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Ergonomics Studies on Foot Reach Tasks for Obese Individuals

비만인의 발 도달 작업에 관한 인간공학 연구

2022 년 7 월

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Abstract

Ergonomics Studies on Foot Reach Tasks for Obese Individuals

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Obesity is prevalent worldwide and the obese population continues to increase. Therefore, research is needed to find out the impacts of obesity in basic tasks, and, it could help with ergonomic design in the workplace. Existing ergonomic studies have examined the basic physical abilities of obese people, such as walking and balancing. Through an understanding of the physical capabilities of obese individuals, it is possible to design a workplace that is suitable for obese individuals. Foot reach work is a basic movement that occurs frequently in the workplace. In light of the results of

ergonomic research related to obesity, it is possible that the foot reach task will exhibit a different result.

Despite the importance mentioned above, understanding how obesity impacts physical performance and discomfort rating is still insufficient. Particularly, no studies have been found that have examined the effects of obesity on foot reach. Therefore, this study aims to investigate the impact of obesity on foot reach and develop a method to improve the performance of obese groups. To accomplish the objectives, three major studies were conducted.

In the study 1, the impact of obesity was investigated in the foot target reach in a seated position. Task performance and discomfort rating data were analyzed. The differences between the participant groups (non-obese, obese) were compared statistically. It was found that the obese group had a statistical difference from the non-obese group in reaction time, movement time, and task completion time. In terms of discomfort rating, there was no significant difference between the obese and the non-obese group.

In the study 2, the impact of obesity in standing posture was investigated as an expanding study of study 1. In the standing position, the movement time decreased, but the reaction time increased. There was no significant interaction effect between participant group and posture factors. Foot reach in a seated position was more uncomfortable. As a result of task performance time analysis, a significant interaction effect between posture and target distance was observed.

In the study 3, a study was conducted to propose the prediction model. It describes the possible range of foot reach for workers using the existing prediction model. Task performance time data is used to present an area that optimizes the foot reach task of obese/non-obese workers. It was found that obese people have a smaller foot reach area.

The above-mentioned findings investigate the impact of obesity on foot reach task and provide an understanding that helps design workplaces for obese people. Based on the findings from study 1, it was possible to understand how obesity affects foot reach in a seated position. The findings provided in the study 2 would be helpful to provide an understanding of the possible changes in performance in standing posture. The results of study 3

provide inspiration for workplace improvements for obese workers. For obese workers, it is possible to propose increasing the size of the target where the reduced foot reach performance is evident.

Keywords: Obesity, foot operation, foot reach, perceived discomfort

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Chapter 1

Introduction

1.1 Research Background

The obesity rate in the global population has steadily increased over the past 40 years, and, currently, more than a half billion people are estimated to be obese (Hales et al. 2017; Vidra et al. 2019; WHO statistics 2020). The prevalence of obesity is also reflected in the worker population (Hertz et al. 2004). In the United States, over a quarter of all workers were classified as obese (Caban et al. 2005; Gu et al. 2014; Luckhaupt et al. 2014).

The prevalence of obesity has been linked to various occupational health problems. Gates et al. (2008) reported that obese workers suffered more pain in the same work environment and had a higher absenteeism rate compared to non-obese workers. It has been observed that obese workers submit more insurance claims for work-related injuries than those who are normal weight (Østbye et al. 2007; Pollack et al. 2007). The annual medical cost attributable to obesity among full-time employees in the U.S. was estimated to be over $70 billion in 2006 (Finkelstein et al. 2010). Obesity has also been linked with decreased work productivity (Gates et al. 2008; Lehnert et al. 2013; Nigatu et al. 2016; Schmier et al. 2006). Gates et al. (2008), Schmier et al. (2006) and Lehnert et al. (2013) reported that obesity-related costs had increased steadily through decrease in work productivity such as absenteeism rate. Nigatu et al. (2016) reported that obesity was associated with lower work functioning, and, obese workers experienced higher physical and cognitive demands than non-obese in the same workplace.

The obesity-associated problems above are thought to be in part due to the lack of considerations on the unique characteristics of the obese worker population in the design of work tasks. Developing relevant knowledge that informs the work task design is crucial for accommodating the obese workforce in the workplace and also ensuring the quality of work life for them.

Despite past research efforts, however, there still exist many knowledge gaps concerning the obese worker population and the work task design for them. One such knowledge gap pertains to the impacts of obesity on the performance and physical stresses of foot-operated work tasks. Foot-operated work tasks have long been an important research topic in ergonomics and are an integral part of various work activities, including driving (Beh and Hirst 1999; Collet et al. 2010; Mortimer 1974; Park et al. 2000; Young et al. 2011), heavy machinery operations (Yadav and Tewari 1998) and manufacturing machine operations (Corlett and Bishop 1978). Many studies have investigated factors that affect foot movement time, which is a major work performance measure, and have modelled the relationship between target-related parameters, such as target width and target distance, and performance (Chan and Chan 2009; Chan and Hoffmann 2015; Chan and Ng 2008; Drury 1975; Hoffmann 1991; Park and Myung 2012; Rohr 2006; Warshawsky-Livne and Shinar 2002). Despite the importance, however, few previous studies seem to have examined the impacts of obesity in the context of foot-operated work tasks – the authors are not aware of any.

1.2 Research Objectives

This study investigated the obesity effects on foot reach task. 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 the impact of obesity on performance and discomfort rating in seated foot reach,
- Study 2) To examine the effects of posture and obesity were compared and analyzed.
- Study 3) To suggest the possible foot reach range for obese/non-obese individuals. In order to develop the prediction model, the regression equation was employed.

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, obesity effect on seated foot reach were examined. In the study 2, The effect of obesity on foot reach not only in seated posture but also in standing posture was investigated. In the study 3, a possible foot reach range for obese/non-obese people was proposed. 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. Furthermore, the overall structure of the dissertation was described.

In Chapter 2, a review of existing ergonomics studies related to obesity was conducted. Also, previous studies related to foot target research and studies related to balance control were reviewed. Existing research related to the reach envelope model has also been presented.

In Chapter 3, obesity effects on task performance and discomfort ratings during seated reach were examined. Target distance and target direction were used as experimental variables. Two participant groups (non-obese, obese) were statistically compared in task performance and discomfort ratings.

In Chapter 4, the effects of obesity and posture on target reach task were investigated. The effect of obesity on foot reach in a standing position was investigated. Two participant groups (non-obese, obese) were statistically compared in task performance and discomfort ratings.

In Chapter 5, a foot movement time prediction model was developed. The possible working range has been determined based on the employee's posture and obesity levels.

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
• Literature Review on Foot Target Reach Task
• Literature Review on Reaction time

Chapter 3. Obesity effects on seated foot reaches
• Two Participants Group (obese and non-obese)
• Movement Distance and Movement Direction
• Movement Time, Reaction Time, Task Performance Time and Discomfort Ratings

Chapter 4. The effects of obesity and posture on foot reach tasks: task performance and perceived discomfort
• Two Participants Group (obese and non-obese)
• Movement Distance, Movement Direction and Posture (sitting and standing)
• Movement Time, Reaction Time, Task Performance time and Discomfort Ratings

Chapter 5. Models for predicting standing and seated foot target reach movement times of obese and non-obese operators
• Regression equation
• Optimal Range to Prevent Injury

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

Figure 1.1: The overall structure of the dissertation

Chapter 2

Literature Review

2.1 Obesity Effects on Physical Function and Performance

Research has been conducted to support the work task design for the obese workforce. The obesity studies concerning physical work capacity investigated how obesity impacts body flexibility and muscle strength, which are the general characteristics of the musculoskeletal system (Chaffin, 2006).

Ramachandran et al. (2006), Park et al. (2010) and Jeong et al. (2018) found that the Range of Motion (RoM) of the obese group was smaller on some joint motions than the non-obese population. The RoM reduction of the obese group was more remarkable for those joint movements that cause interference between fat tissues. Cavuoto (2013) investigated the impacts of obesity on muscle endurance tasks. The absolute muscle strength of the obese group was greater than that of the non-obese group, but the relative power of the obese group was smaller than that of the non-obese group.

Ramachandran (2006) found the impacts of obesity on joint motions and its impact are not uniform across all joint motions. Xu et al. (2008) examined the effect of obesity on the lifting task, which showed significant differences in the kinematics of the trunk when the obese group performed the lifting task. It was observed that the obese group used a lifting pattern which overloaded the joints. In a study by Kitagawa and Miyashita (1978), it was found that the obese group generates less power in proportion to Lean Body Mass (LBM) than the non-obese group, which is known to be associated with muscle strength. The study argued that the reason for the result was the obese people being less active than the non-obese people. Lafortuna et al. (2005) examined the effect of obesity on muscle strength. The researcher found that the isotonic muscle strength of quadriceps was higher in the obese group than in the non-obese group, but there is no difference in the muscle strength of pectorals. Maffiuletti et al. (2007) compared the quadriceps' muscle strength of the obese group to that of the non-obese group.

In this study, there was no difference in muscle strength in proportion to LBM, which was due to the strengthened quadriceps muscles by the increased body weight. Most of the obesity-related ergonomics studies concluded that the main reason for the decrease in physical work capacity in the obese group is the increased joint moments due to the fat masses attached to each body part.

The studies on work-related physical stresses examined the impacts of obesity on postural discomfort and biomechanical stresses during manual tasks. Park et al. (2009) examined the difference of body discomfort ratings in various work postures between the obese and the non-obese. In this study, there was a statistically significant difference in the discomfort score between the obese group and the non-obese group. The obese reported higher degree of discomfort than the non-obese. Park and the colleagues argued that the obese group may have experienced greater levels of discomfort because of the body mass of the obese group imposing a greater burden in maintaining posture than the non-obese group. Singh et al. (2015) investigated the obesity effect in the lifting task and found that the L5/S1 compression force of the obese group exceeded the NIOSH standard of 3400N. This result suggests that the current NIOSH standards may not fully accommodate the obese population and an appropriate cut-off criterion for the obese people should be established. Most studies concluded that the obese group showed more discomfort than the non-obese group when they take the posture.

The studies on physical task performance examined how obesity impacts human motion and work performance. Pataky et al. (2014) examined the function capacity of walking, balancing, and sit-to-stand movement for obese women. Experimental results showed that the obese group had a slower walking speed and a larger sit-to-stand time. There was no significant difference in the balancing performance. Berrigan et al. (2008) investigated the effect of obesity on arm target reach task performance in standing and seated. In the study, the obese subjects showed a significantly higher movement time during standing than the non-obese subjects. Regarding this result, Berrigan argued that the obese people seem to have lower arm movement performance due to the additional workload being consumed in balance control while standing. Singh et al. (2009) studied the effect of obesity on postural control performance in prolonged standing. The obese group showed more postural sway and a sharper increase in postural sway over time than the non-obese population. Singh and the colleagues argued that additional fat may make postural control more difficult, making balancing tougher for the obese people. Researches on the impact on physical task performance concluded that the task performance of the obese decreased compared to that of the non-obese.

2.2 Literature Review on Foot Target Reach Task

Foot-operated work tasks have long been an important research topic in ergonomics and are an integral part of various work activities, including driving (Beh and Hirst 1999; Collet et al. 2010; Mortimer 1974; Park et al. 2000; Young et al. 2011), heavy machinery operations (Yadav and Tewari 1998) and manufacturing machine operations (Corlett and Bishop 1978). Research on foot-operated work was similar to the research on hand-operated work, mostly focusing on accommodating work-site design variables and adjusting design variables for safety.

Many studies have investigated factors that affect foot movement time, which is a major work performance measure, and have modelled the relationship between target-related parameters, such as target width and target distance, and performance (Chan and Chan 2009; Chan and Hoffmann 2015; Chan and Ng 2008; Drury 1975; Hoffmann 1991; Park and Myung 2012; Rohr 2006; Warshawsky-Livne and Shinar 2002). Studies on foot-operated work studies have identified factors that affect foot movement time, which is a major work performance measure, and modeled the relationship between the factors and performance.

The early research study that developed a foot movement time model was suggested by Drury (1975). Drury’s model is based on the Fitts’ law (Fitts, 1954), which states that the reach task performance time is predicted by task’s index of difficulty, which is calculated by the distance and the width of the target in the target selection task. Drury's results show that under low difficulty conditions, movement time is proportional to the distance to the target, without being affected by the width of the target. Drury argued that the reason for this result was that foot motion under low difficulty conditions caused ballistic movement that did not require visual processing time. Rohr (2006) found that the impact of gender on foot movement time The experimental results showed that men have faster movement times than women for target reach tasks with higher task difficulty. Warshawsky-Livne & Shinar, D. (2002) investigated the effects of uncertainty, transmission type, driver age and gender on the brake time. The study results showed that age affects brake-reaction time. Gender did not affect the brake-reaction time, but brake-movement time, which is the travel time from the accelerator pedal to the brake pedal, was significantly affected. The male drivers showed shorter brake-movement time than the female driver.

Hoffmann (1991) investigated the change in movement time according to pedal placement between the accelerator pedal and the brake pedal, and compared the findings with the experimental results of Drury (1975). In a study by Chan and Ng (2008), the difference in movement time between the seated posture and the standing posture in the lateral foot movement was found. In this experiment, the lateral foot movement time in the seated posture was greatly increased. Chan and Ng argued that the faster movement times with standing posture was explained by the different muscles used for the two postures.

Chan and Hoffmann (2015) summarized the preceding foot movement experiments and compared the effects of factors related to foot movement such as the direction of movement and posture when start to move. The reason why longer movement time during standing was explained that the different muscles were activated between seated and standing. Park and Myung (2012) argued that the existing movement time prediction model underestimates the exercise time because the real foot movement trajectories are not straight lines, but arcs. To summarize the previous studies, the foot movement time model is suggested by Drury and it is a significant-level prediction model based on the distance between the target and the width of the target.

Fitts (1954) applied the information theory to the human motor system and proposed a theory that predicts human movement. Fitts focused on hand movement, and Drury (1975) applied Fitts' research to confirm that Fitts' theory applies to foot-pedal design. The core of the Fitts paradigm is that the target factors determine a person's movement time. The strength of Fitts' research is that it is possible to predict human movements at a very high level with one variable called the Index of Difference. Some researchers have proposed an expansion model that more precisely predicts movement time based on hand movement direction as a potential extension of the Fitts study (Murata and Iwase 2001; Cha and Myung 2013). Chan and Hoffmann (2015) comprehensively analyzed how the Fitts law for each posture changes foot movement.

Foot-based interaction is also receiving much attention in the HCI field. In most cases, foot-based interaction is considered an auxiliary role for hand-based interaction, which is doing complex tasks. Although there are studies that define the form of foot-based interaction (Rovers and Van Essen 2006; Pearson and Weiser 1986), most foot-based studies are limited to effortless movements. For the study of foot-based interaction, a study was conducted to find out the structure of the human lower body. The lower body can walk, foot reaches, and so on due to various joint movements. Studies on ankle, knee, and hip joints were conducted, and movement of each joint was defined. Velloso et al. (2015) summarized the gestures that can come out of the foot interaction through an overall review of the foot gesture.

2.3 Literature Review on Reaction time

The time delay between the presentation of sensory input and the matching behavioral response is referred to as reaction time. For simple reaction time, Donders (1868) was the first researcher, demonstrating that a simple reaction time is faster than a recognition reaction time and that the choice reaction time is the longest. Several studies have examined the effect of expanding the number of possible stimuli in recognition and choice trials. In choice reaction time studies, Hick (1952) discovered that response was proportional to log(N), where N is the number of various possible stimuli. Type of stimulus was also one of the many studies covered. Many studies have found that reaction times to sound are faster than reaction times to light, with mean auditory reaction rates of 140-160 milliseconds and visual reaction times of 180-200 milliseconds (Galton, 1890; Welford 1980; Brebner and Welford 1980).

There have also been many studies on various factors affecting reaction time. Arousal, or state of attention, including muscle tension, is one of the most studied elements influencing reaction time. Reaction time is quickest with an intermediate degree of arousal and slows when the person is either too calm or tense (Welford 1980). Age is also known as a factor that affects reaction time. Simple reaction time shortens from infancy to the late 20s, then steadily grows till the 50s and 60s, and then rapidly lengthens when the person reaches his 70s and beyond. (Welford 1977; Rose et al. 2002).

In addition, it is generally known that men have a faster reaction time than women. According to Bellis (1933), the average time to press a key in reaction to light was 220 milliseconds for males and 260 milliseconds for females; for sound, the difference was 190 milliseconds (males) to 200 milliseconds (females). Welford (1980) discovered that when a subject is tired, his reaction time slows. Singleton (1953) found that the deterioration due to fatigue is more pronounced when the response time task is complex.

There have also been studies showing that distraction increases reaction time. Richard et al. (2002) and Lee et al. (2001) investigated that college students given a simulated driving task had higher reaction times when given a simultaneous auditory task. According to Hsieh et al. (2007), simulated vibration of a computer monitor increased reaction times to stimuli presented on the monitor, worsened mistake rates, and increased visual fatigue. The impact of distraction may vary depending on one's emotional state and previous experiences.

Chapter 3

Obesity Effects on Seated Foot Reaches

3.1 Introduction

This study began after investigating ergonomic studies on obese people. As mentioned above, many ergonomic studies have been conducted on obese people, but recently, there have not been many research trends. As the proportion of obese people has increased due to recent changes in eating habits, research on obese people has once again become important. In order to conduct research on ergonomics related to obese people, many reviews were conducted on ergonomics related to office work. Most of the studies focused on the posture of workers, but there were not many studies that linked dynamic motion and obesity factors in daily life. Most of the existing obesity-related studies were related to the movement of the upper body. Most of the research focused on the task of manipulating objects through the upper body, such as hand reach, grasp, etc. Although lower body movement is also important, there have been no studies examining the relationship between existing lower body movement and obesity factors. Therefore, it was judged that a simple foot approach experiment could provide insight into the ergonomic understanding of obese people.

The purpose of this study was to investigate the impacts of obesity on the task performance and physical comfort level during a simple foot target reach task in order to address the current lack of knowledge. During a laboratory study, obese and non-obese participants completed a simple foot target reach task under 12 different conditions. Reaction time, movement time, task performance time and discomfort ratings were selected as dependent variables of the experiment study. Statistical analyses were conducted to test the research hypotheses below:

H1) The mean reaction time for the seated foot target reach task would be longer for obese than for non-obese individuals,

H2) The mean movement time for the seated foot target reach task would be longer for obese than for non-obese individuals,

H3) The mean task performance time for the seated foot target reach task would be longer for obese than non-obese individuals,

H4) The mean perceived discomfort rating for the seated foot target reach task would be higher for obese than non-obese individuals

H5) There is an interaction effect between the participant group and other target variables on reaction time.

H6) There is an interaction effect between the participant group and other target variables on movement time.

H7) There is an interaction effect between the participant group and other target variables on task performance time.

H8) There is an interaction effect between the participant group and other target variables on discomfort rating.

3.2 Research Methods

3.2.1 Study Participants

Two participant groups, defined in terms of body mass index (BMI), were considered in recruiting the study participants: non-obese (BMI < 25 kg/m^2) and obese (BMI ≥ 30 kg/m^2). A total of 34 participants, 15 obese males and 19 non-obese males, were recruited. During the participant recruitment process, only individuals who were free of obvious neurological and musculoskeletal disorders were considered. None of the participants had prior experience in a job that involved foot operation of controls. The study participants were recruited through internet advertisements. The study participants were paid for their study participation.

Table 3.1: Summary of demographic data for the two participant groups

Dimensions	obese (n=15)	non-obese (n=19)
	Mean±SD	Mean±SD
Age (years)	32.5 ± 8.4	31.6 ± 10.6
Height (cm)	173.2 ± 6.0	174.5 ± 6.4
Body mass (kg)	101.3 ± 14.3	70.7 ± 7.5
BMI (kg/m^2)	33.7 ± 4.1	23.2 ± 1.9

3.2.2 Experimental Task and Conditions

The participants performed a set of seated foot target reach trials. Prior to the beginning of a foot reach task trial, each participant was seated upright on a stool. The stool height was adjusted such that the torso-thigh and knee included angles of the participant were approximately 90 degrees. The right foot was placed on a start position (a start pedal) defined on the floor (see Figure 3.2 for the description of the experimental setup).

A computer monitor screen was placed in front of the participant. The computer monitor screen signalled the beginning of a task trial by displaying a red rectangle at its center. At the presentation of the start signal, the participant was instructed to perform the required foot reach trial as quickly as possible - a foot reach trial required pressing a target pedal placed at one of 12 target positions on the floor.

The target pedal was placed on the designated target position prior to each trial. The 12 target positions were combinations of 3 movement distances (17 cm, 34 cm, and 51 cm) and 4 movement directions (left-diagonal, forward, right-diagonal, and right lateral). The Index of Difficulties of all targets used in the experiment were less than 3, which was expected to induce ballistic movements according to Gan and Hoffman (1988).

For each target position, each participant conducted 2 foot reach trials; therefore, each participant performed a total of 24 foot reach trials. The presentation order of the 24 foot reach trials was randomized for each participant. The time between the onset of each trial (each monitor screen signal) was 1 minute. The total duration to complete the entire protocol was less than 30 minutes.

Rating	Description
0	Rest
1	Very, very easy
2	Easy
3	Moderate
4	Somewhat hard
5	Hard
6	
7	Very hard
8	
9	
10	Maximal

Figure 3.1: Borg CR 10 scale

3.2.3 Data Collection and Analyses

For each task trial, reaction, movement and task performance times were collected. Reaction time was defined as the time duration between the time when the visual stimulus appeared on the computer monitor screen and the time when the participant started to take his foot off the start pedal. Movement time was defined as the duration between the time when the participants started to move and the time when he successfully reached and pressed the target pedal. Task performance time was defined as the sum of the reaction and movement times. Additionally, each participant subjectively evaluated the level of discomfort associated with each foot reach trial. A modified 10-point discomfort rating scale from Borg (See Figure 3.1) was employed.

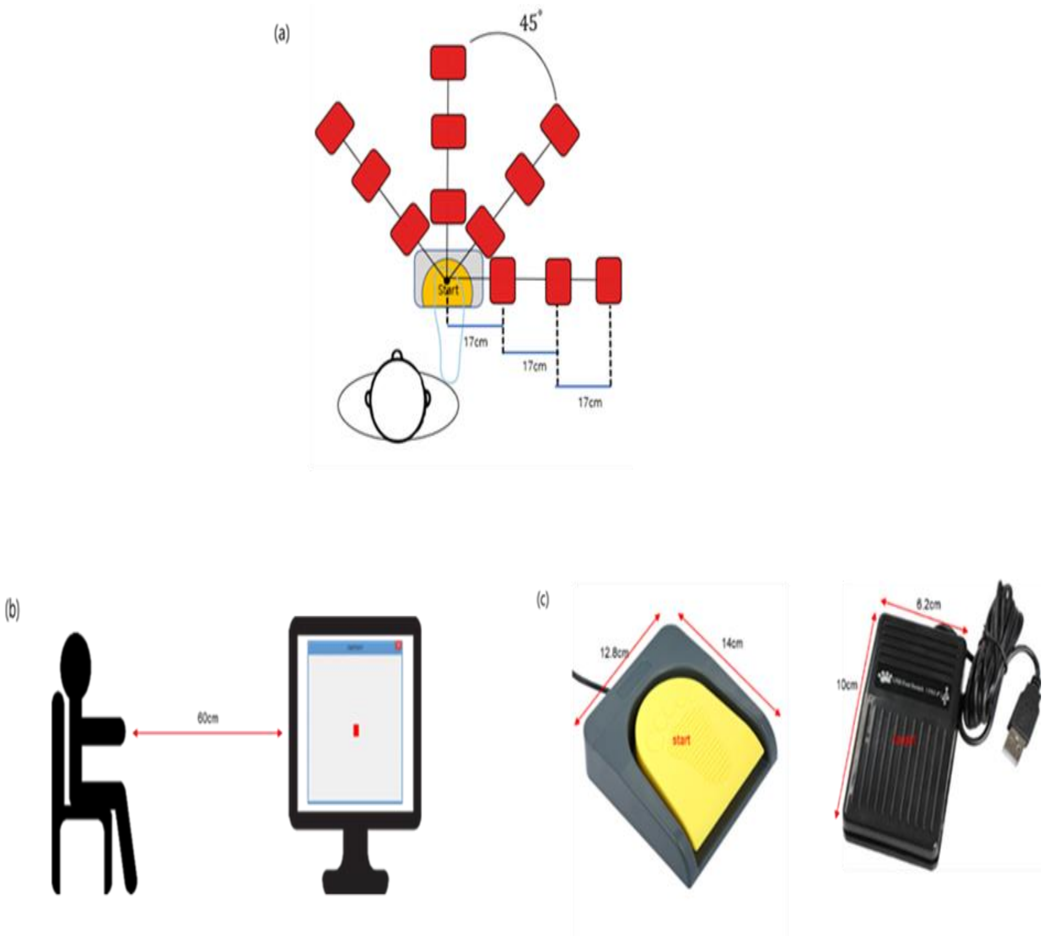

Figure 3.2: Experimental set-up: (a) start and 12 target positions (4 movement directions × 3 movement distances), (b) monitor screen location, (c) width and height dimensions of start and target pedals

The independent variables of the study were movement direction (4 levels), movement distance (3 levels), and participant group (2 groups). The objective dependent measures were: movement time, reaction time and performance time (sum of reaction and movement times). The subjective dependent measure was discomfort rating. The objective dependent measures were recorded using a computer program developed in-house using Visual Basic for Applications in Excel. After finishing each trial, the participants conducted subjective discomfort rating using the discomfort rating scale. ANOVAs were conducted to test the effects of the independent variables and their interactions on each of the dependent variables. Post-hoc Bonferroni tests were performed for a series of pairwise comparisons. The Bonferroni correction was used for the pairwise comparisons. All statistical tests were conducted at an alpha level of 0.05 using SPSS 23.0 (SPSS INC., Chicago, USA).

3.3 Results

3.3.1 Main Effects on Movement Time

Figures 3.3(a)-3.3(c) present the factor level means for each of the three independent variables, respectively. The three main factors, that is, participant group, movement distance and movement direction, were found to have significant effects on movement time. None of the interactions was found to be significant.

3.3.2 Main Effects on Reaction Time

Figures 3.4(a)-3.4(b) present the factor level means for each of the three independent variables, respectively. None of the interactions was found to be significant.

3.3.3 Main Effects on Task Performance Time

Figures 3.5(a)-3.5(b) present the factor level means for each of the three independent variables, respectively. None of the interactions was found to be significant.

3.3.4 Main Effects on Discomfort ratings

Figures 3.6(a) and 3.6(b) present the factor level means for movement distance and movement direction, respectively. Movement distance and movement direction were found to have significant effects on mean discomfort rating. No significant mean difference was found between the two participant groups. None of the interactions were found to be significant.

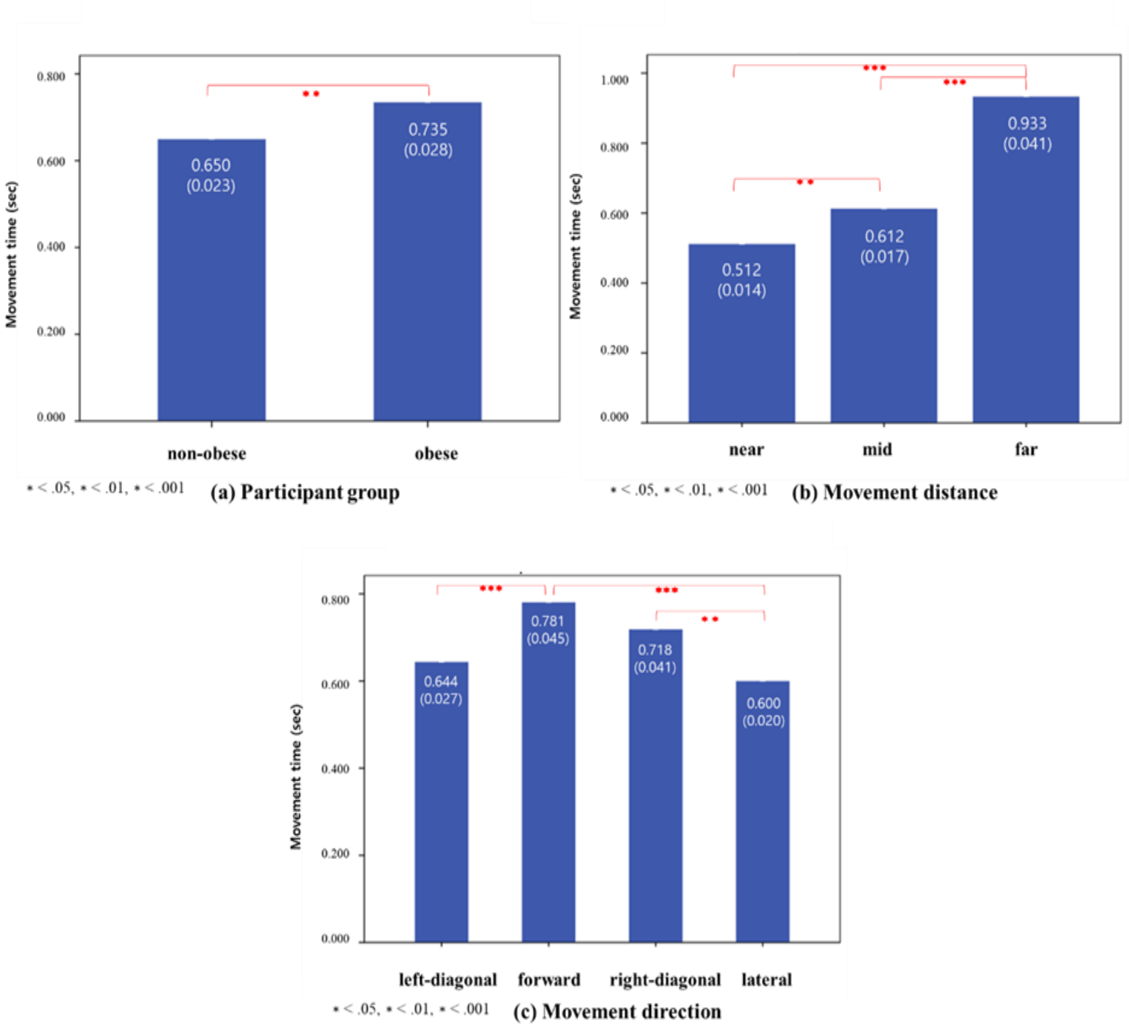

Figure 3.3: Main effects on movement time: (a) participant group, (b) movement distance, (c) movement direction

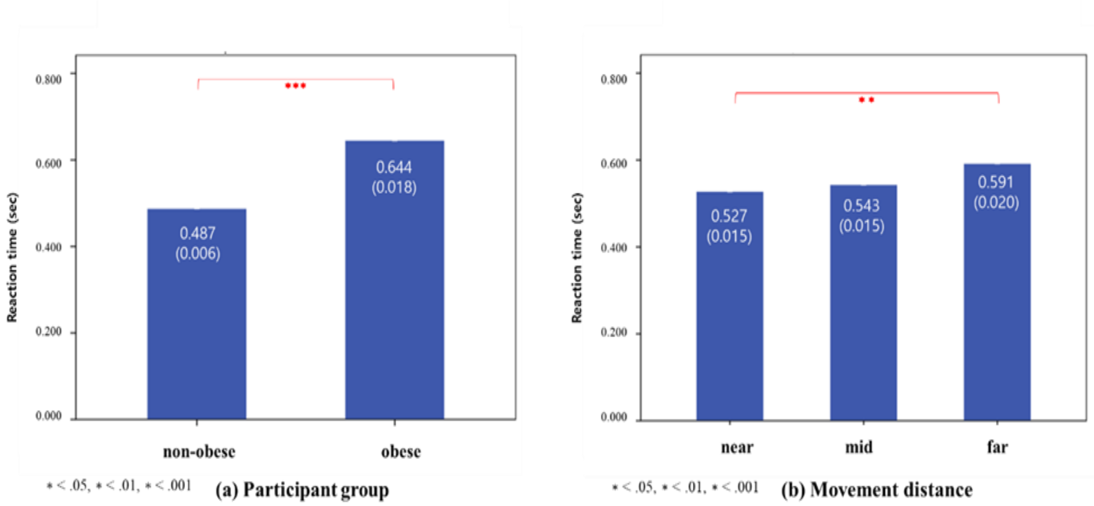

Figure 3.4: Main effects on reaction time: (a) participant group, (b) movement distance

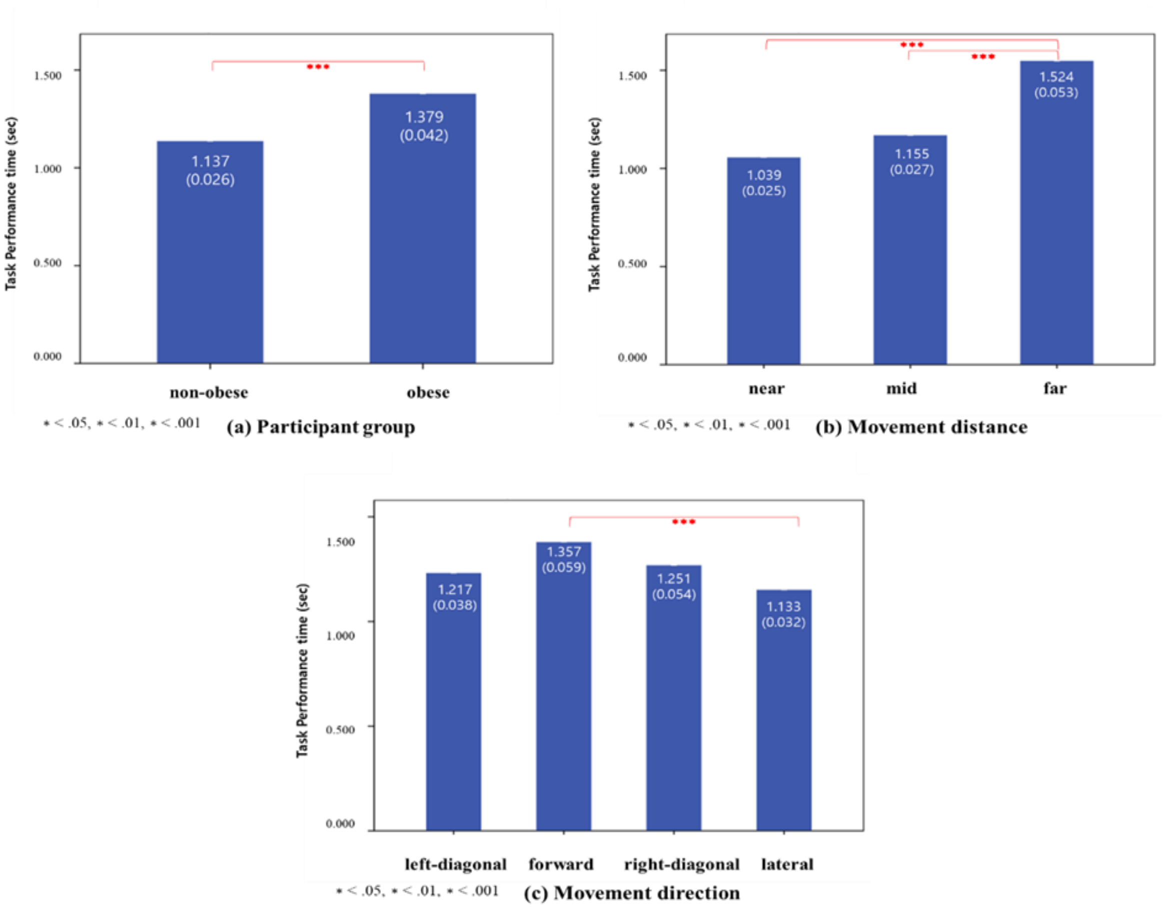

Figure 3.5: Main effects on task performance time: (a) participant group, (b) movement distance, (c) Movement direction

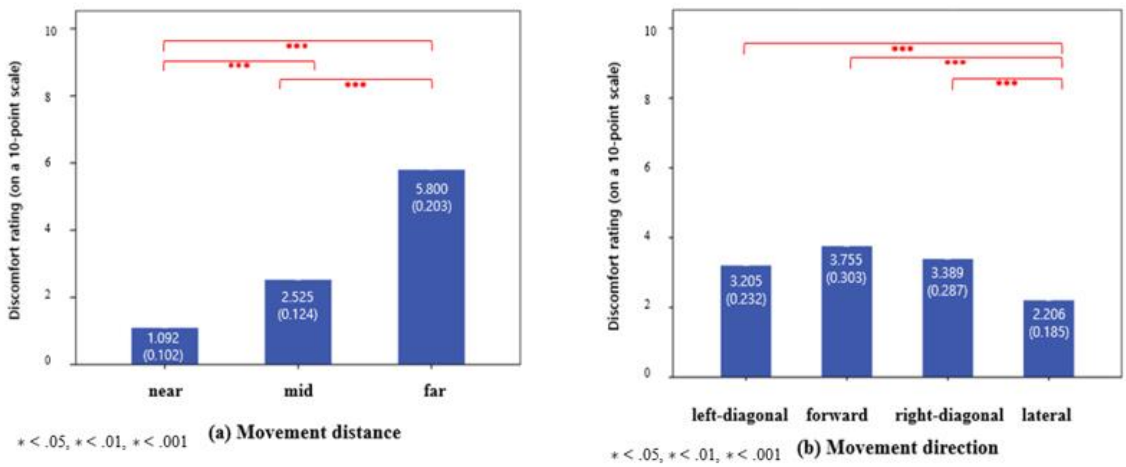

Figure 3.6: Main effects on discomfort ratings: (a) movement distance, (b) movement direction

3.4 Discussions

The current study empirically examined the obesity effects on task performance and perceived discomfort during seated foot reach. Movement time, reaction time, task performance time and discomfort rating were measured in this study. In each task trial, reaction, movement, and task performance times were recorded. The response time was defined as the period of time between the time when the visual stimulus appeared on the computer monitor and when the participant began to lift his foot from the pedal. The movement time was defined as the period of time between the time the participants started moving and reached and pressed the target pedal successfully. The total task performance time was calculated by summing the reaction and movement times. In addition, each participant subjectively evaluated the level of discomfort associated with each of the foot reach trials. An adaptation of Borg (1990) discomfort rating scale was used.

For movement time, all of the three independent variables, participant group, movement distance and movement direction, were found to be significant while no significant interaction effects were identified (Figure 3.2): the obese group had a larger mean movement time than the non-obese group; the mean movement time increased as movement distance increased; the forward direction was associated with the longest mean movement time while the lateral direction, the shortest.

From a simple physics standpoint, the observed obesity-associated increase in movement time can be logically attributed to the extra fat mass in the obese body. According to the definition of mass and relatedly that of moment of inertia in the classical mechanics, the extra fat mass has the effect of decelerating a human motion.

It should be noted that the decelerating effect of the extra fat mass might have been counteracted by increasing joint moments and thus internal muscle forces. However, such counteraction was likely to be difficult for many of the obese participants as it would require sufficiently large muscular strengths. Obesity has been associated with reduced muscular strength and muscle quality – Cavuoto and Nussbaum (2013) reported that the mean relative strength (strength per unit body mass) of obese participants was smaller than that of non-obese; Kitagawa and Miyashita (1978) found that obese individuals had lower strength values per kg of Lean Body Mass (LBM) than non-obese; Park et al. (2006) found that the strength per unit of regional muscle mass of obese participants was significantly lower that of non-obese. The decrease in muscle quality has been attributed to intermuscular and intramuscular adipose tissues (Hilton et al. 2008; Yoshida et al. 2012).

Even for the obese participants with enough muscular strengths, it is likely that some of them consciously or unconsciously chose to not counteract the decelerating effect of the extra fat mass but increase movement time because the counteraction would increase the biomechanical stresses during the foot reaches. In fact, some of the obese participants, in addition to increasing movement time, might have adopted movement patterns that reduce the biomechanical stresses - relatedly, Duvigneaud et al. (2008) and Xu et al. (2008) have shown that obese individuals utilize such motion strategies during manual lifts. However, in this study, kinematic motion data were not collected, and, therefore, it was not possible to verify this possibility.

Another possible reason for the observed obesity-associated increase in movement time is the obesity-associated joint RoM reductions. Jeong et al. (2018) reported that pre-obesity and obesity were associated with joint RoM reductions for hip extension and flexion, knee flexion and ankle plantar flexion. Among the joint motions, hip flexion and ankle plantar flexion were involved in the foot reach trials examined in this study. The RoM reductions may have reduced the possible range of joint angle-time trajectories during foot reaches, and, therefore, may have adversely impacted minimizing movement time. Relatedly, some studies have shown a positive correlation between RoM and physical performance during sports activities (Behm et al. 2016; Young et al. 2006).

Finally, the observed obesity impact on movement time could be related to brain changes linked with obesity (Mehta and Shortz 2014; Alosco et al. 2014; Walther et al. 2010). D'Hondt et al. (2008) and Gentier et al. (2013) reported that obesity negatively influences not only gross but also fine motor control, and, suggested that obesity compromises information processing and sensory integration for motor tasks.

The observed effects of movement direction and distance on movement time were consistent with those reported in previous studies (Chan and Hoffmann 2015; Chan and Ng 2008; Drury and Woolley 1995; Hoffmann 1991; Park and Myung 2012). The increase in movement time due to increasing movement distance can be explained on the basis of the Fitts' law (Drury 1975).

The effects of movement direction shown in Figure 2 are thought to be attributed to the differences in the joint motions required. For example, during the forward reaches to the far target, extreme knee extension and ankle plantar flexion were observed, whereas during lateral reaches, less extreme hip abduction was observed without much knee and ankle joint movements.

As for reaction time, participant group and movement distance were found to be significant. It should be noted that the movement distance effect has not been reported previously - previous foot reach studies generally did not examine reaction time data (Chan and Hoffmann 2015; Hoffmann 1991). The obesity-associated increase in reaction time might be related to obesity-associated decreases in cognitive functions reported by multiple studies (Elias et al. 2003; Elias et al. 2005; Fergenbaum et al. 2009; Gunstad et al. 2006; Gunstad et al. 2007; Sellbom and Gunstad 2012). Again, obesity has been suggested to slow down information processing and hinder sensory integration for motor tasks (D'Hondt et al. 2008; Gentier et al. 2013).

The obesity-associated increase in reaction time may also be interpreted in light of the memory drum theory (Henry and Rogers 1960). The memory drum theory predicts that simple reaction time increases with the complexity of a motor response to be initiated - more complex responses produced by longer programs were thought to require greater storage space and consequently more read out time from storage prior to movement initiation (Greg Anson 1982; Henry and Rogers 1960). The extra fat mass in the obese body is thought to likely increase the complexity of motor responses for foot target reaches as it requires increasing internal muscle forces and thus coordination of more motor units. The extra fat mass also acts as an additional constraint on motion planning - obese individuals would have to find and utilize motion patterns that meet the muscular strength constraints and/or mitigate the increases in biomechanical stresses due to the extra fat mass. Such motion patterns may be more complex than those utilized by non-obese individuals. More research is needed to confirm this expectation.

The results for performance time were similar to those for movement time - performance time was found to be affected by participant group, movement distance and movement direction. The similarity may be because movement time accounts for a large portion of the task performance time.

As for perceived discomfort rating, no significant mean difference was found between the obese and non-obese groups. This result was rather surprising when considered in light of Park et al. (2009), which found differences in perceived postural stress between obese and non-obese participants during static posture maintenance. The lack of significant between-group difference may be because the foot movement task was low in difficulty. A repetitive foot reach task may reveal some between-group differences in perceived discomfort – a future study is warranted.

As for movement distance, discomfort increased as the distance increased. This result was not surprising as an increase in foot travel distance implies longer and larger muscular exertions.

In terms of movement direction, the forward direction was found to be the most uncomfortable direction. Related to this, extreme joint positions, such as large knee extension and ankle plantar flexion angles close to the joint RoM limits, were observed at the end of the movement, for many of the participants during forward reaches, especially when the movement distance was 51cm. On the other hand, during lateral reaches, such extreme joint motions were not observed – even when the movement distance was 51cm, knee extension, ankle plantar flexion and hip abduction angles were not close to the respective joint RoM limits.

Some limitations of this study existed. First, all participants were male so that it could not identify the gender effect. Warshawsky-Livne (2002) showed that gender effects exist on brake reaction and movement time. Study to examine the interaction effects between gender and obesity would be possible for future study.

Average BMI of the obese group in this study is under 35, which is not accommodate all obese population. Further study of the morbid obese (BMI >35) population could be a valuable research topic. In this study, all experiment conditions were conducted in seated position. Considering existing researches (Chan and Hoffmann, 2015; Chan and Ng, 2008) investigating the effect of posture on foot movement time, future study is necessary to verify the main effect of posture on foot movement time.

Chapter 4

The effects of obesity and posture on foot reach tasks: task performance and perceived discomfort

4.1 Introduction

Foot target reach is a basic element of foot control operation, which occurs in various work tasks or situations, including vehicle operation (Mortimer 1974; Glass and Suggs 1977; Yadav and Tewari 1988; Beh and Hirst 1999; Kumar et al. 2009; Collet et al. 2010; Mehta et al. 2011), manufacturing and industrial machine operation (Corlett and Bishop 1975; Corlett and Bishop 1978; Trump and Etherton 1985; Trump and Etherton 1986; Collins et al. 1986), healthcare tasks (Kim et al. 2009; Zhou and Wiggermann 2017), robot control (Lux et al. 2010; Abidi et al. 2018; Huang et al. 2019; Huang et al. 2021), and human computer interaction (Kim and Kaber 2009; Saunders and Vogel 2015; Velloso et al. 2015; Felberbaum and Lanir 2018; Biele 2022). For this reason, much research on foot target reach has been conducted in ergonomics.

Several research studies have examined foot target reach focusing on task related factors, such as target size, movement distance, movement direction and posture (standing vs seated) (Drury 1975; Park and Myung 2012; Chan and Ng 2008; Chan and Hoffman 2015). Drury (1975) developed a model that predicts foot reach movement time based on pedal size and movement distance. The model was a modification of Fitts' law and showed a good fit to the movement time data. Park and Myung (2012) developed an angular Fitts' model. The model predicted the time of angular foot movement (rotation around the fixed heel contact point) and showed better performance than the existing versions of Fitts' law for linear foot movement. Some studies examined 'posture' as a factor. Two postures were considered: the standing and seated postures. Chan and Ng (2008) compared the standing and the seated posture in lateral foot movement time. It was found that foot movement time was shorter for the standing than for the seated position. Chan and Hoffmann (2015) also investigated the effects of posture (standing and seated), movement direction (forward/ lateral) and movement distance on foot movement time. The study reported that foot movement was faster for the lateral than the forward direction. Through experiments, Chan et al. (2016) obtained a critical ID point from the foot reach to the ballistic movement to the visual control movement. In the foot movement, the critical ID value was smaller than that of the hand movement.

Some other studies have investigated the impacts of personal variables on foot target reach (Broen and Chiang 1996; Warshawsky-Livne and Shinar 2002; Rohr 2006; Baek et al. 2021). Rohr (2006) investigated the effect of gender on hand and foot movement time. The study reported that compared with the female participants, the male participants moved faster for both the upper and lower limbs, particularly for the more complex tasks. Warshawsky-Livne and Shinar (2002) examined the effect of gender on foot movement time and found that the foot movement time of men was slightly faster than the foot movement time of women. Broen and Chiang (1996) investigated the effect of age on braking response time.

Driver age was significantly correlated with response time, as older drivers took longer to respond. Baek et al. (2021) investigated the obesity level impacts on seated foot target reach performance and discomfort. It was found that the reaction time and the movement time of the obese group were longer than those of the non-obese group.

Despite past research on foot target reach, however, there still remain knowledge gaps. One such knowledge gap is the lack of studies on the obesity impacts on standing foot target reach. Consideration of obesity is important in the ergonomics design of work tasks as the obese population represents a significant portion of the current workforce (Park et al. 2010; Jeong et al. 2018; Park et al. 2009; Singh et al. 2015; Singh et al. 2009). A relevant research study would provide the knowledge for the design of work tasks involving foot control operation for the obese worker population. Also, it would help enhance our understanding of the obesity impacts on whole-body goal-directed human movements with the foot as the end-effector.

To address the knowledge gap above, the primary objective of the current study was to empirically investigate the impacts of obesity level on the performance and perceived discomfort of standing foot target reach. The main hypothesis of the study was that the condition of obesity is associated with decreased task performance and increased perceived discomfort. Obese and non-obese participants performed a set of standing foot target reaches varying in movement distance and movement direction. We combined the collected dataset with the seated foot target reach dataset from Baek et al. (2021), and, statistically analyzed the combined dataset. This allowed testing the main hypothesis and also examining various main and interaction effects, including those related to the 'posture' factor (standing vs. seated). Statistical analyses were conducted to test the main research hypotheses below:

H1) Does reaction time/movement time/task performance time/discomfort rating vary depending on the participant group (non-obese/ obese) in the foot reach task?

H2) Does the reaction time/movement time/task performance time/discomfort rating vary depending on the posture (seated/ standing) in the foot reach task?

H3) In each dependent variable, is there a 3-way interaction effect between the participant group factor, movement distance, and movement direction?

H4) Is there a 3-way interaction effect between the posture factor, movement distance, and movement direction in each dependent variable?

4.2 Research Methods

4.2.1 Study Participants

Two groups of participants, defined in terms of body mass index (BMI), were recruited in this study: non-obese (18.5 kg/m2 $\leq$ BMI $<$ 25 kg/m2) and obese (BMI $\geq$ 30 kg/m2). Only those without apparent neurological or muscle abnormalities were considered for participation. A total of 36 participants, 17 obese males and 19 non-obese males, were recruited through internet advertisements. Table 1 provides a demographic summary for each participant group. None of the participants had prior experience in a job in which foot controls were used extensively. The participants were compensated for their time.

The participants were informed about the experimental protocol prior to the main experiment, and, all questions were answered; they signed an informed consent form. The study was approved by the Institutional Review Board at Seoul National University.

Table 4.1: Summary of demographic data for the two participant groups

Dimensions	obese (n=17)	non-obese (n=19)
	Mean±SD	Mean±SD
Age (years)	32.6 ± 7.9	31.6 ± 10.6
Height (cm)	173.5 ± 6.8	174.5 ± 6.4
Body mass (kg)	101.6 ± 14.5	70.7 ± 7.5
BMI (kg/m^2)	33.7 ± 3.8	23.2 ± 1.9

4.2.2 Experimental Task and Conditions

The participants conducted a set of foot target reach trials in two different body positions (standing and seated). In the standing condition, each participant performed standing foot target reaches for 12 different target positions (Figure 4.1a) - the 12 target positions were the combinations of 3 movement distances (17 cm, 34 cm, and 51 cm) and 4 movement directions (left-diagonal, forward, right-diagonal, and right lateral); the initial foot positions were the same across all foot target reach trials. For each target position, each participant performed 2 repetitions of foot target reach. Thus, each participant performed a total of 24 foot target reaches. The order of the 24 foot target reaches was randomized for each participant.

Prior to the start of each standing trial, the participant was standing in front of a large computer monitor screen. The right foot was depressing the start pedal on the floor (Figure 4.1b). The target pedal was also placed at the target position for the trial (Figure 4.1b). The start and the target pedal are shown in Figure 4.1c, along with the dimensions. The monitor screen signaled the beginning of the trial by showing a red rectangle in its center (Figure 4.1d). The participant was instructed to complete the required foot reach as quickly as possible.

In the seated condition, similarly to the standing condition, the participants performed 24 seated foot target reach trials. The initial foot position and the 12 target positions were the same. The only difference was that the participatns were seated on a stool. Part of the dataset for the seated condition was from Baek et al. (2021).

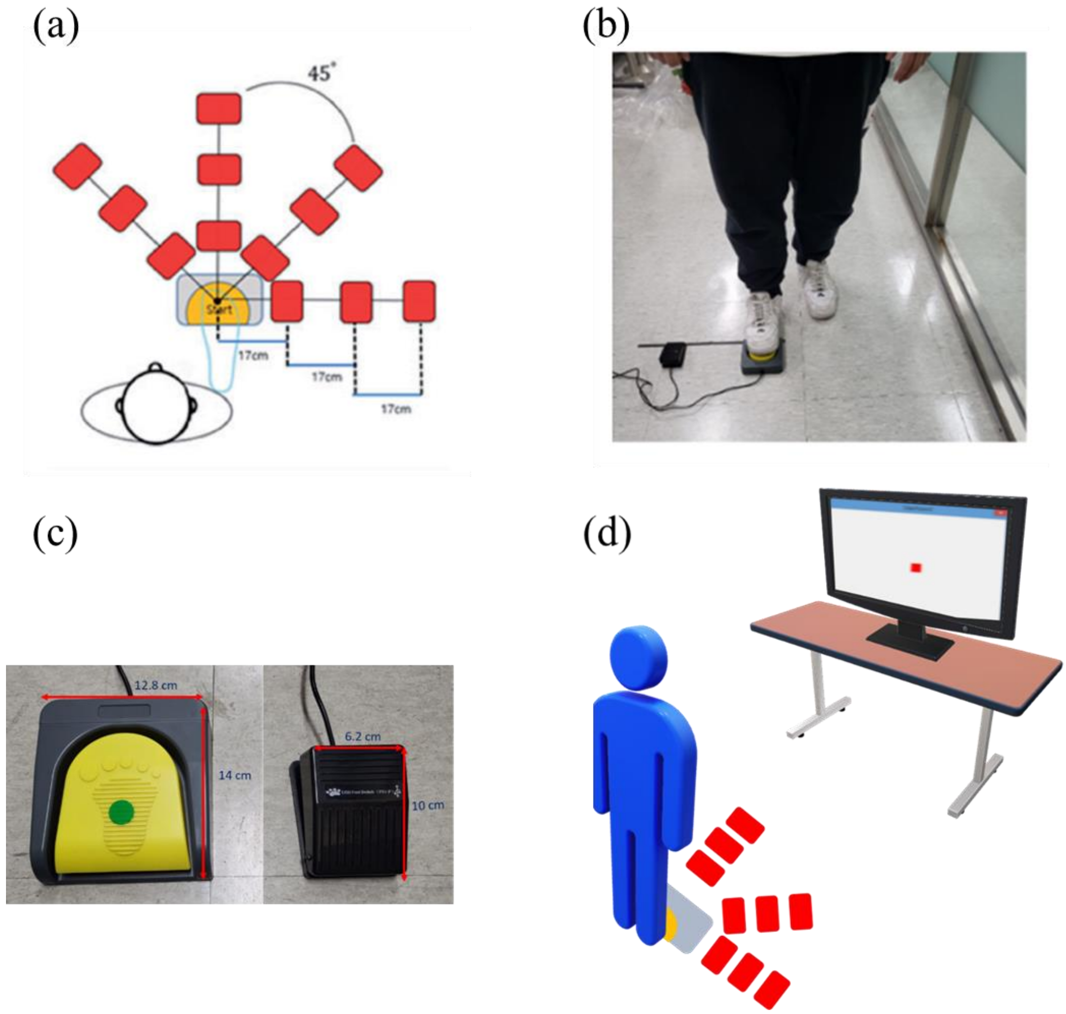

Figure 4.1: Experimental set-up: (a) start and 12 target positions (4 movement directions × 3 movement distances), (b) The initial body position at the beginning of an experimental task trial, (c) specification of start pedal & target pedal, (d) monitor screen location

4.2.3 Data Collection and Analyses

For each reach trial in both the seated and the standing condition, reaction, movement and task performance times were collected. Reaction time referred to the time duration between the time when the red rectangle appeared on the computer monitor screen signaling the beginning of a reach trial and the time when the participant started to take his/her foot off the start pedal. Movement time referred to the time duration between the time when the participants started to take his/her foot off the start pedal and the time when he/she successfully reached and pressed the target pedal. Task performance time was the sum of the reaction and the movement time. The time data were recorded using a Visual Basic computer program developed in-house. Additionally, the level of perceived discomfort for each reach trial was recorded - immediately after the completion of a reach trial, the participants subjectively rated the level of discomfort for the trial using a 10-point modified Borg scale (Borg, 1990).

Four independent variables were considered in this study: body position (2 levels; seated and standing), movement direction (4 levels), movement distance (3 levels), and participant group (non-obese and obese). The dependent measures were: movement time, reaction time, performance time and discomfort rating. ANOVAs were conducted to test the effects of the independent variables and their interactions on each of the dependent variables. Post-hoc Bonferroni pairwise comparisons were performed when necessary. The Bonferroni correction was used for the pairwise comparisons. All statistical tests were conducted at an alpha level of 0.05 using SPSS 26.0 (SPSS INC., Chicago, USA)."

4.3 Results

4.3.1 Main Effects on Movement Time

Figures 4.2(a)-4.2(d) present the factor level means for each of the four independent variables, respectively. The four main factors, that is, participant group, posture, movement distance and movement direction, were found to have significant effects on movement time.

4.3.2 Interaction Effects on Movement Time

Figures 4.3 and 4.4 present graphs of factors with significant interaction effect. Posture was observed to have a significant interaction with movement direction and movement distance, respectively. The 3-way interaction effect was also found. It was found that the movement time increased significantly when performing a far-forward foot reach in a seated position.

4.3.3 Main Effects on Reaction Time

Figures 4.5(a)-4.5(d) present the factor level means for each of the four independent variables, respectively. The four main factors, that is, participant group, posture, movement distance and movement direction, were found to have significant effects on reaction time.

4.3.4 Main Effects on Task Performance Time

Figures 4.6(a)-4.6(c) present the factor level means for each of the three independent variables, respectively. The three main factors, that is, participant group, movement distance and movement direction, were found to have significant effects on task performance time.

4.3.5 Interaction Effects on Task Performance Time

Figures 4.7 present graph of factors with significant interaction effect. Posture was observed to have a significant interaction with movement distance.

4.3.6 Main Effects on Discomfort Rating

Figures 4.8(a)-4.8(c) present the factor level means for each of the three independent variables, respectively. The three main factors, that is, posture, movement distance and movement direction, were found to have significant effects on discomfort rating.

4.3.7 Interaction Effects on Discomfort Rating

Figures 4.9 and 4.10 present graphs of factors with significant interaction effects. Posture was observed to have a significant interaction with movement. The 3-way interaction effect was also found. It was found that the discomfort rating increased significantly when performing a far-forward foot reach in a seated position.

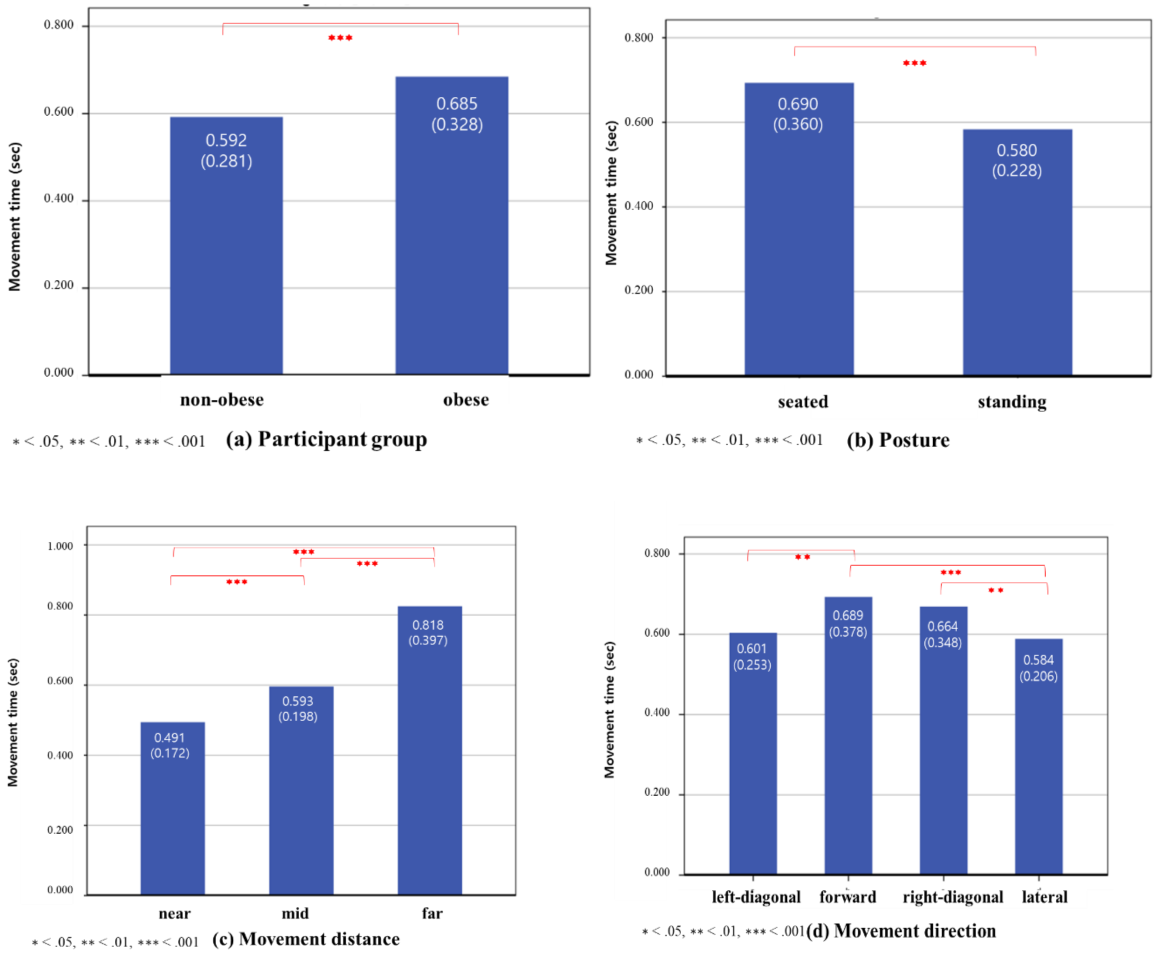

Figure 4.2: Main effects on movement time: (a) participant group, (b) posture, (c) movement distance, (d) movement direction

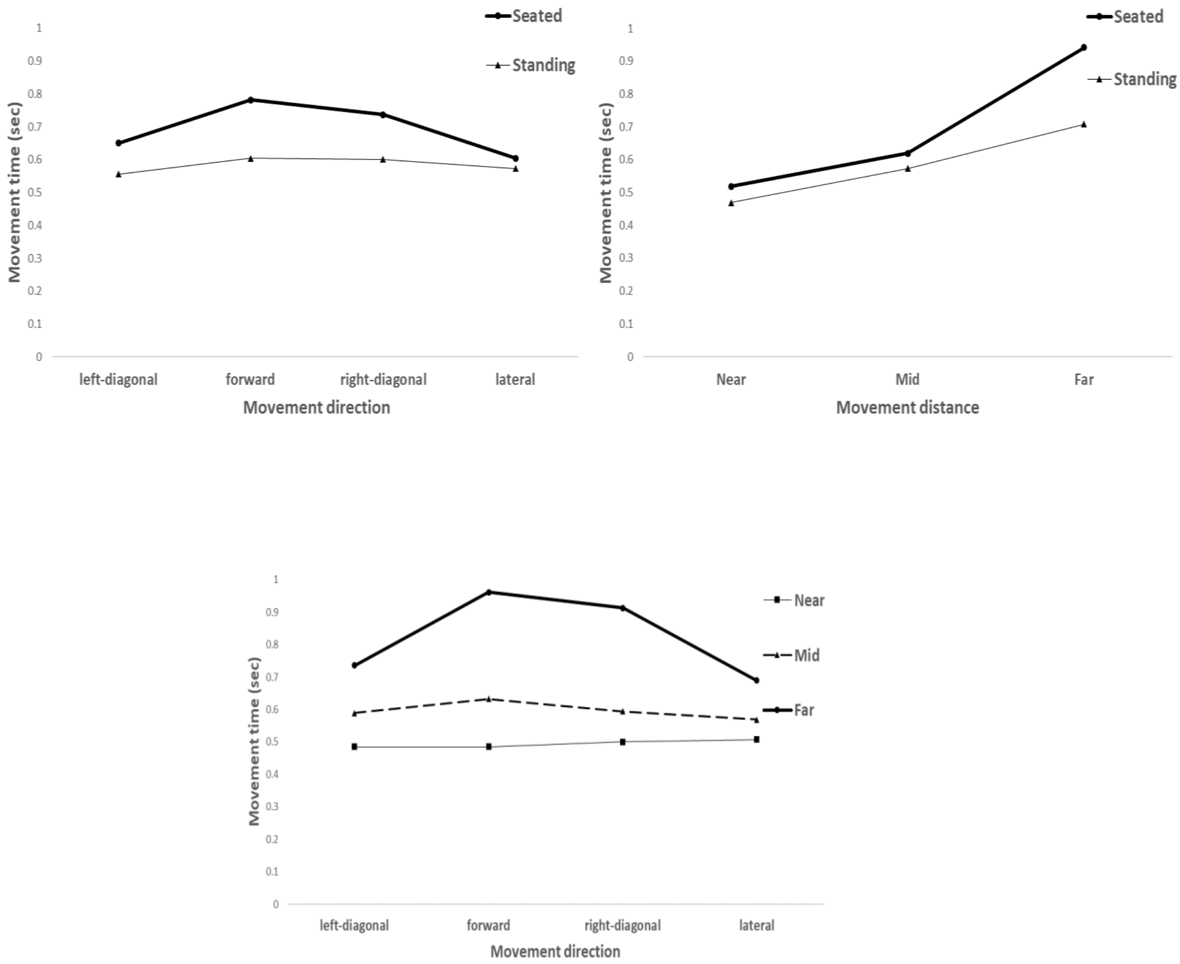

Figure 4.3: Line graphs of 2-way interaction effects on movement time: (a) posture × movement direction, (b) posture × movement distance, (c) movement direction × movement distance

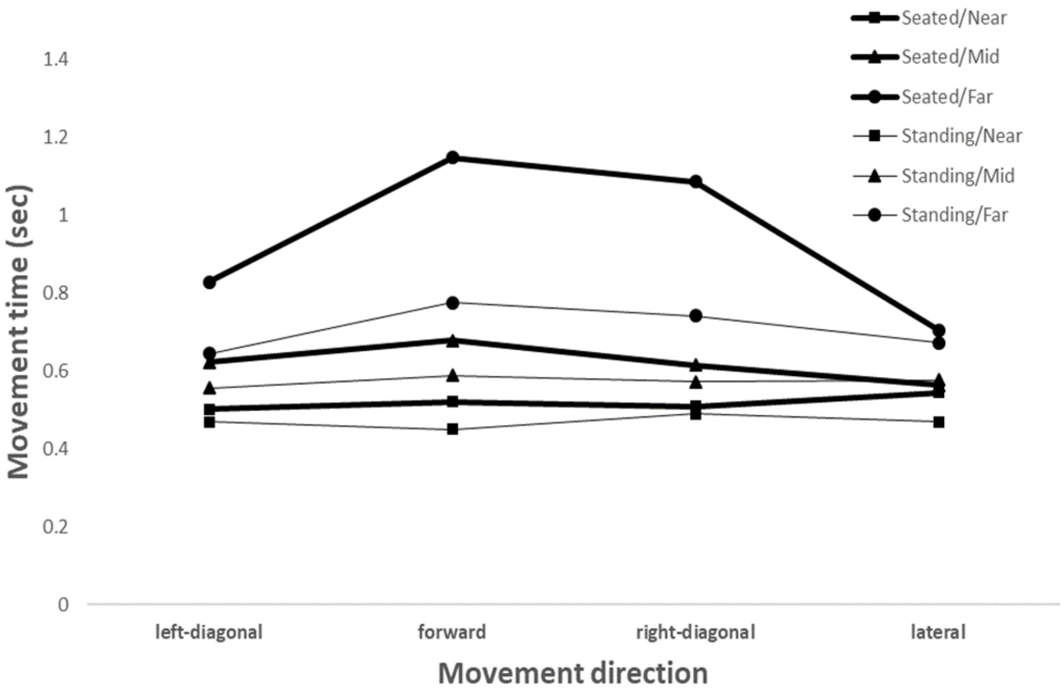

Figure 4.4: Line graphs of 3-way interaction effect on movement time

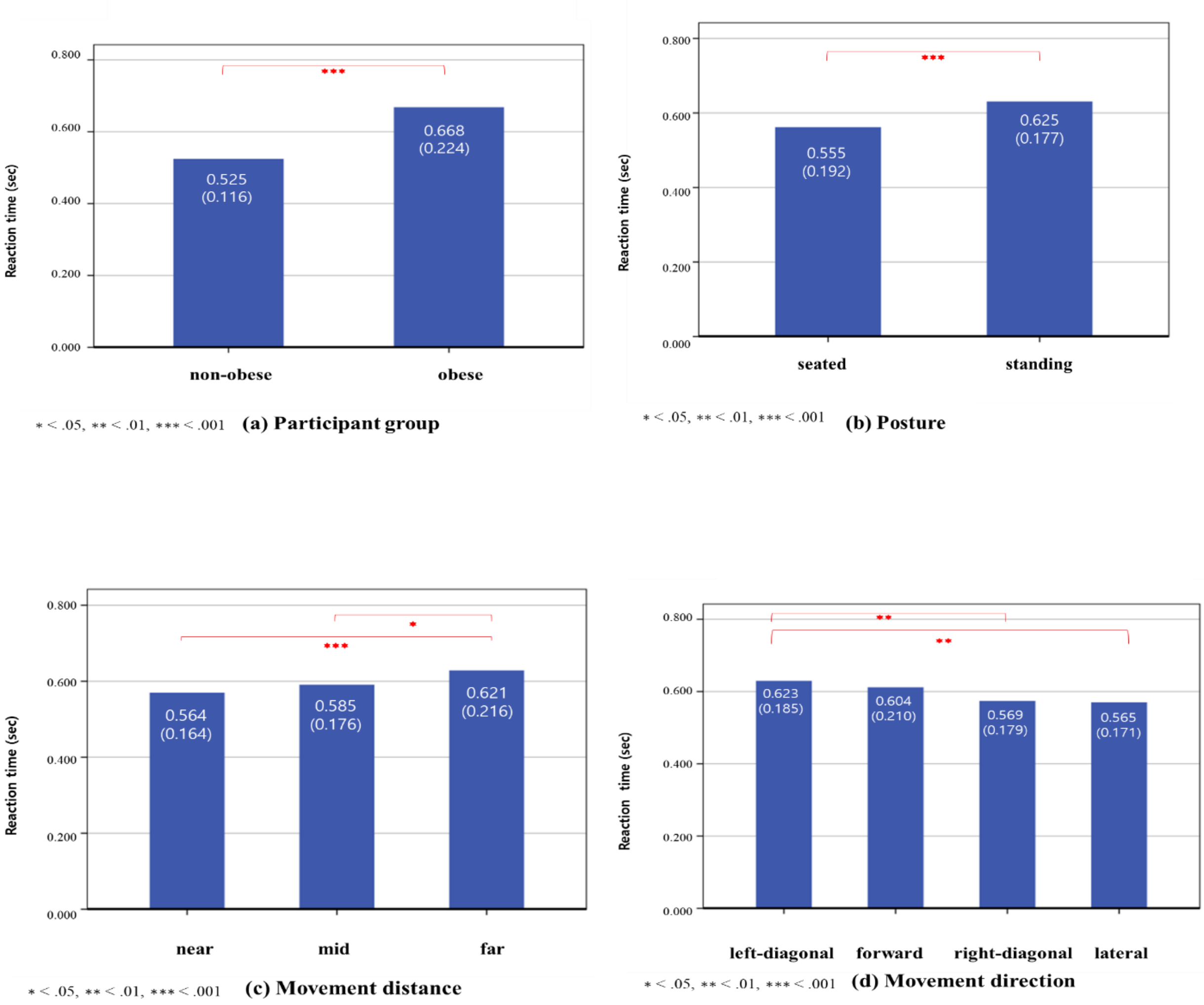

Figure 4.5: Main effects on reaction time: (a) participant group, (b) posture, (c) movement direction, (d) movement distance

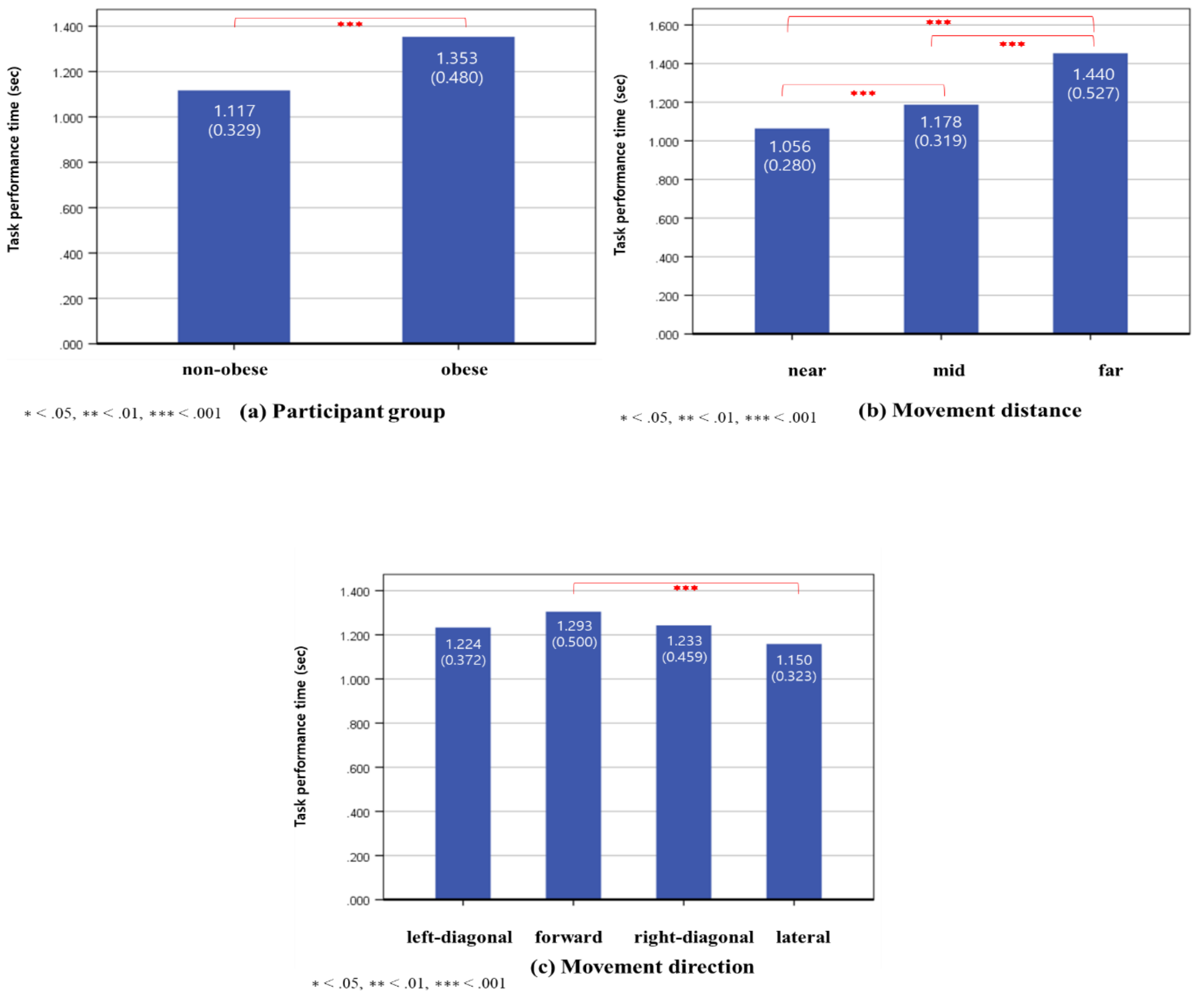

Figure 4.6: Main effects on task performance time: (a) participant group, (b) movement direction, (c) movement distance

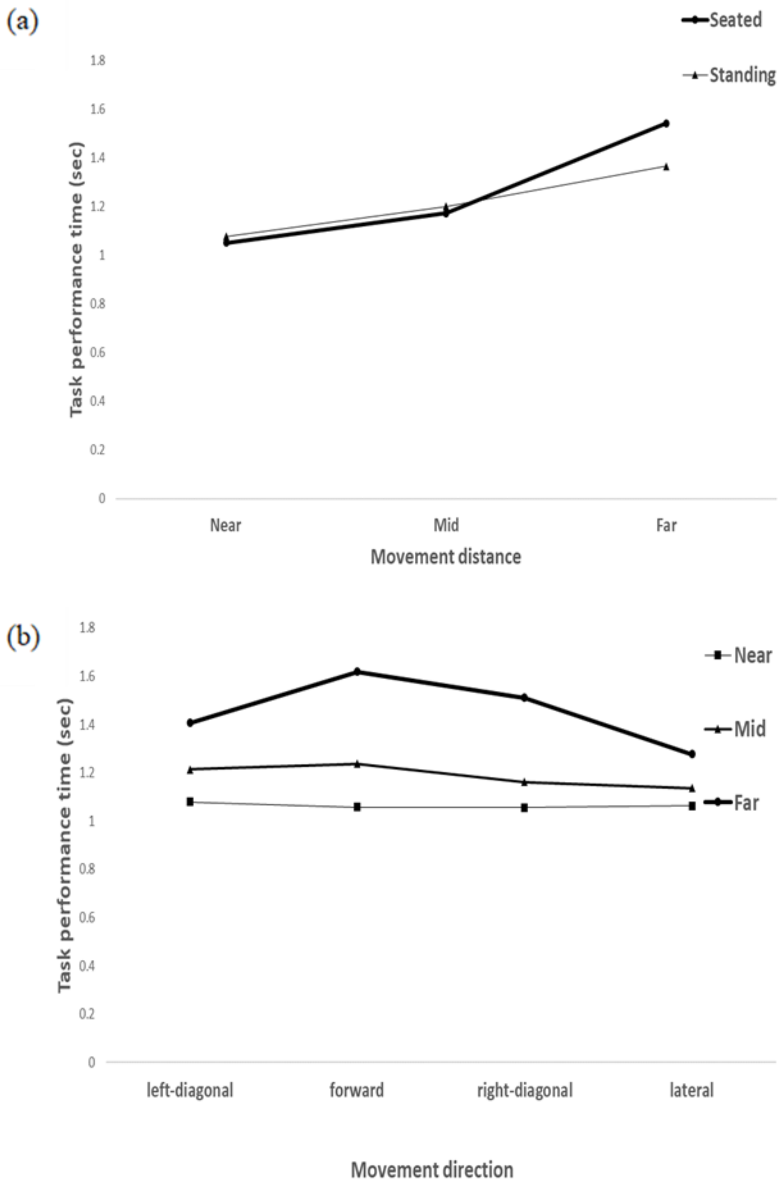

Figure 4.7: Line graphs of 2-way interaction effects on task performance time: (a) posture × movement distance, (b) movement direction × movement distance

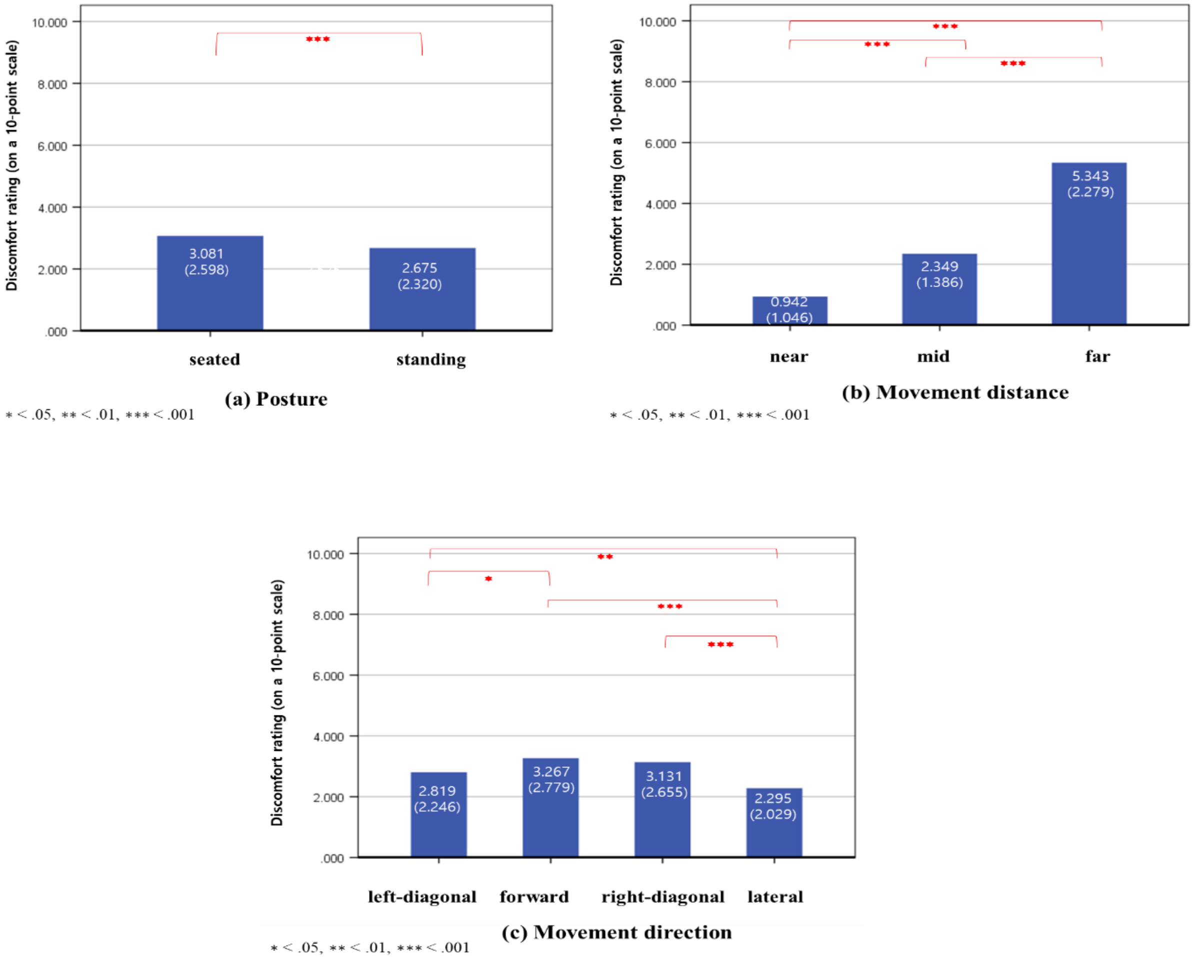

Figure 4.8: Main effects on discomfort rating: (a) posture, (b) movement distance, (c) movement direction

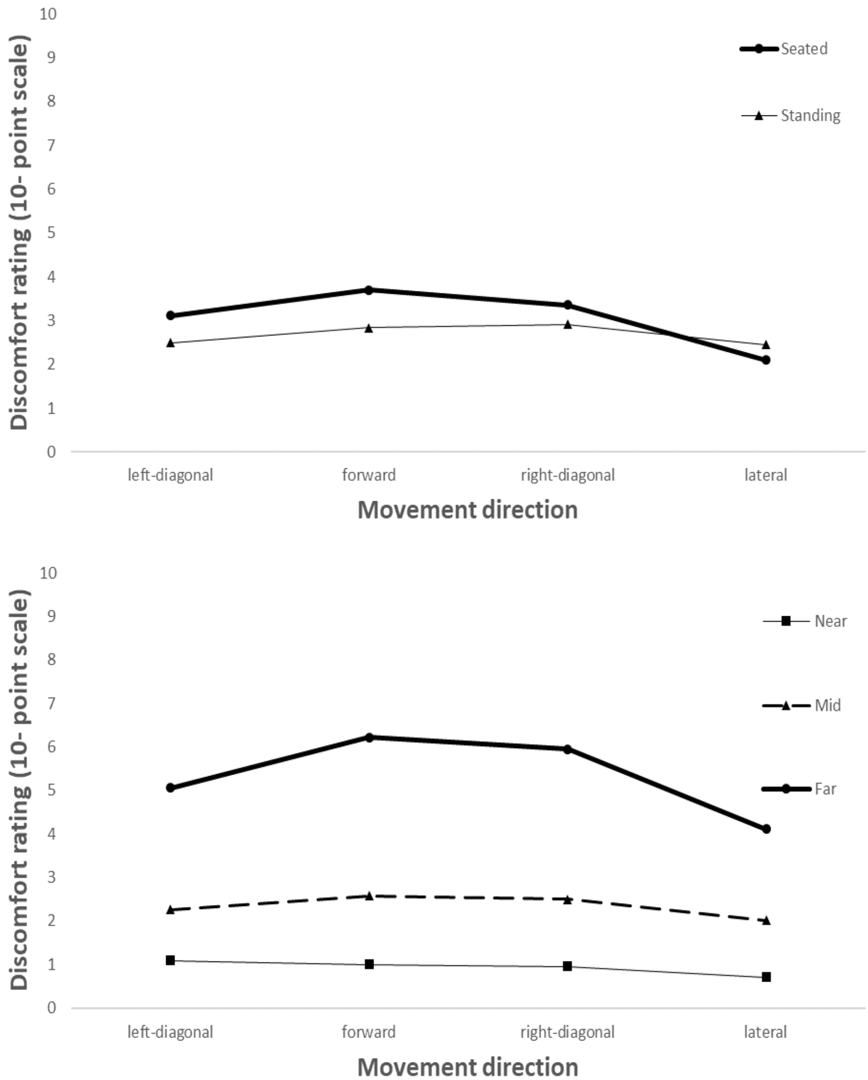

Figure 4.9: Line graphs of 2-way interaction effects on discomfort rating:
(a) posture × movement direction, (b) movement direction × movement distance

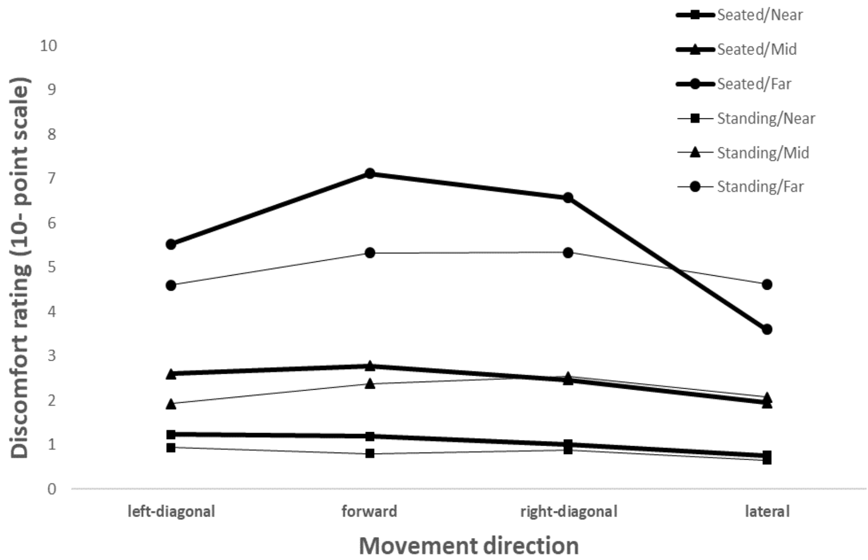

Figure 4.10: Line graphs of 3-way interaction effect on discomfort rating

4.4 Discussions

For movement time, all of the four independent variables, posture, participant group, movement distance and movement direction, were found to be significant and several significant interaction effects were identified: the obese group had a larger mean movement time than the non-obese group (Figure 4.3a); the mean movement time was shorter for the standing posture than the seated posture (Figure 4.3b); the mean movement time increased as movement distance increased (Figure 4.3c); the forward direction was associated with the longest mean movement time while the lateral direction, the shortest (Figure 4.3d). The effect of movement direction was more pronounced in the seated condition than in the standing condition. The effect of movement distance was more pronounced in the seated condition than in the standing condition. The effect of movement direction was pronounced only in the far distance condition. It was found that a longer movement time increase was caused by a distant foot reach in the forward direction from a seated position.

The mean movement time in the standing posture was shorter than the mean movement time in the seated posture. Apparently, standing and seated posture do not require the same lower limb actions, and each requires a different set of muscles. It might take a long time because the foot reach is unfamiliar with the sitting position. Foot reach in a standing position can be seen as a step in gait, and walking is a familiar behaviour in everyday life.

It was found that the movement time of the obese group was longer. This result is the same result as Baek et al. (2021)'s study of foot target reach in a seated position. According to Cavuoto and Nussbaum (2013), obese individuals have a lower strength per unit body mass than non-obese individuals; Kitagawa and Miyashita (1978) observed that obese individuals have lower strength values per kilogram of lean body mass (LBM) compared to non-obese individuals; According to Park et al. (2006), obese participants had significantly lower strength per unit of muscle mass than non-obese participants. Adipose tissues both intermuscular and intramuscular have been implicated in reducing muscle quality (Hilton et al. 2008; Marcus et al. 2012). The decrease in Range of Motion (RoM) due to obesity may have affected movement time. Park et al. (2010) and Jeong et al. (2018) reported reduced RoM in some lower body joints of obese people. Relatedly, some studies have shown a positive correlation between RoM and physical performance during sports activities (Behm et al. 2016; Sandamas et al. 2020; Rahman and Islam 2020).

Forward foot reach took the longest time and it was found that the longer the foot reach from a long distance, the longer it took. The observed effects of movement direction and distance on movement time were consistent with those reported in previous studies (Chan and Hoffmann 2015; Chan and Ng 2008; Drury and Woolley 1995; Hoffmann 1991; Park and Myung 2012). The increase in movement time due to increasing movement distance can be explained on the basis of the Fitts' law (Drury 1975).

A 3-way (posture x movement direction x movement distance) significant interaction effect was observed. It was found that more time was required when performing a forward reach from a long distance in a seated position. The cause, it is determined, is that each challenging conditions are compounded to create an extreme movement. In ergonomics, extreme posture was known not only to cause great discomfort but also to reduce performance (Burgess-Limerick 2007; Roper and Yeh 2007; Stock 1991). Similar to Baek et al. (2021), the effect of movement direction was thought to be attributed to the differences in the joint motions required. For example, during the forward reaches to the far target, extreme knee extension and ankle plantar flexion were observed, whereas during lateral reaches, less extreme hip abduction was observed without much knee and ankle joint movements.

As for reaction time, posture, participant group, movement direction and movement distance were found to be significant: the obese group had a larger mean reaction time than the non-obese group (Figure 4.6a); the mean reaction time in the standing posture was longer than the seated posture (Figure 4.6b); the mean reaction time increased as movement distance increased (Figure 4.6c); the left-diagonal direction was associated with the longest mean reaction time (Figure 4.6d). This is the first study to examine the parameters that influence reaction time during foot reach. - previous foot reach studies generally did not examine reaction time data (Chan and Hoffmann 2015; Hoffmann 1991).

The obesity-associated increase in reaction time might be related to obesity-associated decreases in cognitive functions reported by multiple studies (Elias et al. 2003; Elias et al. 2005; Fergenbaum et al. 2009; Gunstad et al. 2006; Gunstad et al. 2007; Sellbom and Gunstad 2012). Obesity has been suggested to slow down information processing and hinder sensory integration for motor tasks (D'Hondt et al. 2008; Gentier et al. 2013).

Standing was associated with a longer reaction time than sitting. The observation may be explained by the balance control that occurs in standing. The additional workload due to balance control seems to have interfered with motor control. There may also be a change in the reaction time of muscles employed depending on posture for other reasons. A study showing that each muscle has a different contraction time may have led to a variation in reaction time (Winter 2009).

There was a significant difference in reaction time between left-diagonal movement and right-diagonal/lateral movement. It is possible for the results to differ depending on whether a particular movement is familiar or unfamiliar. Hulstijn and van Galen (1988) argued that there is a difference in reaction time between familiar and unfamiliar characters in writing. There may not be a significant effect if the number of repetitions of foot reach is increased.

It was found that the reaction time increased when moving a long distance. The memory drum theory suggested by Henry and Rogers (1960) indicates that simple reaction time increases with the complexity of a motor response to be initiated. Moving longer distances in the motor planning stage is assumed to solve more complicated problems, which can be seen as an increase in reaction time.

The results for performance time were similar to those for movement time - performance time was found to be affected by participant group, movement distance and movement direction: the obese group had a larger mean task performance time than the non-obese group (Figure 4.7a); the mean task performance time increased as movement distance increased (Figure 4.7b); the forward direction was associated with the longest mean movement time while the lateral direction, the shortest (Figure 4.7c). The effect of movement distance was more pronounced in the seated condition than in the standing condition (Figure 4.8a). The effect of movement direction was pronounced only in the far distance condition (Figure 4.8b). The similarity may be because movement time accounts for a large portion of the task performance time. There was no significant difference in posture, according to the results, this is because the influence of reaction time and movement time is opposite depending on the posture.

As for perceived discomfort rating, posture, movement distance and movement direction, were found to be significant and several significant interaction effects were identified: the mean discomfort rating in the seated posture was greater than the standing posture (Figure 4.9a); the mean discomfort rating increased as movement distance increased (Figure 4.9b); the forward direction was associated with the highest mean discomfort rating (Figure 4.9c). It was found that a greater discomfort rating increase was caused by a distant foot reach in the forward direction from a seated position (Figure 4.11).

No significant mean difference was found between the obese and non-obese groups. Considering the study by Park et al. (2009), which found differences in perceived postural stress between obese and non-obese participants during the maintenance of static posture during the study, this result is rather surprising. It is possible that the low difficulty level of the foot movement task explained the lack of significant between-group differences. A repetitive foot reach task may reveal some differences in perceived discomfort between groups - further research is necessary.

During the foot reach, it was found that they felt more uncomfortable when sitting than when standing. Discomfort may have increased because of restrictions on movement due to the chair when sitting. In contrast to the results of this study, Drury (2008) found that working standing up was more uncomfortable than sitting down. In the case of a task that requires movement of the lower body, it is thought that the seated position is more uncomfortable. The influence of posture varies according on the type of task.

3-way (posture x movement direction x movement distance) significant interaction effects were observed. It was found that the discomfort was higher when reaching forward from a long distance from a seated position. Similar to the case of movement time, it is thought that the discomfort increases further as it becomes an extreme movement.

Overall, as for the obesity impacts on standing foot target reaches, the current study revealed that: obesity increases movement and reaction time during standing foot target reaches in a manner similar to the case of seated foot target reaches (Baek et al., 2021). Thus, compared with non-obese, obese people may be more likely to experience difficulties in performing work tasks involving standing foot target reaches.

The current study also found significant posture x movement distance x movement direction interaction effects on movement time and perceived discomfort – the far target reaches in the left-diagonal, the forward and the right-diagonal direction resulted in substantially longer mean movement times and larger mean discomfort ratings for the seated position than for the standing position.

The study findings would serve as useful knowledge for the ergonomic design of foot operated systems. In particular, the following design implications may be suggested on the basis of the current study results and also in light of the Fitts' (1954) law:

For obese operators, movement distances during foot target reaches can be reduced to compensate for obesity-associated increases in movement time and reaction time. This is so for both the standing and the seated condition,

For the standing as well as the seated condition, target size can be increased for obese operators to reduce obesity-associated increases in movement time, and

For both obese and non-obese workers, far-target foot reaches for the forward and diagonal directions must be avoided during a seated work task. If they cannot be avoided, the seated work task may be changed to a standing work task through work task redesign. The use of a standing work task, however, should be done only when the biomechanical and physiological costs of standing do not exceed its benefits in terms of the movement time and perceived discomfort of foot target reaches.

The first two design implications are intended for obese workers but they are indeed beneficial to not only obese but also non-obese operators.

Some limitations of the current study are described here along with future research ideas: First, this experiment recruited only younger male subjects. Future studies may consider both sexes and different age groups along with obesity levels in order to fully understand how these personal variables affect foot target reaches. Second, the current study examined only one-time foot target reaches. Investigations on repetitive foot target reaches with the time duration as a task-related variable are needed as they would greatly inform the design of various foot-operated work tasks in the real-world. Finally, the current study examined foot target reaches performed in the absence of any obstructions in the workspace. Understanding how the presence of obstructions in the workspace affects foot target reach performance and how it interacts with personal variables, such as obesity level, would help design foot-operated work tasks.

Chapter 5

Models for predicting standing and seated foot target reach movement times of obese and non-obese operators

5.1 Introduction

Many studies have been conducted to understand human performance during movement tasks. Fitts' law (Fitts 1954) is the most commonly used model for predicting the movement time required for a target pointing task. With the extension of Fitts' law, there were studies that considered movement direction (Boritz and Cowan 1991; Cha and Myung 2010; Hoffmann et al. 2011; Jagacinski and Monk 1985; MacKenzie and Buxton 1992; Zeng et al. 2012). Most studies have found that there is an effect due to the difference in movement direction.

Drury (1975) demonstrated that Fitts' law could also be applied to foot movement tasks in a pedal design study. Gan and Hoffmann (1988) showed that a ballistic movement occurs at low ID (ID $<$ 3), which meant that movement time could be predicted only with movement distance. Due to the size of the foot, the foot movement is a ballistic movement with an ID of less than 3.

A modification of Fitts' Index of Difficulty (ID) may be necessary when correlating data of foot movement times due to the width of the shoe increasing the available target width. It has been shown that the available ID is given in previous research studies (Drury and Hoffmann 1992; Hoffmann and Sheikh 1991). When the available ID value is small (less than about three), Gan and Hoffmann (1988) found that, for hand movements, the movement time was given by an expression in which MT was linear with the square-root of movement distance.

The effects of direction and posture were also investigated in the foot movement study. Chan and Ng (2008) investigated lateral foot movement times in seated and standing postures. Chan and Hoffmann (2015) presented a predictive model for foot movement time according to posture and direction of movement (forward/ lateral). Baek et al. (2021) showed that the foot movement time of obese group took longer than that of non-obese group.

Foot movement would be different from hand movement. Hoffmann (1991) compared foot movement and hand movement prediction models. Under the same conditions, foot movements took longer than hand movements. Foot movement in a standing posture may also be more difficult due to problems such as balance control.

However, existing studies have presented only predictive models for forward/lateral directions, and no model has yet existed to predict foot movement for different targets varying both in movement distance and movement direction. Creating a general prediction model for foot movements may support the ergonomics design of foot operation tasks.

This study provides foot movement prediction models under various conditions through experiments. Movement time prediction models using the movement distance and movement angle as independent variables are presented. Four prediction models were created according to posture and obesity level.

5.1.2 Previous research works on the movement time prediction model

Fitts' law (Fitts, 1954; Fitts and Peterson, 1964) is a model of human psycho-motor behavior, originally developed on the basis of information theory. Fitts derived an Index of Difficulty (ID) for a pointing task given by Equation 1,

$$MT = a + b\log2(2A/W) \quad (1)$$

The log term refers to the index of difficulty (ID), which reflects how difficult the combination of W and A is to a user. According to Fitts' law, the movement time (MT) to select a specific target is a function of the target width (W) and the distance from the start point to the target (A). Drury suggested Equation 2 as a foot movement time prediction model.

$$MT\ (ms) = 189 + 55\ ID \quad (2)$$

Gan and Hoffmann stated that target width has little effect in movement with low ID conditions. Equation 3 is a foot movement prediction model using the target distance.

$$MT\ (ms) = 107 + 11.2\ \sqrt{A} \quad (3)$$

Chan and Hoffmann (2015) suggested a prediction model according to posture and directional conditions. Equation 4 is a forward foot movement prediction model in standing condition.

$$MT\ (ms) = 394 + 370\ A \quad (4)$$

5.2 Research Methods

The study participants were divided into two groups based on their body mass index (BMI): non-obese (18.5 kg/m^2 $\leq$ BMI < 25 kg/m^2) and obese (BMI $\geq$ 30 kg/m^2). Only individuals with no obvious neurological or muscle problems were chosen for participation. A total of 36 individuals, 17 obese males and 19 non-obese males, were recruited using online advertisements. There was no prior experience in foot controls in any of the participants' jobs. The study participants were paid for their study participation.

Prior to the main experiment, participants were educated about the experimental methodology, and any queries were answered; they signed an informed consent form. The study was approved by the Institutional Review Board at Seoul National University.

The participants took part in a set of foot target reach experiments. Foot target reach was performed under two experimental conditions (standing, seated). Participants prepare for the standing condition by placing their right foot on the start pedal and standing upright. The right foot was placed on the start position (the start pedal) defined on the floor. The participant was placed in front of a computer monitor screen. A red rectangle displayed in the center of the computer screen marked the beginning of the task trial. When the start signal was presented, the participant was instructed to complete the required foot reach as quickly as possible - a foot reach trial required pressing a target pedal placed at one of 12 target positions on the floor. The target pedal was placed on the designated target position prior to each trial.

Three distances of movement, 170, 340 and 510 mm were used. The width of the target pedal was 62 mm and the length was 100 mm. The target pedal was placed in accordance with the movement direction so that the width value was constant. Available IDs were calculated based on previous researches (Drury and Hoffmann 1992; Hoffmann and Sheikh 1991; Hoffmann 1995). The available ID was 3 or less under all conditions of this experiment; thus, all foot movements were ballistic movements. Four different movement directions were considered: left-diagonal, forward, right-diagonal, and lateral. The angle of the target pedal was defined as the angle formed in the forward direction in the starting pedal. It can be seen that the angle of the target pedal in the forward direction is 0 degrees and the lateral direction is 90 degrees. When the start signal occurs, a timer was started and stopped when the shoe hit the target pedal. The movement time was defined as the time from the start pedal to the target pedal when the signal was generated.

Four foot movement prediction models were created using regression analyses. The square root of movement distance and the absolute value of movement angle were used as the predictor variables. For comparison, the original Fitts' model and the Gan and Hoffmann's model were also created. The analysis was divided into four cases according to the posture (seated/standing) and the participant group (obese/non-obese).

In this study, three types of prediction models were created. First, the data were modelled using the following conventional Fitts' model (Equation 5):

$$\text{MT (ms)} = \text{a} + \text{b}\,log_2(2\text{A}/\text{W}), (5)$$

where MT represents the time to move the right foot from the starting pedal to the target pedal, and A and W are the distance from the starting pedal to the target pedal and the width of the target pedal. The width of the target pedal was 62 mm, all of which were the same. Second, a prediction model using only distance variables was also created by referring to the study by Gan and Hoffmann (Equation 6):

$$\text{MT (ms)} = \text{a} + \text{b}\sqrt{A}, (6)$$

where MT represents the time to move the right foot from the starting pedal to the target pedal, and A is the distance from the starting pedal to the target pedal.

Finally, a predictive model was created by adding distance and angle variables (Equation 7):

$$MT\ (ms) = a + b\sqrt{A} + c|\theta|,\ (7)$$

where MT represents the time to move the right foot from the starting pedal to the target pedal, and A and θ are the distance from the starting pedal to the target pedal and the angle an angle away from the forward direction.

5.3 Results

Each model was created for four datasets according to posture (seated/standing) and participant group (obese/non-obese). For the Fitts' model, the r-square value under the non-obese/sit condition was 0.676, 0.835 under the non-obese/stand condition, 0.550 under the obese/sit condition, and 0.868 under the obese/stand condition. For the Gan and Hoffmann model, the r-square value under the non-obese/sit condition was 0.711, 0.861 under the non-obese/stand condition, 0.591 under the obese/sit condition, and 0.892 under the obese/stand condition. For the prediction model with added angle variables, the r-square value under the non-obese/sit condition was 0.819, 0.881 under the non-obese/stand condition, 0.696 under the obese/sit condition, and 0.943 under the obese/stand condition.

Table 5.1-5.3 shows the results of the prediction model of foot movement time by participant group and posture. It was found that as the distance increased, the movement time increased and as the distance decreased in the lateral direction. It was found that the overall movement time of the obese group was greater.

Table 5.1: Summary of the Fitts's prediction model of by participant group and posture

Participant group	Posture	Formula
Non-obese	Seated	$MT\ (ms) = 269 * ID + 243$
Non-obese	Standing	$MT\ (ms) = 132 * ID + 658$
Obese	Seated	$MT\ (ms) = 309 * ID + 350$
Obese	Standing	$MT\ (ms) = 219 * ID + 606$

Table 5.2: Summary of the Gan and Hoffmann's prediction model of by participant group and posture

Participant group	Posture	Formula
Non-obese	Seated	$\mathrm{MT\ (ms)} = 1464 * \sqrt{distance} + 302$
Non-obese	Standing	$\mathrm{MT\ (ms)} = 712 * \sqrt{distance} + 692$
Obese	Seated	$\mathrm{MT\ (ms)} = 1696 * \sqrt{distance} + 408$
Obese	Standing	$\mathrm{MT\ (ms)} = 1175 * \sqrt{distance} + 662$

Table 5.3: Summary of the prediction model with the added angle variable of by participant group and posture

Participant group	Posture	Formula
Non-obese	Seated	$\text{MT (ms)} = 1464 * \sqrt{distance} - 127\,\lvert\text{angle}\rvert + 402$
Non-obese	Standing	$\text{MT (ms)} = 712 * \sqrt{distance} - 24\,\lvert\text{angle}\rvert + 710$
Obese	Seated	$\text{MT (ms)} = 1696 * \sqrt{distance} - 159\,\lvert\text{angle}\rvert + 533$
Obese	Standing	$\text{MT (ms)} = 1175 * \sqrt{distance} - 63\,\lvert\text{angle}\rvert + 712$

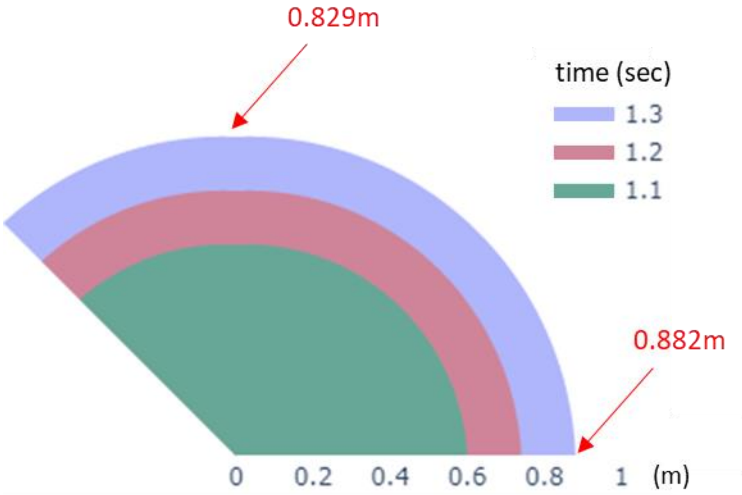

Figure 5.1: The predicted range of the foot movement time in non-obese groups in standing condition

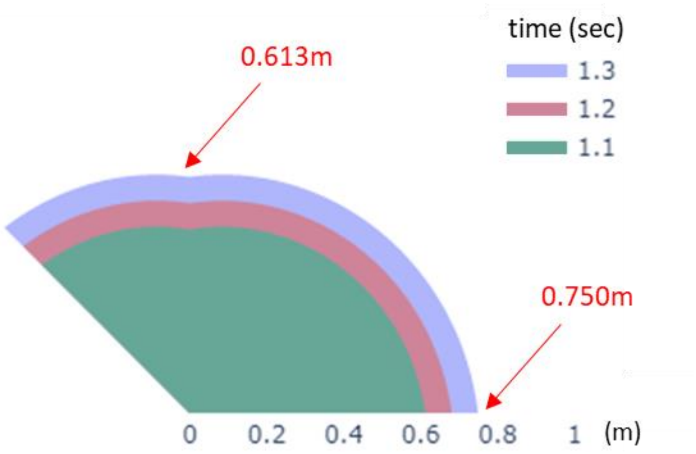

Figure 5.2: The predicted range of the foot movement time in non-obese groups in seated condition

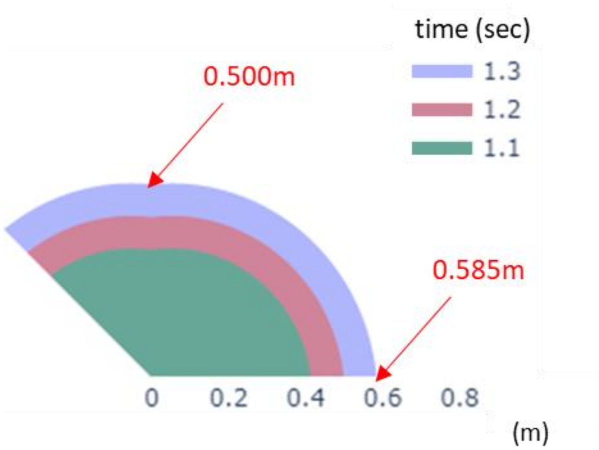

Figure 5.3: The predicted range of the foot movement time in obese groups in standing condition

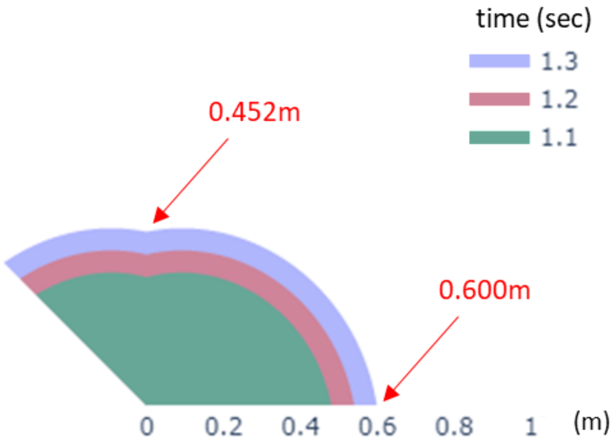

Figure 5.4: The predicted range of the foot movement time in obese groups in sitting condition

Figure 5.1-5.4 visually depicts the predicted mean movement time range for each of the four equations. Among the areas that take 1.3 seconds of predicted performance time when standing and performing foot reach, it was found that the non-obese group could go 0.829m in the forward direction and 0.882m in the lateral direction, and the obese group took 0.500m in the forward direction and 0.585m in the lateral direction. Among the areas that take 1.3 seconds of expected travel time when seated foot reach, it was found that the non-obese group could go 0.829m in the forward direction and 0.882m in the lateral direction, and the obese group took 0.500m in the forward direction and 0.585m in the lateral direction. It was found that it had the widest range under the non-obese standing condition. In the case of obese people, it was found that the range of the lateral direction was slightly wider in the seated position. Figure 5.5-Figure 5.8 shows the effect of the angle on movement time for each distance level. Figure indicates that the effect of angle on movement time was larger for the seated position than for the standing position. It also shows the obesity impacts on movement time - across different task conditions, mean movement time was larger for the obese group than for the non-obese group.

Overall, concerning the prediction of foot movement time, it was found that using movement distance as a variable rather than ID in the prediction model increases the r-square value. Also, it was found that the predictive model using the variable ‘angle’ improved the r-square value, and the influence was found to be larger, especially for the seated condition.

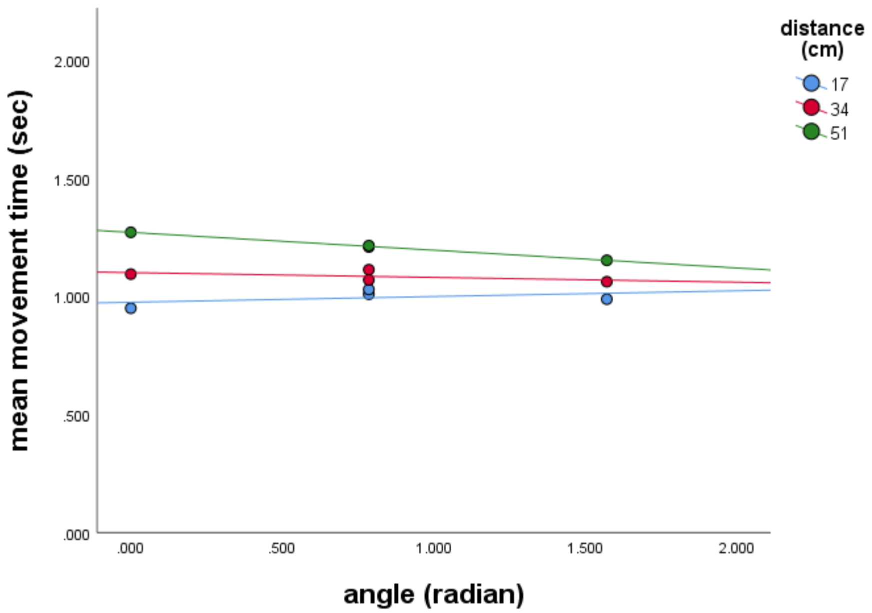

Figure 5.5: Mean movement time of the foot movement showing the effect of angle variables (non-obese groups in standing condition)

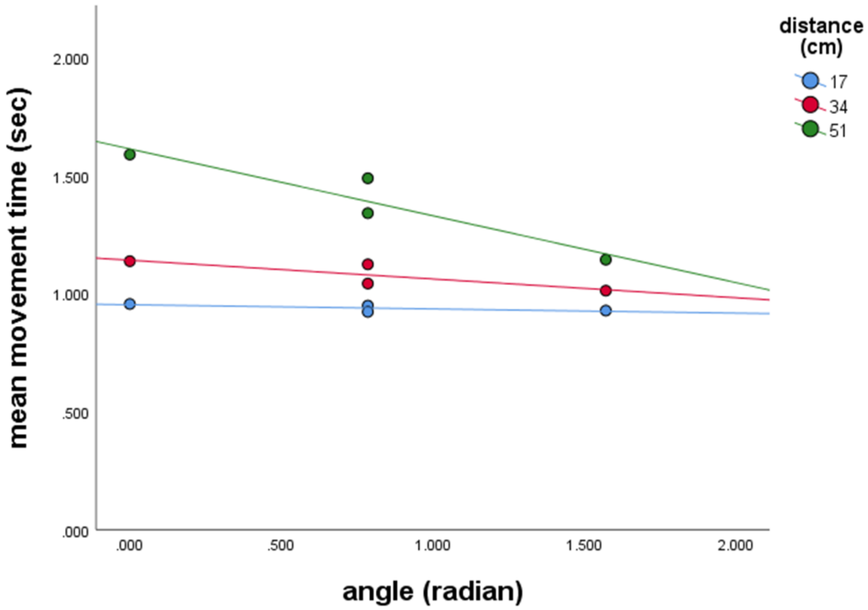

Figure 5.6: Mean movement time of the foot movement showing the effect of angle variables (non-obese groups in seated condition)

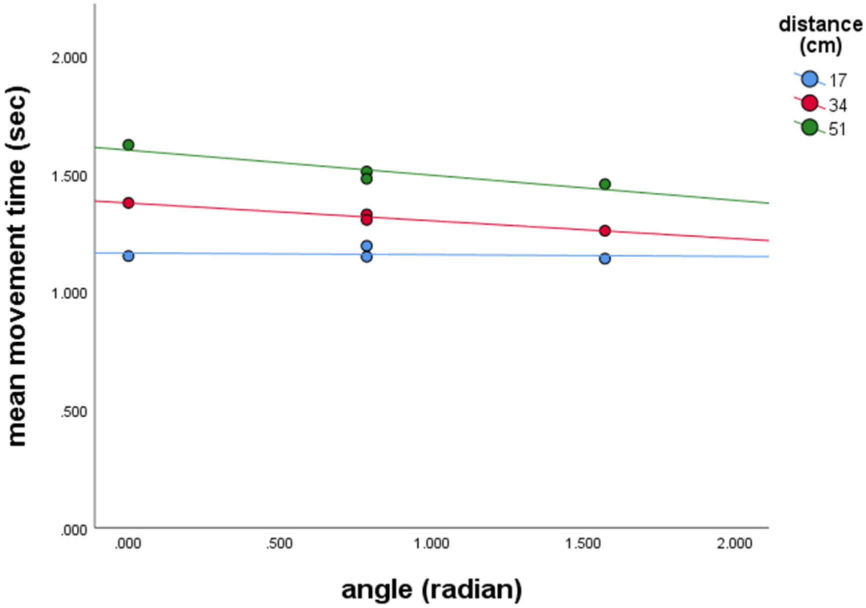

Figure 5.7: Mean movement time of the foot movement showing the effect of angle variables (obese groups in standing condition)

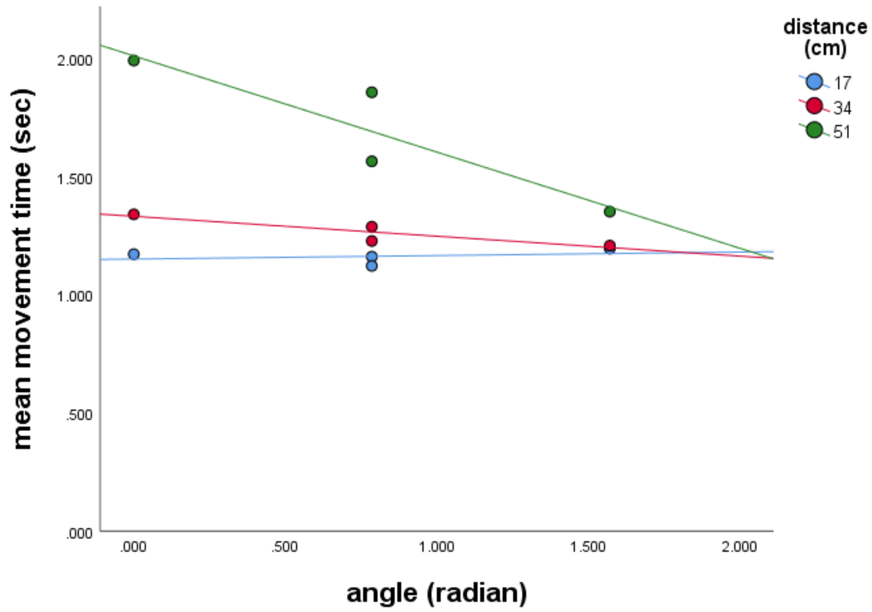

Figure 5.8: Mean movement time of the foot movement showing the effect of angle variables (obese groups in seated condition)

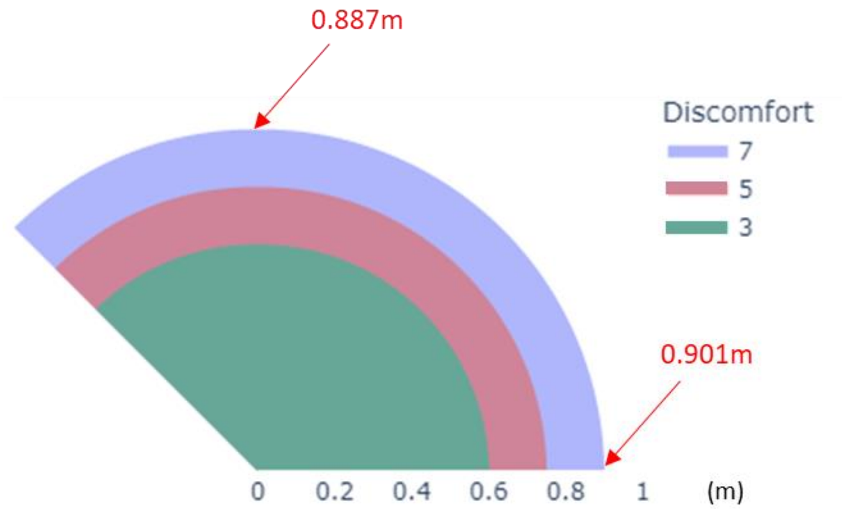

Figure 5.9: The predicted range of the discomfort during foot reach in non-obese groups in standing condition

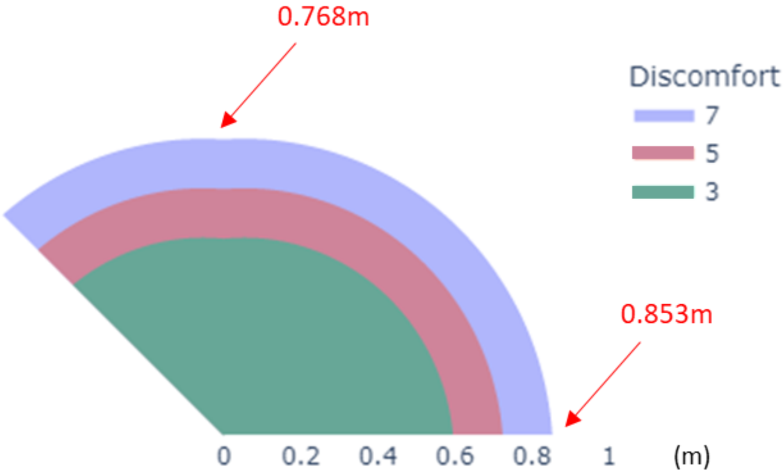

Figure 5.10: The predicted range of the discomfort during foot reach in non-obese groups in seated condition

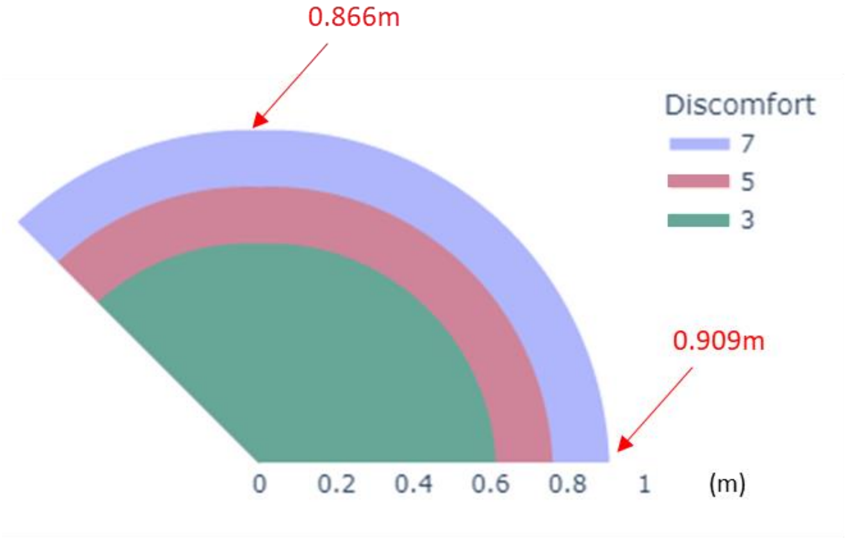

Figure 5.11: The predicted range of the discomfort during foot reach in obese groups in standing condition

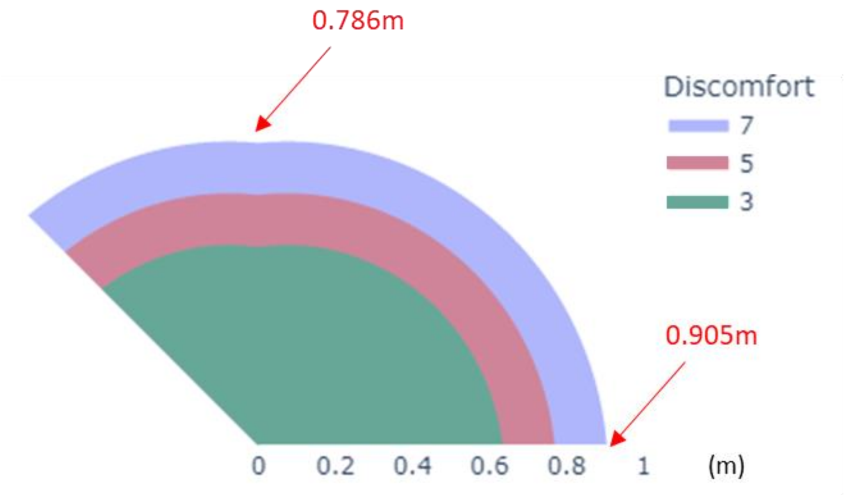

Figure 5.12: The predicted range of the discomfort during foot reach in obese groups in seated condition

Similar models could be created using discomfort data. Figure 5.9-5.12 visually depicts the predicted mean discomfort range for each of the four equations. In terms of discomfort, there was no significant difference between the obese and non-obese groups. Similar to the movement time model, it was observed that a broader range of foot reach would be possible in the standing posture.

5.4 Discussions

The foot movement time prediction model developed using the Fitts' ID showed a low predictive capability. In the case of hand movement, a highly predictive model is possible because the width of the finger is not large enough to affect the ID. However, in the case of foot movement, it is thought that the existing Fitts' model is not suitable because the width of the shoe is large enough to affect the ID. Hoffmann (1991) found that if a small tip was attached to the end of the shoe, the foot movements showed the characteristics of visual-controlled movements. It was also found that foot movement took about 1.7 times longer than hand movement, which indicates that foot movement is more difficult.

It was found that the 'angle' effect on movement time was more pronounced for the seated position than for the standing position. This is consistent with the decrease in the movement time of the laterals observed in Chan and Hoffmann's study (2015) of foot movement in the forward and lateral direction. The diagonal movement had a value between the forward direction and the lateral direction, and through this, a high-level prediction model can be made by replacing it with an angle variable.

This study showed that among the different movement directions, the forward direction had the highest mean movement time in the seated task condition. This may be attributed to the observation that the seated foot target reach motions for the forward direction involved lifting the upper legs (and therefore lower legs as well) more than the motions for the other directions. The muscular efforts for lifting the leg segments may be the reason the forward direction incurred the longest movement time. Related to this, Cha and Myung (2013) reported that hand pointing tasks involving lifting the arm segments above the shoulder level resulted in larger movement times than tasks without such arm elevation.

It is also important to find out how the human factor affects human movement in future research. Warshawsky-Livne and Shinar (2002) investigated the effect of age and gender on brake reaction time. Brogmus (1991) conducted a large-scale study on the effect of hand movement on age, and presented a movement time prediction equation containing age (Equation 8). It is necessary to add a human factor as a variable for a good prediction model.

$$MT\ (ms) = -40+[-15+0.3(age)]2+ [69+1.1(age)]\ log_2(2A/W) \quad (8)$$

The r-square value of the foot movement time prediction model of the standing posture was higher than that of the seated posture. In the case of Fitts' law, it may not fit well if movement is restricted. Fitts assumes that there is no significant restriction on the movement of the body. However, there is a high possibility that there will be restrictions on movement due to posture when actually doing foot movement. This seems to have appeared as a low r-square value of the prediction model in seated condition. Conducting a study that quantifies the negative effect due to posture would help create a more accurate model.

The study's findings would be helpful in the ergonomic design of foot-operated systems. Therefore, based on the current study results, the following design implications may be proposed:

- Temporary standing foot reach work is recommended to increase work efficiency.
- It is recommended that the target be positioned laterally to improve foot reach operations.

Through the results of this study, it seems that it is possible to help understand the user's foot movement range. in the workplace. In the case of obese group, it was found that it took at least 1.3 seconds to make a foot movement for a target more than 60 cm away. It is important to place the range of the target pedal within 60 cm for efficient work. If quick foot movement is required, it is recommended to place the pedal in the lateral direction or to stand up.

Chapter 6

Conclusion

6.1 Summary

The objective of the current study was to examine the obesity effects on task performance and perceived discomfort during foot reach. In relation to the research objectives, three major studies were conducted. Study 1 examined obesity effects on performance and perceived discomfort during seated foot reach. Study 2 investigated obesity and posture effects on performance during foot reach. Study 3 proposed a new foot movement prediction model based on the results of Study 2.

In study 1, the effect of obesity was investigated on foot target reach in a seated position. Task performance as well as discomfort ratings were evaluated. Statistics were conducted to compare the differences between the two participant groups (non-obese and obese). The obese group showed a statistically significant difference in reaction time, movement time, and task completion time compared with the non-obese group. According to the discomfort rating, there was no significant difference between the obese and non-obese groups.

According to study 2, the effects of obesity on standing posture were investigated as an extension of study 1. Although the movement time decreased in the standing position, the reaction time increased. There was no significant interaction between posture factors and participant groups. Sitting in an uncomfortable position made it more difficult to reach the foot. Based on the analysis of task performance time, there was a significant interaction effect between posture and target distance.

Research was conducted in study 3 to develop high accuracy performance time prediction model. By using the prediction model, it is now possible to estimate the actual recommended scope of work by the operator. Furthermore, task performance data is used to study an area that can optimize the foot reach task for obese workers. It was found that obese people had a smaller range in the predicted movement time area.

Study findings provide an understanding of the impact of obesity on foot reach tasks and can be used to design work environments for obese individuals. In light of the findings from study 1, it was possible to understand how obesity affects foot reach while seated. It is likely that the results provided in the study 2 will assist in elucidating potential changes in standing posture. Findings from study 3 can be used to inspire workplace improvements for obese workers. The size of the target may be increased for obese workers whose foot reach is reduced.

Overall, the results from the current study suggest that: obesity increases reaction time and movement time during foot reaches, and, obese people may be more likely to experience difficulties in performing work tasks involving foot reaches. The study findings would serve as useful knowledge for the ergonomic design of foot operated systems.

6.2 Implications

In particular, the following design implications may be suggested on the basis of the current study results and also in light of the Fitts' law (1954): For obese operators, movement distances during foot target reaches can be reduced to compensate for obesity-associated increases in movement time and reaction time. Forward foot target reaches can be avoided or replaced with lateral ones through modifying a layout of controls to counteract obesity-associated increases in movement time. Target size can be increased to reduce obesity-associated increases in movement time. The above design implications are indeed beneficial to not only obese but also non-obese operators.

Also, it may be possible to ameliorate obesity-associated increases in reaction time by making targets more salient by increasing their sizes or using more salient colors. However, clearly further studies are needed to test these possibilities.

The results of this study can be helpful when preparing pedal placement guidelines in workplace. It is expected that stable work can be continued by proposing a marginal work cycle according to the pedal position in the workplace where repeated foot-reach work occurs. Through additional experiments, it is also possible to propose a maximum working time for each pedal position.

Through the data of this study, it seems that it may be possible to help the optimal pedal placement of various foot-operated workplaces. Previous studies have proposed a movement prediction model. This is a case of performing in a space under specific conditions such as inside a car, and may not be applicable to general foot approach due to interference from obstacles, etc.

Some limitations of the current study are described here along with future research ideas: first, 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 may not reflect muscular strength. In future studies, indexes related to muscle capacity may be adopted. In this study, all experiment trials were conducted in a seated position.

Using the results of this study, a foot reach performance prediction model can be created. There is a Fitts model as a performance prediction model for a representative target reach. In this model, it was argued that only the location of the target and the size of the target affect the movement time. As a result of this study, it was found that human factors such as posture and obesity also showed significant differences, and it is expected that a model can be used to predict the performance of general foot target reach.

6.3 Future Research Ideas

Future studies are needed to examine how the obesity impacts on foot reach tasks vary across different body positions (seated and standing). Future studies may investigate developing new models predicting the impacts of personal variables, including BMI. For example, Drury's model (Drury 1975) is sufficient to predict foot movement times as a function of target-related variables (target width and movement distance) but it could be improved by adding BMI and other personal variables as additional input variables. Such new prediction models could be useful for supporting universal design.

This study conducted an experiment using foot-based interaction as the main task. However, HCI research see foot-based interaction as primarily a role of aiding busy hand-based interaction (Alexander et al. 2012). Studying the patterns that appear when hand interaction and foot reach occur simultaneously would be possible.

Further research is needed to determine possible gender impacts. Only male participants were recruited because it was difficult to recruit obese females. The study results also seem to suggest a need for obesity studies concerning the design of vehicle pedal layouts. Appropriate placement of vehicle pedals is critical to driving safety as it affects the braking distance. Using a study that investigates the force distribution of the population in brake pedal manipulation (Mortimer 1974) or a study that investigates the distribution of foot pressure of obese people while walking (Cau et al. 2014), future studies that investigate the effect of obesity on force distribution during foot reach would be possible. Additional research on the vehicle pedal positions that benefit both non-obese and obese drivers is warranted.

It might be beneficial to develop a database that directly provides the optimal range of reach for future research. In this study, since there is only foot reach data for men of a narrow age group, foot reach data for the entire population can be collected and applied to this study methodology to develop tools that help design general workplaces.

In order to maximize the interference effect of balance control, a more difficult foot approach task can be considered. In this study, movement time rather had a decreasing effect while standing, but if the mental load increases, it is highly likely to affect the actual movement time increase.

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Appendix A. The ANOVA tables

Table A.1: The ANOVA results for reaction time

Tests of Between-Subjects Effects

Dependent Variable: Reaction time (sec)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	6.774[a]	47	.144	4.988	.000
Intercept	296.591	1	296.591	10264.908	.000
G	4.301	1	4.301	148.859	.000
P	.993	1	.993	34.364	.000
Dir	.527	3	.176	6.084	.000
Dis	.488	2	.244	8.446	.000
G * P	.008	1	.008	.282	.596
G * Dir	.084	3	.028	.970	.406
G * Dis	.047	2	.023	.805	.448
P * Dir	.019	3	.006	.216	.886
P * Dis	.015	2	.008	.264	.768
Dir * Dis	.075	6	.013	.433	.857
G * P * Dir	.027	3	.009	.314	.815
G * P * Dis	.019	2	.009	.323	.724
G * Dir * Dis	.033	6	.006	.192	.979
P * Dir * Dis	.099	6	.017	.572	.752
G * P * Dir * Dis	.082	6	.014	.471	.830
Error	22.884	792	.029		
Total	322.308	840			
Corrected Total	29.658	839			

a. R Squared = .228 (Adjusted R Squared = .183)

List of abbreviations are as follows: G (Participant group); P (Posture); Dir (Movement direction); Dis (Movement distance)

Table A.2: The ANOVA results for movement time

Tests of Between-Subjects Effects

Dependent Variable: Movement time (sec)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	27.457[a]	47	.584	8.982	.000
Intercept	339.951	1	339.951	5226.551	.000
G	1.785	1	1.785	27.440	.000
P	2.520	1	2.520	38.749	.000
Dir	1.592	3	.531	8.156	.000
Dis	15.944	2	7.972	122.562	.000
G * P	.005	1	.005	.070	.792
G * Dir	.054	3	.018	.277	.842
G * Dis	.231	2	.116	1.779	.169
P * Dir	.605	3	.202	3.101	.026
P * Dis	1.595	2	.797	12.261	.000
Dir * Dis	2.237	6	.373	5.733	.000
G * P * Dir	.072	3	.024	.369	.775
G * P * Dis	.036	2	.018	.277	.758
G * Dir * Dis	.103	6	.017	.264	.953
P * Dir * Dis	.837	6	.139	2.144	.046
G * P * Dir * Dis	.060	6	.010	.153	.989
Error	51.514	792	.065		
Total	417.198	840			
Corrected Total	78.971	839			

a. R Squared = .348 (Adjusted R Squared = .309)

List of abbreviations are as follows: G (Participant group); P (Posture); Dir (Movement direction); Dis (Movement distance)

Table A.3: The ANOVA results for task performance time

Tests of Between-Subjects Effects

Dependent Variable: Task performance time (sec)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	43.325[a]	47	.922	6.896	.000
Intercept	1271.606	1	1271.606	9513.595	.000
G	11.627	1	11.627	86.990	.000
P	.349	1	.349	2.614	.106
Dir	2.250	3	.750	5.612	.001
Dis	22.002	2	11.001	82.303	.000
G * P	.001	1	.001	.004	.950
G * Dir	.120	3	.040	.298	.827
G * Dis	.483	2	.241	1.806	.165
P * Dir	.726	3	.242	1.811	.144
P * Dis	1.922	2	.961	7.190	.001
Dir * Dis	2.692	6	.449	3.356	.003
G * P * Dir	.041	3	.014	.102	.959
G * P * Dis	.097	2	.049	.363	.696
G * Dir * Dis	.107	6	.018	.133	.992
P * Dir * Dis	1.320	6	.220	1.646	.131
G * P * Dir * Dis	.125	6	.021	.156	.988
Error	105.860	792	.134		
Total	1409.290	840			
Corrected Total	149.185	839			

a. R Squared = .290 (Adjusted R Squared = .248)

List of abbreviations are as follows: G (Participant group); P (Posture); Dir (Movement direction); Dis (Movement distance)

Table A.4: The ANOVA results for discomfort rating

Tests of Between-Subjects Effects

Dependent Variable: Discomfort rating

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	3193.748[a]	47	67.952	27.956	.000
Intercept	6876.795	1	6876.795	2829.156	.000
G	4.160	1	4.160	1.711	.191
P	31.972	1	31.972	13.154	.000
Dir	121.338	3	40.446	16.640	.000
Dis	2805.699	2	1402.849	577.141	.000
G * P	5.626	1	5.626	2.315	.129
G * Dir	8.747	3	2.916	1.200	.309
G * Dis	.311	2	.156	.064	.938
P * Dir	42.790	3	14.263	5.868	.001
P * Dis	11.897	2	5.948	2.447	.087
Dir * Dis	88.029	6	14.671	6.036	.000
G * P * Dir	1.597	3	.532	.219	.883
G * P * Dis	.902	2	.451	.185	.831
G * Dir * Dis	5.416	6	.903	.371	.897
P * Dir * Dis	43.207	6	7.201	2.963	.007
G * P * Dir * Dis	2.088	6	.348	.143	.990
Error	1925.105	792	2.431		
Total	12075.785	840			
Corrected Total	5118.853	839			

a. R Squared = .624 (Adjusted R Squared = .602)

List of abbreviations are as follows: G (Participant group); P (Posture); Dir (Movement direction); Dis (Movement distance)

국문초록

세계보건기구(World Health Organization)에 따르면, 비만이란 과도하게 신체에 지방이 축적된 물리적 상태로 정의된다. 비만을 정의하는 변수 중 널리 쓰이는 것으로 BMI(Body mass index)가 있으며, 체중을 키의 제곱으로 나눈 값으로 계산된다. BMI가 30 이상인 경우 비만으로 분류되고, 35 이상인 경우 고도비만으로 분류된다. 비만 인구는 매년 증가하는 추세로, WHO에 따르면 2016년 성인 중 19억명이 과체중(BMI 25 이상 30 이하)에 해당한다. 이 중 6억 5천만명이 비만으로 분류되어, 전체 성인 중 13%에 달한다. 2020년 기준 5세 이하의 아동 3900만명이 과체중이거나 비만인 것으로 추정되며, 3억 4천만명의 청소년 인구도 과체중이거나 비만으로 집계되고 있어 앞으로도 계속 비만인구는 증가할 것으로 예측되었다. 비만인구가 증가함에 따라 비만인 작업자의 비율도 꾸준히 증가하고 있으며, 결국 비만으로 발생하는 작업자의 능률 및 지각불편도에 대한 연구가 점점 더 필요한 실정이다. 많은 일상 생활과 작업활동에서 인간은 계속해서 육체적 과업 또는 자세를 유지하는 과업을 수행하고 있다. 따라서, 비만인들이 이런 육체적 과업을 수행할 때, 어떠한 양상을 보이는지에 대해 연구하는 것은 매우 중요하다고 할 수 있다. 기존 인간공학 연구에서 비만 관련 연구는 주로 자세 유지나 걷기 등과 같은 기초적인 것에 국한되어 있었다.

위에서 언급한 중요성에도 불구하고, 아직까지 일반적인 과업을 수행할 때, 비만이 신체적 능력 및 불편도에 어떠한 영향을 미치는지에 대한 연구는 미흡한 실정이다. 특히, 발 도달 작업 같은 기본적인 동작 같은 경우에도 비만의 영향을 알아본 연구는 전무하다. 따라서, 본 연구의 목적은 발 도달 작업에서 비만이 미치는 영향에 관해 파악하는 것이다. 이러한 연구 목적의 달성을 위해 크게 3가지 주요 연구가 수행되었다.

연구 1에서는 앉은 자세에서 발 도달 작업을 수행할 때 비만이 미치는 영향에 대해서 파악하였다. 비만인 그룹과 일반인 그룹을 모집하여 다양한 타겟의 위치 배치에 따른 발 도달 능력을 알아보았다. 실험 결과, 비만인 그룹과 일반인 그룹간 반응 시간, 이동 시간, 과업 수행 시간에 통계적으로 유의한 차이가 나타남을 확인할 수 있었다. 지각불편도는 비만인 그룹과 일반인 그룹간 유의한 차이가 나타나지 않았다.

연구 2에서는 연구 1의 확장으로 자세 요인을 추가적으로 넣어 실험을 수행하였다. 기존 연구 1의 데이터를 활용하여, 추가적인 비만인 모집을 수행한 후 데이터 수집을 진행하였다. 실험 분석 결과, 서 있는 자세에서도 앉은 자세와 마찬가지로 비만의 영향이 나타남을 확인할 수

있었다. 앉은 자세에서 먼 거리를 이동하는 발 도달 과업의 경우, 더 많은 이동 시간이 발생함을 알 수 있었다. 앉아 있는 자세에서 발 도달 과업을 수행할 때 지각불편도가 더 큰 값을 보임을 관측하였다.

연구 3에서는 연구1, 2의 결과 데이터를 통해 예측 발 도달 과업 범위를 제안하는 연구를 수행하였다. 기존 도달 범위 모델의 경우 대부분 손을 활용한 도달 범위를 제안하는 경우가 많았다. 일부 모델 생성 연구에서 최적 발 도달 범위를 제안하는 연구가 있었지만, 비만과 같은 인적 변수를 고려하지 않고 신체치수 등과 같은 변수만을 활용하였다. 본 연구의 데이터를 활용하여, 인적 요인에 따른 최적 발 도달 범위값을 제안하였다. 회귀분석을 통해 수행시간과 불편도에 대한 높은정확도의 예측추정식을 제안하였다. 앉은 자세일 때 수용될 수 있는 최대기준값이 더 작게 나타나는 것으로 보이며, 이를 고려한 발 도달 작업 가이드라인을 제시하였다.

본 연구의 결과를 통해 비만이 발 도달 과업에서 미치는 영향에 대한 이해를 향상시켰으며, 비만인 작업자들을 위해 최적의 발 도달 작업을 할 수 있는 작업장 설계에 도움이 되는 방법론을 제시하였다. 또한, 본 연구를 통해 기존 발 도달 작업 관련 인간공학 분야에 도움이 되는 지식을 제공할 수 있을 것으로 기대하고 있다. 비만이 발 도달 작업에

미치는 영향을 알 수 있게 되며, 발 도달 작업에서 발생하는 주관적 불편도에 대한 예측 모델을 생성할 때 비만요인과 작업자세를 적용할 수 있을 것으로 기대하고 있다. 또한 본 연구를 통해 실제 산업현장에서 비만인을 위한 작업 설계를 도와줄 수 있을 것이다. 추후 여성 작업자들의 발도달 작업 데이터를 수집하여 모든 작업자들에 대한 디지털 휴먼 모델링을 생성하는 것을 기대하고 있다. 비만인들의 부상 및 근골격계 질환 위험을 예방하여 경제적 이득을 가져올 수 있으며, 실제 비만인 작업자의 능률을 향상시켜 작업자의 사용자경험(UX) 개선에 도움이 될 것으로 기대하고 있다.

주요어: 비만, 발 도달 작업, 작업 능률, 지각불편도
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