2.85±2.11	2.24 **(< .001*)**	1.93 **(< .001*)**	4.17 **(< .001*)**
	N	.48±.55	2.75±1.02	4.65±1.73	2.63±2.09	2.27	1.90	4.17
	O	.93±.97	3.14±1.42	5.10±1.38	3.06±2.12	2.21	1.96	4.17

*Indicates significant at the .05 level. ‘PL’, 'T', 'N’, and 'O’ denote physical loading, total, normal-weight, and obese, respectively.

Table A.5: Tests of within and between subjects effects for physical discomfort (PD)

	P-value		
	Test of within subject effect		Test of between subject effect
	Physical loading	Physical loading * BMI	BMI group
PD_NL	**< .001***	.180	.093
PD_LM	**< .001***	.129	.155
PD_S	**< .001***	.968	.053

*Indicates significant at the .05 level. 'NL', 'LM' and 'S' denote Number-letter, Letter memory, and Stroop, respectively.

Table A.6: Mean, SD, mean difference, and pairwise comparison p-value for physical discomfort (PD)

		Mean ± SD				Mean difference (Pairwise comparison p-value)		
		PL1	PL2	PL3	Total	PL2–PL1	PL3 – PL2	PL3 – PL1
PD_NL	T	.78±.94	2.87±1.47	4.44±1.67	2.70±2.05	2.09 **(< .001*)**	1.57 **(< .001*)**	3.66 **(< .001*)**
	N	.70±1.06	2.63±1.38	3.90±1.45	2.41±1.85	1.93	1.27	3.20
	O	.86±.84	3.10±1.55	4.95±1.74	2.97±2.20	2.24	1.85	4.09
PD_LM	T	.79±.99	2.68±1.21	4.56±1.66	2.68±2.02	1.89 **(< .001*)**	1.88 **(< .001*)**	3.77 **(< .001*)**
	N	.30±.52	2.63±1.31	4.04±1.96	2.44±2.18	2.33	1.41	3.74
	O	1.26±1.10	2.74±1.14	4.71±1.35	2.90±1.85	1.48	1.97	3.45
PD_S	T	.77±.86	2.85±1.48	4.21±1.63	2.61±1.96	2.08 **(< .001*)**	1.36 **(< .001*)**	3.44 (< .001*)
	N	.48±.55	2.50±1.24	3.88±1.70	2.28±1.87	2.02	1.38	3.40
	O	1.05±1.01	3.19±1.63	4.52±1.54	2.92±2.01	2.14	1.33	3.47

*Indicates significant at the .05 level. ‘PL’, 'T', 'N’, and 'O’ denote physical loading, total, normal-weight, and obese, respectively.

Table A.7: Tests of within and between subjects effects for mental workload (MW)

	P-value		
	Test of within subject effect		Test of between subject effect
	Physical loading	Physical loading * BMI	BMI group
MW_NL	**< .001***	.961	.611
MW_LM	**< .001***	.061	.885
MW_S	**< .001***	.428	.233

*Indicates significant at the .05 level. 'NL', 'LM' and 'S' denote Number-letter, Letter memory, and Stroop, respectively.

Table A.8: Mean, SD, mean difference, and pairwise comparison p-value for mental workload (MW)

		Mean ± SD				Mean difference (Pairwise comparison p-value)		
		PL1	PL2	PL3	Total	PL2–PL1	PL3 – PL2	PL3 – PL1
MW_NL	T	1.33±1.06	2.35±1.53	3.68±1.59	2.46±1.70	1.02 **(< .001*)**	1.33 **(< .001*)**	2.35 **(< .001*)**
	N	1.25±1.15	2.28±1.71	3.55±1.54	2.36±1.74	1.03	1.27	2.30
	O	1.41±.98	2.43±1.36	3.81±1.66	2.55±1.67	1.02	1.38	2.40
MW_LM	T	1.29±1.23	2.35±1.48	3.89±1.82	2.51±1.86	1.06 **(< .001*)**	1.54 **(< .001*)**	2.60 **(< .001*)**
	N	1.10±1.27	2.28±1.52	4.25±1.94	2.54±2.05	1.18	1.97	3.15
	O	1.48±1.19	2.43±1.47	3.55±1.67	2.48±1.67	.95	1.12	2.07
MW_S	T	.99±.93	2.45±1.53	3.44±1.48	2.29±1.67	1.46 **(< .001*)**	.99 **(< .001*)**	2.45 **(< .001*)**
	N	.85±.84	2.08±.89	3.35±1.39	2.09±1.47	1.23	1.27	2.50
	O	1.12±.1.00	2.81±1.91	3.52±1.60	2.48±1.83	1.69	.71	2.40

*Indicates significant at the .05 level. ‘PL’, 'T', 'N’, and 'O’ denote physical loading, total, normal-weight, and obese, respectively.

Appendix B. Figures for Manual Load Lifting/Lowering Task: ΔHR, PE, PD, and MW

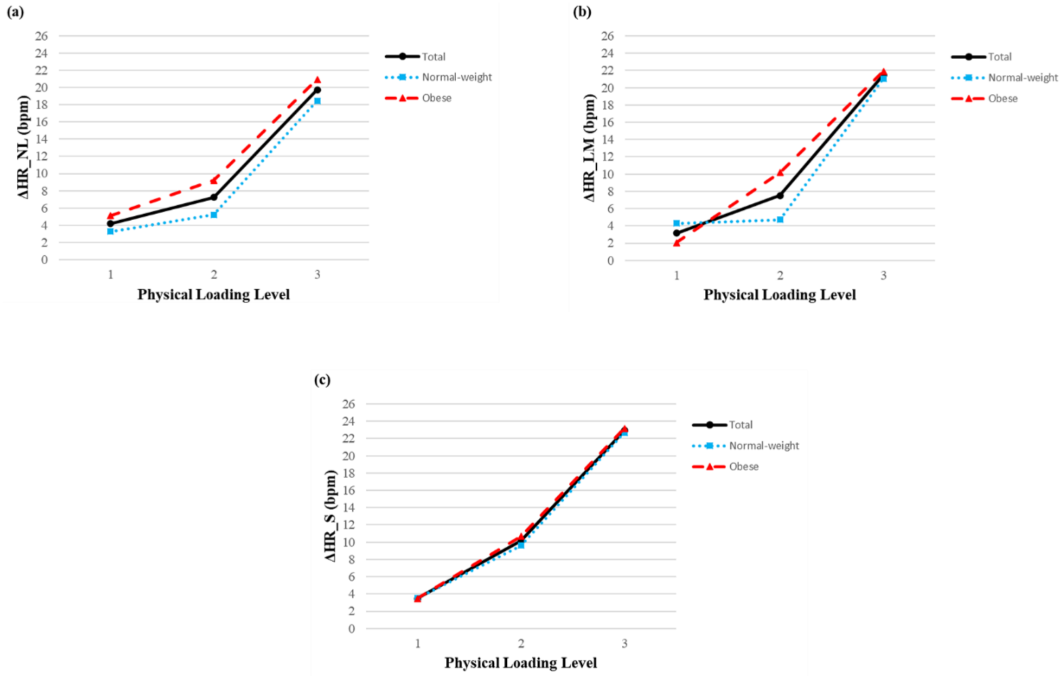

Figure B.1: Line graphs of ΔHeart Rate (ΔHR): (a) ΔHR_NL, (b) ΔHR_LM, and (c) ΔHR_S

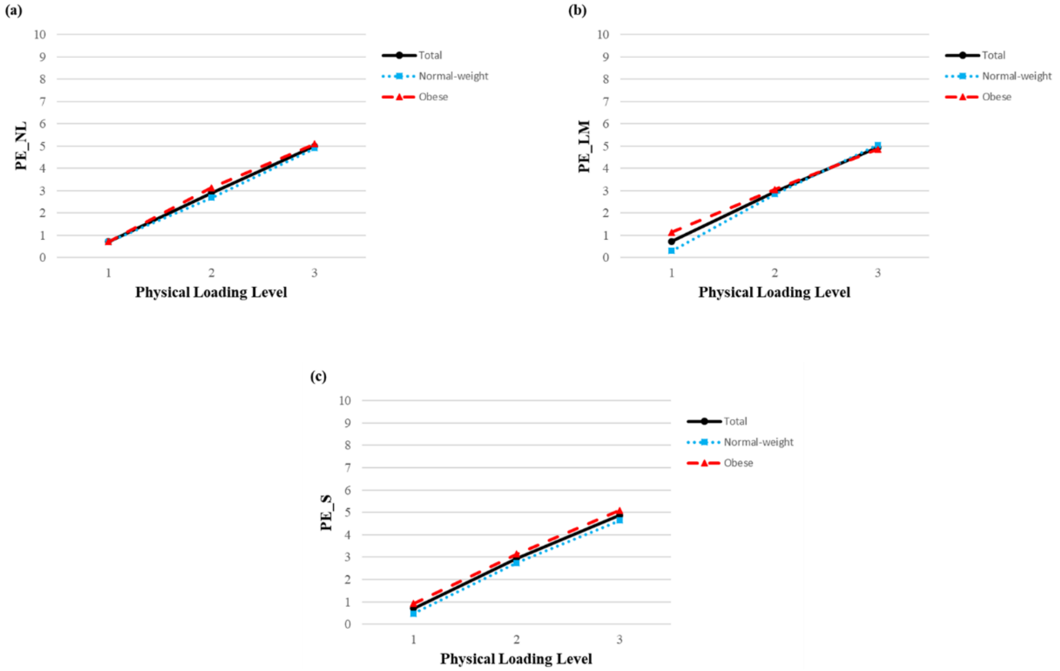

Figure B.2: Line graphs of perceived exertion (PE): (a) PE_NL, (b) PE_LM, and (c) PE_S

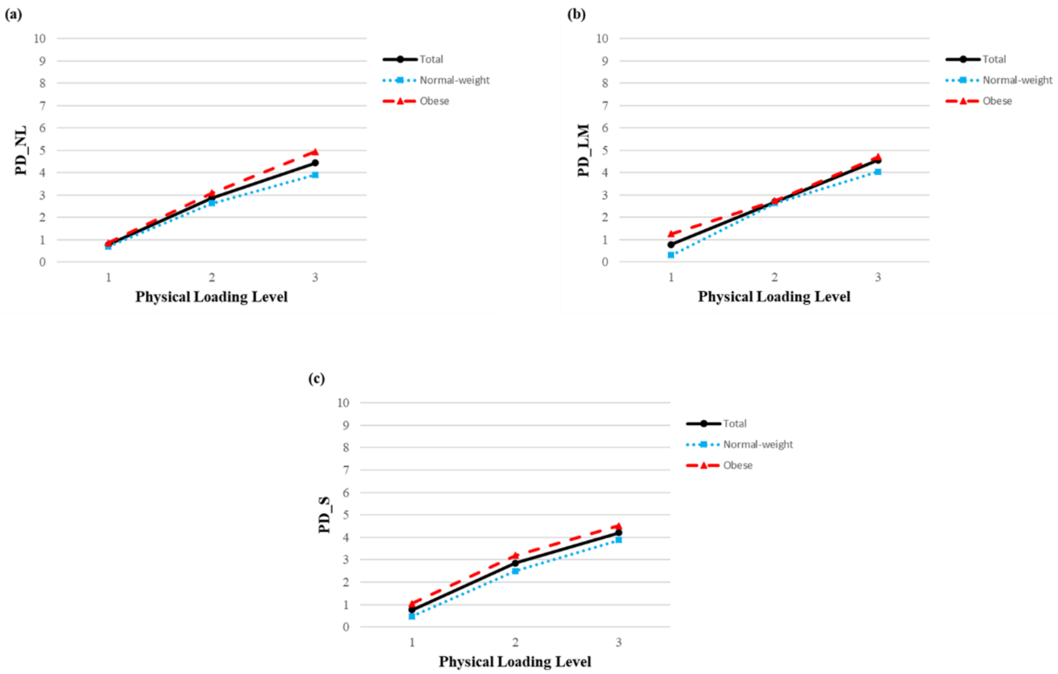

Figure B.3: Line graphs of physical discomfort (PD): (a) PD_NL, (b) PD_LM, and (c) PD_S

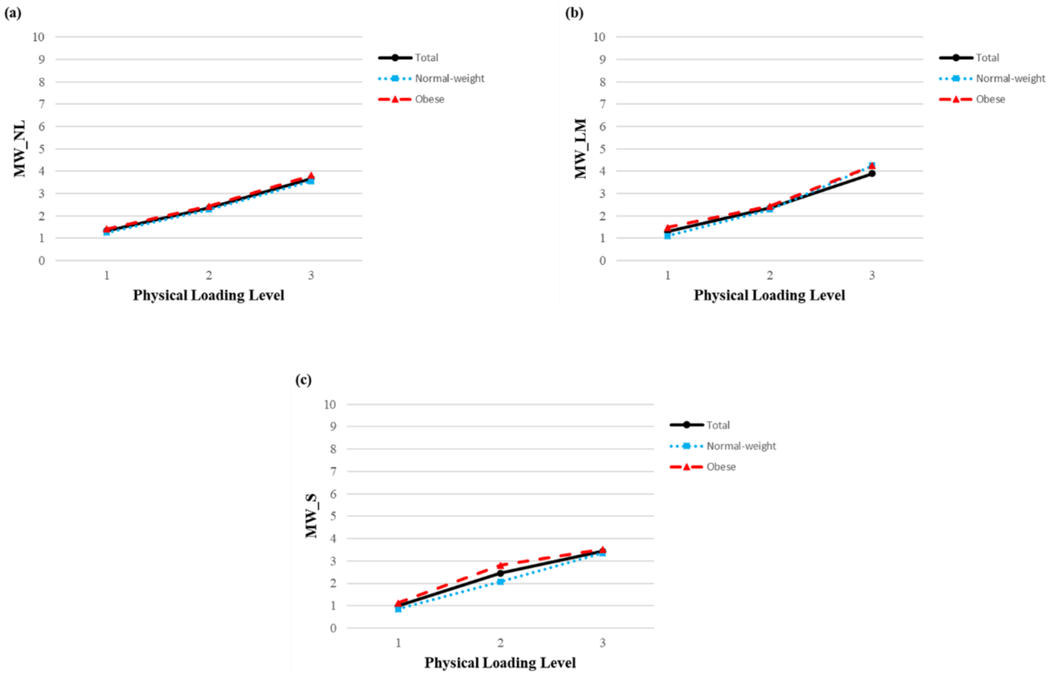

Figure B.4: Line graphs of mental workload (MW): (a) MW_NL, (b) MW_LM, and (c) MW_S

Appendix C. Tables for Postural Holding Task: Postural sway, ΔHR, PE, PD, and MW

Table C.1: Tests of within and between subjects effects for postural sway data

	P-value		
	Test of within subject effect		Test of between subject effect
	Postural loading	Postural loading * BMI	BMI group
Sway Path_NL (SP_NL)	**< .001***	**.010***	.254
Sway Path_LM (SP_LM)	**< .001***	**.002***	.064
Sway Path_S (SP_S)	**< .001***	**.028***	.110
Sway Area_NL (SA_NL)	**.015***	.230	.206
Sway Area_LM (SA_LM)	**.001***	.168	.093
Sway Area_S (SA_S)	**< .001***	.236	.133
Sway Maximal Amplitude_ML_NL (SMA_ML_NL)	**< .001***	.093	.145
Sway Maximal Amplitude_ML_LM (SMA_ML_LM)	**< .001***	.343	.135
Sway Maximal Amplitude_ML_S (SMA_ML_S)	**< .001***	.683	.061
Sway Maximal Amplitude_AP_NL (SMA_AP_NL)	**< .001***	.065	**.025***
Sway Maximal Amplitude_AP_LM (SMA_AP_LM)	**.001***	.064	**.021***
Sway Maximal Amplitude_AP_S (SMA_AP_S)	**< .001***	.059	**.004***

*Indicates significant at the .05 level. 'NL', 'LM', 'S', 'ML', and 'AP' denote Number-letter, Letter memory, Stroop, medio-lateral, and anterior-posterior, respectively.

Table C.2: Mean, SD, mean difference, and pairwise comparison p-value for sway path

		Mean ± SD				Mean difference (Pairwise comparison p-value)		
		PL1	PL2	PL3	Total	PL2–PL1	PL3 – PL2	PL3 – PL1
SP_NL (mm)	T	1248±547	2467±1130	2943±1309	2220±1262	1219 **(< .001*)**	476 (.104)	1695 **(< .001*)**
	N	1483±654	2224±845	2585±1021	2097±958	741 **(.011*)**	361 (.743)	1102 **(.002*)**
	O	1013±267	2711±1333	3302±1484	2342±1504	1698 **(< .001*)**	591 (.186)	2289 **(<. 001*)**
SP_LM (mm)	T	1318±435	2931±1048	3042±1226	2430±1242	1613 **(< .001*)**	111 (1.000)	1724 **(< .001*)**
	N	1451±437	2605±864	2610±761	2222±889	1154 **(< .001*)**	5 (1.000)	1159 **(< .001*)**
	O	1184±400	3258±1133	3473±1454	2638±1493	2074 **(< .001*)**	215 (.662)	2289 **(< .001*)**
SP_S (mm)	T	1182±433	2825±1277	2865±1171	2291±1290	1643 **(< .001*)**	40 (1.000)	1683 **(< .001*)**
	N	1282±441	2433±832	2608±916	2108±953	1151 **(.001*)**	175 (1.000)	1326 **(< .001*)**
	O	1082±412	3218±1526	3121±1354	2474±1543	2136 **(< .001*)**	-97 (1.000)	2039 **(< .001*)**

*Indicates significant at the .05 level. ‘PL’, 'T', 'N’, and 'O’ denote postural loading, total, normal-weight, and obese, respectively.

Table C.3: Mean, SD, mean difference, and pairwise comparison p-value for sway area

		Mean ± SD				Mean difference (Pairwise comparison p-value)		
		PL1	PL2	PL3	Total	PL2–PL1	PL3 – PL2	PL3 – PL1
SA_NL (mm^2)	T	689±1213	1137±949	1608±1802	1145±1409	448 **(.047*)**	471 (.407)	919 **(.028*)**
	N	804±1576	823±472	1299±1611	976±1328	19	476	495
	O	575±709	1450±1192	1917±1965	1314±1476	875	467	1342
SA_LM (mm^2)	T	915±1156	1649±1422	1814±1542	1459±1427	734 **(.016*)**	165 (1.000)	899 **(.009*)**
	N	922±1284	1276±1461	1386±1495	1195±1407	354	110	464
	O	907±1046	2022±1311	2242±1502	1724±1408	1115	220	1335
SA_S (mm^2)	T	361±304	1207±949	1396±1373	988±1071	846 **(<.001*)**	189 (.488)	1035 **(< .001*)**
	N	335±252	940±944	1144±1546	806±1095	605	204	809
	O	388±353	1474±898	1649±1158	1170±1024	1086	175	1261

*Indicates significant at the .05 level. ‘PL’, 'T', 'N’, and 'O’ denote postural loading, total, normal-weight, and obese, respectively.

Table C.4: Mean, SD, mean difference, and pairwise comparison p-value for sway maximal amplitude_ML (medio-lateral)

		Mean ± SD				Mean difference (Pairwise comparison p-value)		
		PL1	PL2	PL3	Total	PL2–PL1	PL3 – PL2	PL3 – PL1
SMA_ML_NL (mm)	T	22±24	34±16	44±24	34±23	12 **(.003*)**	10 **(.038*)**	22 **(< .001*)**
	N	24±28	29±14	37±21	30±22	5	8	13
	O	20±18	39±18	52±25	37±24	19	13	32
SMA_ML_LM (mm)	T	27±23	39±20	46±20	37±23	12 **(.045*)**	7 **(.043*)**	19 **(.001*)**
	N	27±24	34±22	40±21	34±23	7	6	13
	O	27±22	43±17	52±19	41±22	16	9	25
SMA_ML_S (mm)	T	18±16	35±19	44±21	33±21	17 **(< .001*)**	9 **(.002*)**	26 **(< .001*)**
	N	14±9	33±17	39±19	28±19	19	6	25
	O	23±20	38±21	49±22	37±23	15	11	26

*Indicates significant at the .05 level. ‘PL’, 'T', 'N’, and 'O’ denote postural loading, total, normal-weight, and obese, respectively.

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Table C.5: Mean, SD, mean difference, and pairwise comparison p-value for sway maximal amplitude_AP (anterior-posterior)

		Mean ± SD				Mean difference (Pairwise comparison p-value)		
		PL1	PL2	PL3	Total	PL2–PL1	PL3 – PL2	PL3 – PL1
SMA_AP_NL (mm)	T	32±16	50±20	45±22	42±21	18 **(< .001*)**	-5 (.523)	13 **(.012*)**
	N	30±16	40±11	42±22	37±18	10	2	12
	O	34±16	59±22	48±23	47±23	25	-11	14
SMA_AP_LM (mm)	T	39±21	54±23	50±21	47±22	15 **(.003*)**	-4 (.340)	11 **(.035*)**
	N	38±21	44±18	42±18	42±19	6	-2	4
	O	39±21	63±23	57±22	53±24	24	-6	18
SMA_AP_S (mm)	T	29±14	49±21	44±17	41±19	20 **(< .001*)**	-5 (.348)	15 **(< .001*)**
	N	25±12	39±14	42±17	35±16	14	3	17
	O	33±16	59±22	47±16	46±21	26	-12	14

*Indicates significant at the .05 level. ‘PL’, 'T', 'N’, and 'O’ denote postural loading, total, normal-weight, and obese, respectively.

Table C.6: Tests of within and between subjects effects for △Heart Rate（△HR)

	P-value		
	Test of within subject effect		Test of between subject effect
	Postural loading	Postural loading * BMI group	BMI group
ΔHR_NL	**< .001***	.173	**.004***
ΔHR_LM	**< .001***	.196	**.023***
ΔHR_S	**< .001***	.143	**.039***

*Indicates significant at the .05 level. ‘NL’, ‘LM’ and ‘S’ denote Number-letter, Letter memory, and Stroop, respectively.

Table C.7: Mean, SD, mean difference, and pairwise comparison p-value for ∆Heart Rate (∆HR)

		Mean ± SD				Mean difference (Pairwise comparison p-value)		
		PL1	PL2	PL3	Total	PL2–PL1	PL3 – PL2	PL3 – PL1
∆HR_NL (bpm)	T	2.31±6.12	16.50±13.26	22.69±13.45	13.83±14.24	14.19 **(< .001*)**	6.19 **(.013*)**	20.38 **(< .001*)**
	N	.62±5.80	11.05±13.24	18.67±9.61	10.11±12.36	10.43	7.62	18.05
	O	4.00±6.09	21.95±11.08	26.71±15.63	17.56±15.09	17.95	4.76	22.71
∆HR_LM (bpm)	T	1.69±5.06	14.76±15.40	21.67±15.15	12.71±15.18	13.07 **(< .001*)**	6.91 **(.003*)**	19.98 **(< .001*)**
	N	.24±4.21	11.81±15.34	16.14±9.96	9.40±12.62	11.57	4.33	15.90
	O	3.14±5.52	17.71±15.25	27.19±17.52	16.02±16.83	14.57	9.48	24.05
∆HR_S (bpm)	T	4.40±7.32	16.19±15.01	18.86±13.97	13.15±13.97	11.79 **(< .001*)**	2.67 (.901)	14.46 **(< .001*)**
	N	4.14±6.72	11.00±12.62	16.33±12.13	10.09±11.77	6.86	5.33	12.19
	O	4.67±8.04	21.38±15.68	21.38±15.48	15.81±15.51	16.71	0	16.71

*Indicates significant at the .05 level. ‘PL’, 'T', 'N’, and 'O’ denote postural loading, total, normal-weight, and obese, respectively.

Table C.8: Tests of within and between subjects effects for perceived exertion (PE)

	P-value		
	Test of within subject effect		Test of between subject effect
	Postural loading	Postural loading * BMI	BMI group
PE_NL	**< .001***	.072	**.008***
PE_LM	**< .001***	.311	**.017***
PE_S	**< .001***	.166	**.010***

*Indicates significant at the .05 level. 'NL', 'LM' and 'S' denote Number-letter, Letter memory, and Stroop, respectively.

Table C.9: Mean, SD, mean difference, and pairwise comparison p-value for perceived exertion (PE)

		Mean ± SD				Mean difference (Pairwise comparison p-value)		
		PL1	PL2	PL3	Total	PL2–PL1	PL3 – PL2	PL3 – PL1
PE_NL	T	1.12±1.33	5.05±1.68	5.95±1.77	4.04±2.64	3.93 **(< .001*)**	.90 **(.010*)**	4.83 **(< .001*)**
	N	.96±1.23	4.57±1.40	5.14±1.62	3.56±2.34	3.61	.57	4.18
	O	1.29±1.43	5.52±1.83	6.76±1.55	4.52±2.85	4.23	1.24	5.47
PE_LM	T	1.04±1.13	5.02±1.77	6.17±1.51	4.08±2.66	3.98 **(< .001*)**	1.15 **(< .001*)**	5.13 **(< .001*)**
	N	.86±1.23	4.48±1.47	5.67±1.56	3.67±2.49	3.62	1.19	4.81
	O	1.21±1.03	5.57±1.91	6.67±1.32	4.48±2.78	4.36	1.10	5.46
PE_S	T	1.19±1.46	4.98±1.79	6.00±1.48	4.06±2.60	3.79 **(< .001*)**	1.02 **(< .001*)**	4.81 **(< .001*)**
	N	1.05±1.46	4.33±1.68	5.43±1.40	3.60±2.40	3.28	1.10	4.38
	O	1.33±1.48	5.62±1.69	6.57±1.36	4.51±2.74	4.29	.95	5.24

*Indicates significant at the .05 level. ‘PL’, 'T', 'N’, and 'O’ denote postural loading, total, normal-weight, and obese, respectively.

Table C.10: Tests of within and between subjects effects for physical discomfort (PD)

	P-value		
	Test of within subject effect		Test of between subject effect
	Postural loading	Postural loading * BMI	BMI group
PD_NL	**< .001***	.055	**.016***
PD_LM	**< .001***	.195	**.010***
PD_S	**<. 001***	.066	**.012***

*Indicates significant at the .05 level. 'NL', 'LM' and 'S' denote Number-letter, Letter memory, and Stroop, respectively.

Table C.11: Mean, SD, mean difference, and pairwise comparison p-value for physical discomfort (PD)

		Mean ± SD				Mean difference (Pairwise comparison p-value)		
		PL1	PL2	PL3	Total	PL2–PL1	PL3 – PL2	PL3 – PL1
PD_NL	T	.96±1.26	4.57±1.95	5.38±1.86	3.64±2.57	3.61 **(< .001*)**	.81 **(.005*)**	4.42 **(< .001*)**
	N	.83±1.23	3.95±1.36	4.62±2.11	3.13±2.30	3.12	.67	3.79
	O	1.10±1.31	5.19±2.27	6.14±1.20	4.14±2.75	4.09	.95	5.04
PD_LM	T	1.04±1.18	4.57±1.91	5.83±1.86	3.81±2.64	3.53 **(< .001*)**	1.26 **(< .001*)**	4.79 **(< .001*)**
	N	.83±1.05	3.91±1.95	5.19±1.83	3.31±2.46	3.08	1.28	4.36
	O	1.24±1.28	5.24±1.67	6.48±1.69	4.32±2.73	4.00	1.24	5.24
PD_S	T	1.21±1.43	4.64±1.88	5.71±1.88	3.86±2.59	3.43 **(< .001*)**	1.07 **(< .001*)**	4.50 **(< .001*)**
	N	1.17±1.54	3.95±1.66	5.00±1.97	3.37±2.36	2.78	1.05	3.83
	O	1.26±1.34	5.33±1.88	6.43±1.50	4.34±2.73	4.07	1.10	5.17

*Indicates significant at the .05 level. ‘PL’, 'T', 'N’, and 'O’ denote postural loading, total, normal-weight, and obese, respectively.

Table C.12: Tests of within and between subjects effects for mental workload (MW)

	P-value		
	Test of within subject effect		Test of between subject effect
	Postural loading	Postural loading * BMI	BMI group
MW_NL	**< .001***	.110	**.014***
MW_LM	**< .001***	.197	**.037***
MW_S	**< .001***	.294	**.039***

*Indicates significant at the .05 level. 'NL', 'LM' and 'S' denote Number-letter, Letter memory, and Stroop, respectively.

Table C.13: Mean, SD, mean difference, and pairwise comparison p-value for mental workload (MW)

		Mean ± SD				Mean difference (Pairwise comparison p-value)		
		PL1	PL2	PL3	Total	PL2–PL1	PL3 – PL2	PL3 – PL1
MW_NL	T	1.57±1.40	3.74±2.01	5.00±2.05	3.44±2.32	2.17 **(< .001*)**	1.26 **(< .001*)**	3.43 **(< .001*)**
	N	1.36±1.49	3.19±2.09	4.14±2.24	2.90±2.26	1.83	.95	2.78
	O	1.77±1.31	4.29±1.82	5.86±1.42	3.98±2.27	2.52	1.57	4.09
MW_LM	T	1.81±1.54	4.11±2.05	5.11±2.05	3.67±2.34	2.30 **(< .001*)**	1.00 **(.012*)**	3.30 **(< .001*)**
	N	1.67±1.82	3.64±2.09	4.36±1.93	3.22±2.24	1.97	.72	2.69
	O	1.95±1.23	4.57±1.94	5.86±1.93	4.13±2.36	2.62	1.29	3.91
MW_S	T	1.55±1.39	3.83±1.92	4.79±1.97	3.39±2.23	2.28 **(< .001*)**	0.96 **(.001*)**	3.24 **(< .001*)**
	N	1.38±1.46	3.29±1.79	4.19±1.83	2.95±2.05	1.91	.90	2.81
	O	1.71±1.33	4.38±1.94	5.38±1.96	3.83±2.34	2.67	1.00	3.67

*Indicates significant at the .05 level. 'PL', 'T', 'N', and 'O' denote postural loading, total, normal-weight, and obese, respectively.

Appendix D. Figures for Postural Holding Task: Postural sway, ΔHR, PE, PD, and MW

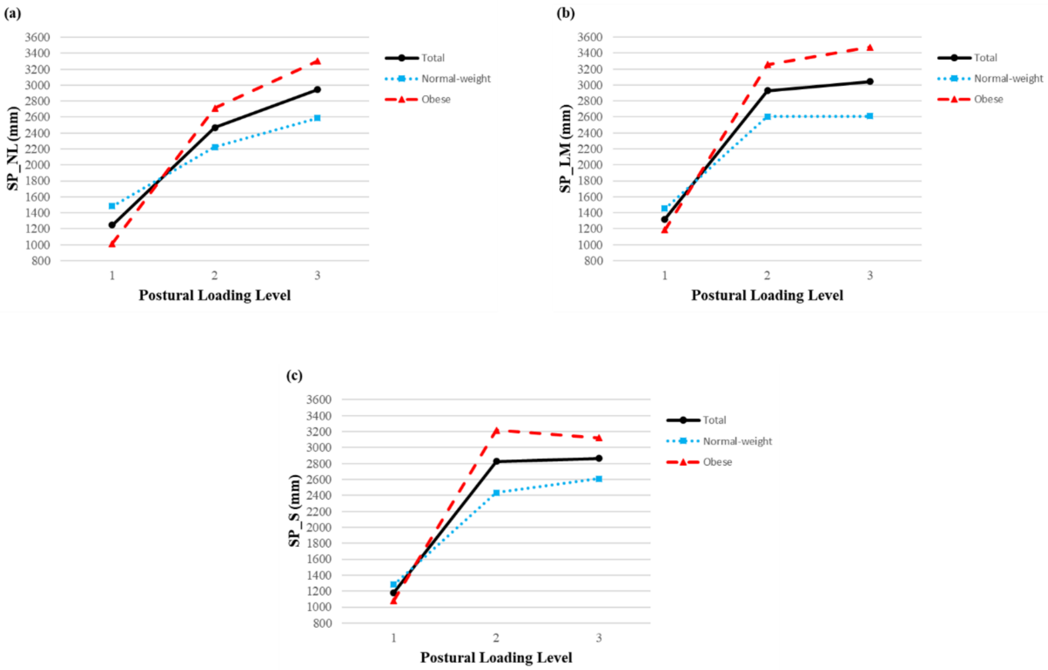

Figure D.1: Line graphs of sway path: (a) SP_NL, (b) SP_LM, and (c) SP_S

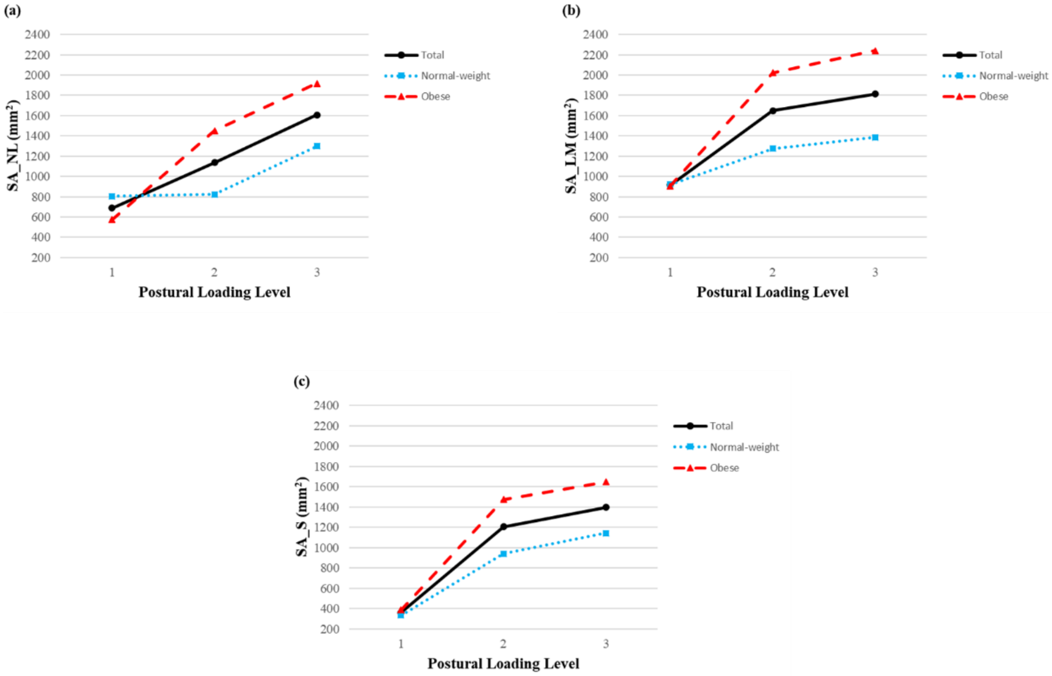

Figure D.2: Line graphs of sway area: (a) SA_NL, (b) SA_LM, and (c) SA_S

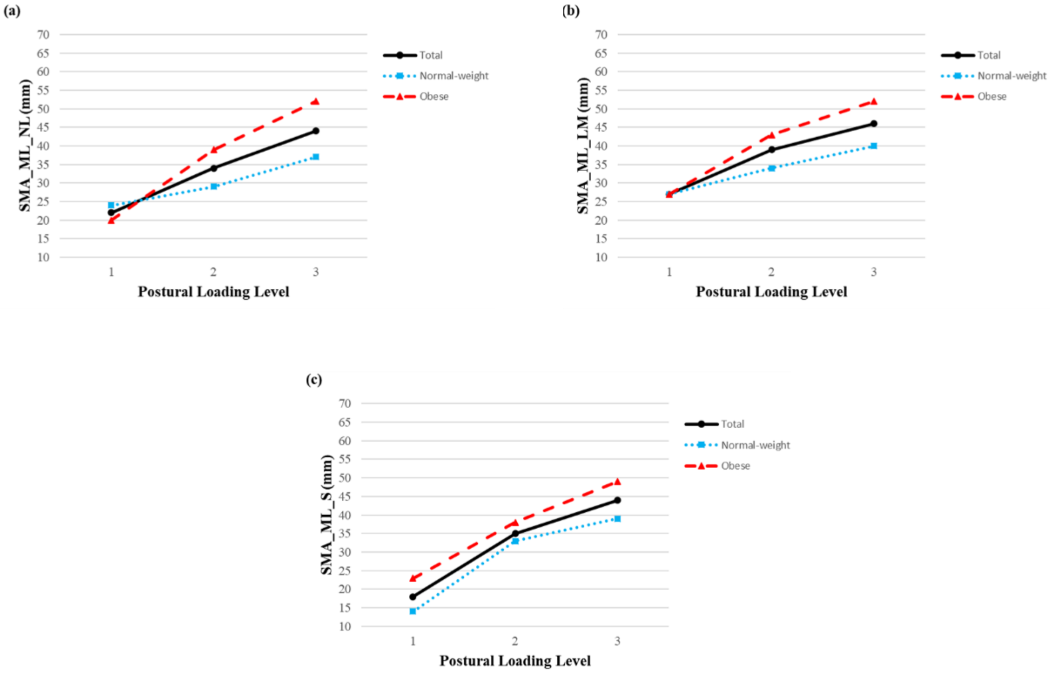

Figure D.3: Line graphs of sway maximal amplitude_ML (medio-lateral): (a) SMA_ML_NL, (b) SMA_ML_LM, and (c) SMA_ML_S

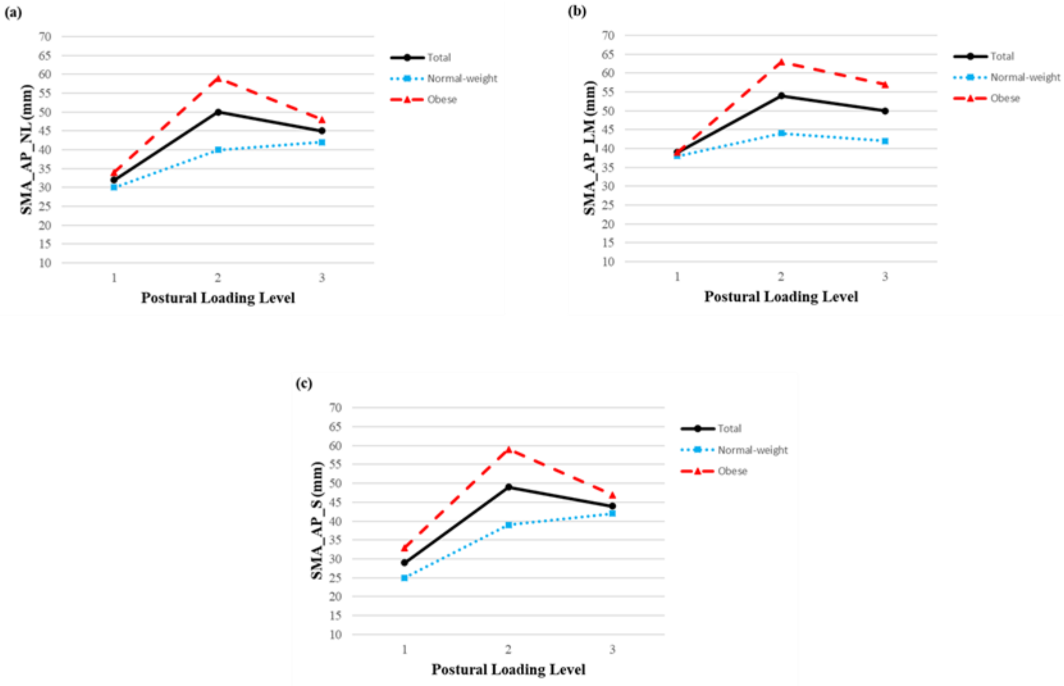

Figure D.4: Line graphs of sway maximal amplitude_AP (anterior-posterior): (a) SMA_AP_NL, (b) SMA_AP_LM, and (c) SMA_AP_S

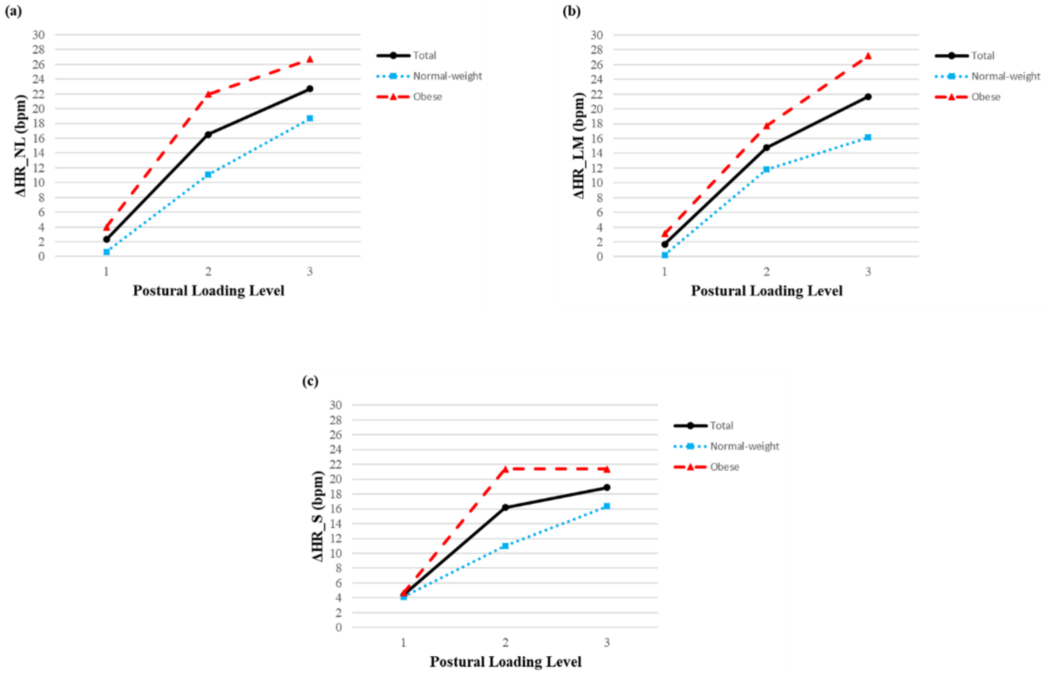

Figure D.5: Line graphs of △Heart Rate (△HR): (a) △HR_NL, (b) △HR_LM, and (c) △HR_S

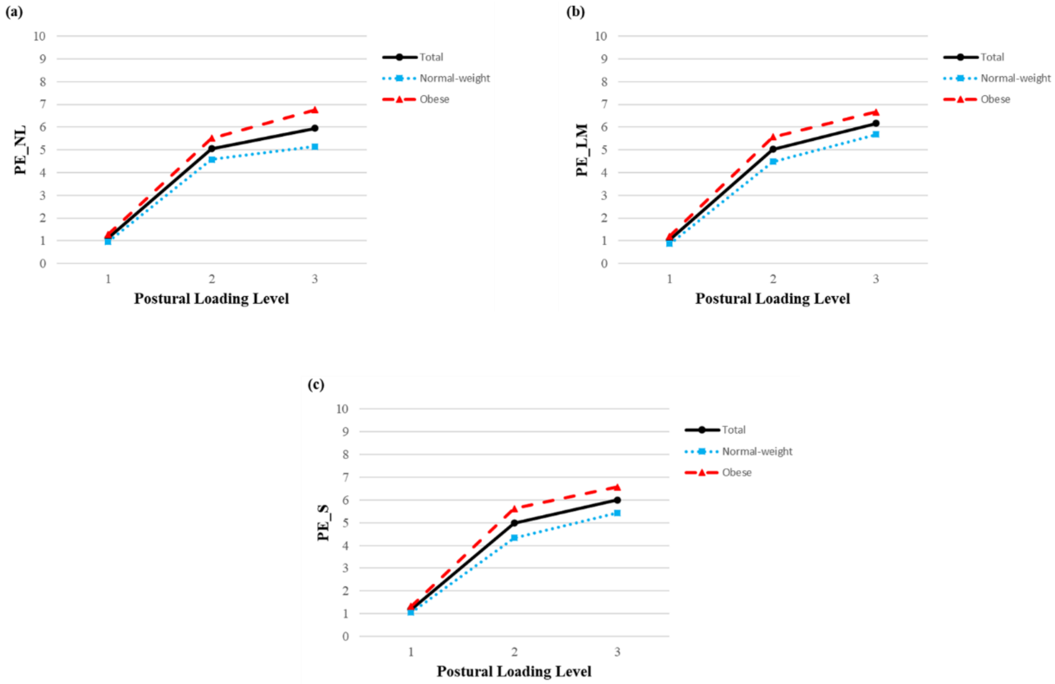

Figure D.6: Line graphs of perceived exertion (PE): (a) PE_NL, (b) PE_LM, and (c) PE_S

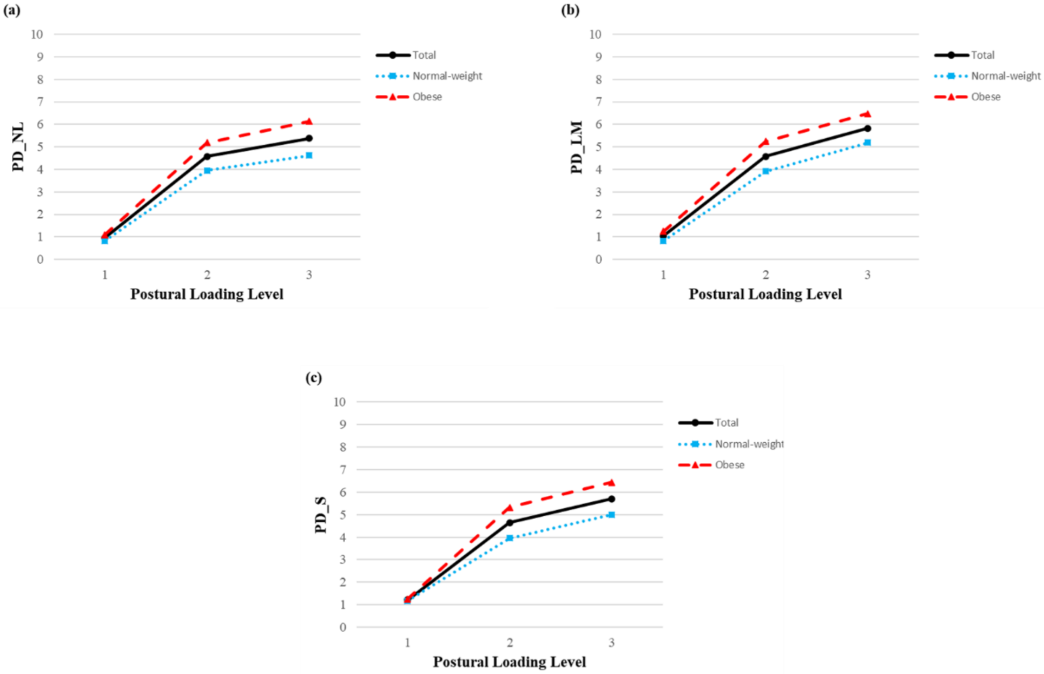

Figure D.7: Line graphs of physical discomfort (PD): (a) PD_NL, (b) PD_LM, and (c) PD_S

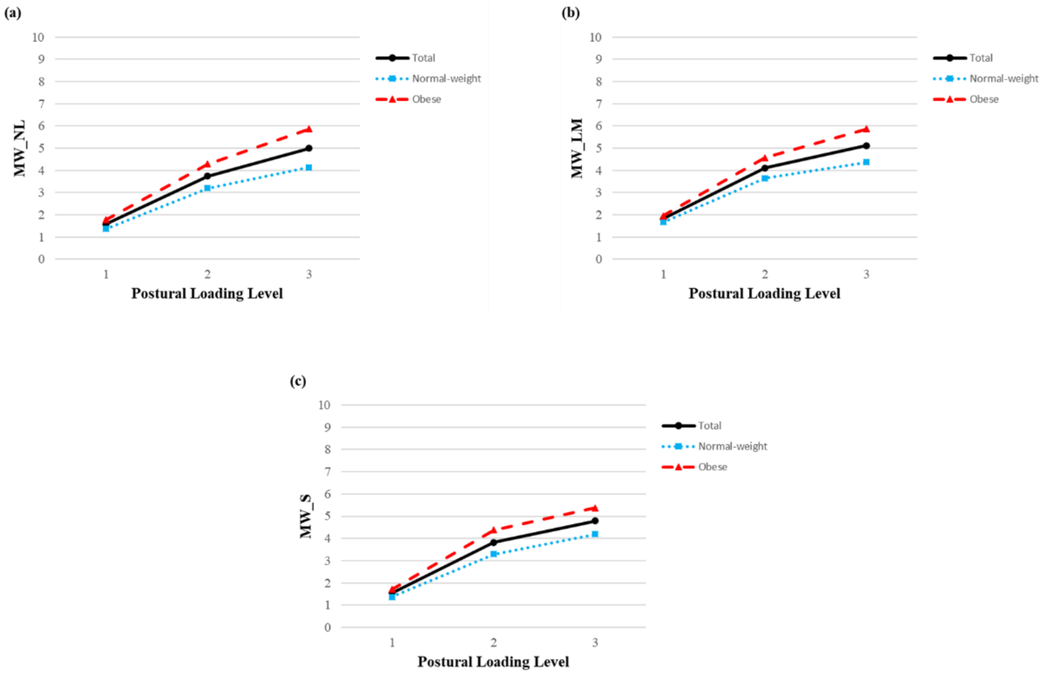

Figure D.8: Line graphs of mental workload (MW): (a) MW_NL, (b) MW_LM, and (c) MW_S

국 문 초 록

비만은 전 세계적으로 만연하고 있으며 미래에도 그 유행은 증가할 것으로 예상된다. 따라서 비만이 신체적 및 인지적 수행능력에 미치는 영향에 대해 연구하는 것은 필요하며, 그것은 잠재적인 산업 문제를 확인하고 해결하는 데에도 도움을 줄 수 있을 것이다. 신체적 인간공학 분야에서는 관절 가동 범위는 중요한 연구 주제이다. 왜냐하면 많은 일상 생활과 작업 활동은 신체 유연성에 영향을 받기 때문이다. 또한 많은 나라에서 노동 인구의 높은 비율이 과체중과 비만 인구이며, 이러한 비율은 미래에도 증가할 것으로 예상된다. 따라서 과체중과 비만이 신체 유연성에 미치는 영향에 대해 이해하는 것은 과체중과 비만인을 위한 다양한 제품과 시스템을 디자인하는 데에 도움을 줄 수 있으며, 산업 문제를 해결하는 데에도 도움을 줄 수 있다. 많은 일상 생활과 작업활동에서 인간은 육체적 과업 또는 자세를 유지하는 과업을 수행하면서 인지적 과업도 수행한다. 이러한 육체적/자세유지 과업과 인지적 과업은 동시에 또는 직후에 이루어진다. 그러므로 육체적/자세유지 과업과 인지적 과업과의 관계에 대해서 연구하는 것은 필요하다. 또한 육체적/자세적 부하가 있을 때 또는 가해진 직후에 비만이 인지수행능력에 미치는 영향에 대해서 연구하는 것도 필요하다. 왜냐하면 비만은 전 세계적으로 만연하고 있으며 미래에도 그 유행은 증가할 것으로 예상되기 때문이다.

위에서 언급한 중요성에도 불구하고, 비만이 신체적 및 인지적 수행능력에 미치는 영향에 대한 이해는 아직 부족하다. 비만이 관절 가동범위에 미치는 영향에 관한 과거 연구는 대부분 신체의 많은 관절들 중에서 일부분만 선택하여 연구를 실시 하였으며, 또한 과체중과 비만 인구 중에서 일부분에 집중하여 연구를 실시하였다. 육체적/자세 부하가

인지수행능력에 미치는 영향에 관한 분야에서는 육체적/자세 부하가 있을 때 또는 가해진 직후에 비만이 인지수행능력에 미치는 영향에 관한 연구는 거의 없었다. 따라서 본 연구의 목적은 비만이 관절 가동범위에 미치는 영향과 육체적/자세 부하가 있을 때 또는 가해진 직후에 비만이 인지수행능력에 미치는 영향에 관해 파악하는 것이다. 이러한 연구 목적을 달성하기 위해서 3가지 주요 연구가 수행되었다.

연구 1에서는 과체중과 비만이 관절 가동범위에 미치는 영향에 대해서 파악하였다. 관절 가동범위에 관한 공용데이터를 분석하였다. 세개의 BMI 그룹(정상체중, 과체중, 비만)이 통계적으로 비교 분석 되었다. 과체중과 비만 그룹은 정상체중 그룹에 비하여 elbow flexion, elbow supination, hip extension, hip flexion, knee flexion, ankle plantarflexion에서 통계적으로 유의미하게 작은 관절 가동범위를 보였다. 과체중과 비만 그룹은 관절 가동범위에서 knee flexion을 제외하고 통계적으로 유의미한 차이가 없었다. Knee flexion에서는 과체중과 비만 그룹 사이에서 통계적으로 유의미한 차이가 있었다.

연구 2에서는 육체적 과업을 수행한 직후에 비만이 인지수행능력에 미치는 영향에 대해서 파악하였다. 수동으로 올리기/내리기 과업이 육체적 과업으로 선정되었다. 비만 그룹은 BMI에 근거하여 두 개의 그룹(정상체중, 비만)으로 나누었다. 인지적 과업에서는 실행 기능(Executive functions)에서 핵심적인 세가지 기능(shifting, updating, inhibition)이 선정되었다. Shifting, updating, inhibition을 측정하기 위해서 숫자-글자 검사(Number-letter task), 글자 기억 검사(Letter memory task), 스트룹 검사(Stroop task)가 사용되었다. 1개의 트라이얼(Trial)은 육체적 과업과 인지적 과업의 조합을 세 번 반복하는 것으로 구성되었다. 실행 기능은 적당한 강도의 육체적 부하가 가해진 직후에 약간 향상되었고, 심한 강도의 육체적 부하가 가해진 직후에는 감소하였다. 또한 실행 기능에 관한 육체적 부하 효과에서 정상체중과 비만 그룹은 서로 다른

패턴을 보였다. 육체적 부하 강도 1에서는 비만 그룹과 정상체중 그룹의 실행 기능에는 서로 차이가 없었다. 적당한 강도의 육체적 부하가 가해진 직후에 정상체중 그룹의 실행 기능은 통계적으로 유의미하게 향상되었지만 비만 그룹에는 그러한 향상이 없었다.

연구 3에서는 자세유지 과업을 수행할 때 비만이 인지수행능력에 미치는 영향에 대해서 파악하였다. OWAS에 근거한 세 개의 자세가 자세유지 과업으로 선정되었다. 자세유지 과업을 할 때 실험참여자는 Force plate 위에서 자세를 유지하도록 하였으며, 압력 중심점(center of pressure, CoP)의 신호가 자세 동요(postural sway) 데이터를 얻기 위하여 수집되었다. 비만 그룹은 BMI에 근거하여 두 개의 그룹(정상체중, 비만)으로 나누었다. 인지적 과업에서는 실행 기능(Executive functions)에서 핵심적인 세가지 기능(shifting, updating, inhibition)이 선정되었다. Shifting, updating, inhibition을 측정하기 위해서 숫자-글자 검사(Number-letter task), 글자 기억 검사(Letter memory task), 스트룹 검사(Stroop task)가 사용되었다. 1개의 트라이얼(Trial)은 30초의 자세유지 과업과 90초 동안 자세 유지 및 인지적 과업을 동시해 수행하는 것으로 구성되었다. 실행 기능은 일반적으로 자세 부하가 있을 때 감소하는 경향을 보였다. 또한 실행 기능에 관한 자세 부하 효과에서 정상체중과 비만 그룹은 서로 다른 패턴을 보였다. 자세 부하가 강도 1에 2로 올라갈 때는 비만 그룹의 실행 기능은 통계적으로 유의미하게 감소되었지만 정상체중 그룹에는 그러한 감소가 없었다. 자세 부하가 강도 2에서 3으로 올라갈 때는 정상 그룹과 비만 그룹 모두 실행 기능이 감소하였지만, 비만 그룹이 더 두드러지게 감소하였다.

위에서 언급한 발견은 비만이 관절 가동범위에 미치는 영향에 관한 이해 뿐만 아니라 육체적/자세 부하가 있을 때 또는 가해진 직후에 비만이 인지수행능력에 미치는 영향에 관한 이해를 향상 시켰다. 연구 1에서 제공한 지식은 비만 인을 위한 작업 과업(올리기, 내리기, 물자 운반 작업) 및

제품/시스템(자동차, 워크스테이션, 가구)의 인간공학적 디자인에 유용할 것이다. 또한 연구 1에서 제공한 지식은 다양한 사이즈의 인간을 대표하는 정교한 디지털 휴먼 모델 개발에 대한 가이드라인을 제공할 수 있을 것이다. 연구 2 및 3의 발견은 일상 생활과 작업 활동에서 인간공학적 가이드라인을 제공하는데 도움을 줄 수 있을 것이다. 육체적/자세 부하와 관련된 인지수행능력의 변화는 작업 환경 및 일상 생활에서 반드시 고려되어야 한다. 특히 작업 환경에서는 안전 뿐만 아니라 작업 생산성을 위해서는 심한 강도의 육체적/자세 부하를 반드시 피해야 한다. 인지수행능력이 감소하면 작업 생산성이 감소할 수 있다. 또한 육체적/자세 부하에 있을 때 정상 체중과 비만 그룹이 실행 기능에서 서로 다른 패턴을 보이는 것도 반드시 고려되어야 한다. 특히 비만인에게는 심한 강도의 육체적/자세 부하 뿐만 아니라 적당한 강도의 육체적/자세 부하도 피하는 것이 필요하다.

주요어: 비만, 관절 가동범위, 실행 기능, 육체적 부하, 자세 부하

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