Obesity Effects on Preferred Driving Postures and Vehicle Interior Component Settings

by

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A thesis submitted to the Graduate Faculty of
Auburn University
in partial fulfillment of the
requirements for the Degree of
Master of Science

Auburn, Alabama
August 6, 2011

Keywords: Obesity, BMI, driving posture, vehicle interior component setting, joint angle

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Abstract

The effects of obesity were investigated with a highly adjustable vehicle mock-up. 44 participants (23 non-obese, 21 extremely obese individuals) were involved in the study. The extremely obese and non-obese group had similar gender compositions and stature characteristics. This study found obesity effects on interior component settings, twelve joint angles and hip joint center position. The significant results are as follows: extremely obese drivers needed more space from steering wheel to seat – extremely obese drivers had greater Seat displacement (Seat X), greater Steering wheel tilt angle and smaller steering wheel column displacement. Also, extremely obese people preferred a smaller Seat back angle. Hip joint center position and most of the joint angles except elbow angles were not significantly different between extremely obese and non-obese individuals. This study suggested new direction for future vehicle design, namely, that considering obesity effects for vehicle interior design is necessary.

Acknowledgments

The Republic of Korea Army is acknowledged for giving me the opportunity to study and for the support during the course of my research.

I first thank Dr. Woojin Park, my thesis advisor. This work could not have been achieved without him. He offered timely guidance to my thesis work. I learned many things from him and I respect him as an excellent professor. To my committee, Drs. Gerard A. Davis and Saeed Maghsoodloo, I really appreciate your help. Dr. Davis provided good comments for my work. Dr. Maghsoodloo offered proper statistical methods. I also give thanks to Dr. Robert Thomas, Dr. Richard Sesek and all the OSE/IP family.

Finally, I thank my wife (Juhee) for all of her love and support during the last two years. I could not finish my work without her love. She supported and encouraged me continuously despite the unfamiliar living environments of the US.

The time in Auburn was one of memorable experiences in my entire life.

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Chapter 1

Introduction

Contemporary automobiles are equipped with adjustable interior components. In most, if not all vehicles, the driver seat, steering wheel and rearview mirror are typically adjustable. Some vehicles even have adjustable pedals. Individuals driving identical vehicles use different configuration settings for these adjustable interior components. Such inter-individual variability in preference seems to be attributable largely to the differences in body dimensions. However, a significant portion of the variability is not explained by anthropometry - drivers with similar anthropometric characteristics exhibit significant differences in their choices of interior component settings. Reed and Flanagan (2000) referred to such non-anthropometric variability as postural variability. Multiple studies in vehicle ergonomics have attempted to characterize the postural variability in driving posture as certain preferred ranges of body joint angles (Rebiffe, 1969; Babbs, 1979; Grandjean, 1980; Porter and Gyi, 1998; Park, Kim, and Lee, 2000; Andreoni, Santambrogio, Rabuffeti, and Pedotti, 2002; Kyung and Nussbaum, 2009).

When designing a vehicle's interior, adjustment ranges of interior components need to be considered to cover sufficient ranges so that the vehicle can accommodate a wide variety of individuals in the consumer population. Such accommodation is important not only because it affects driving comfort, and therefore, influences consumers' purchasing decisions but also it can have profound effects on driver safety and health. Providing sufficient adjustment ranges, however, may not be easily accomplished as vehicle interior design is typically constrained by various engineering, aesthetics, marketing and economy considerations. Thus, understanding different individuals' preferences in driving posture and interior component settings is important in optimizing vehicle interior designs.

In the field of vehicle ergonomics, many research studies have been conducted to understand driver preferences in driving postures and/or interior settings. Several studies focused on identifying the preferred ranges of driving postures and interior settings: for example, Porter and Gyi (1998) provided the preferred ranges of driving postures and interior component settings for drivers in the United Kingdom. An adjustable vehicle mockup was utilized. Park et al. (2000) conducted a similar mockup based study for the South Korean driving population. Kyung and Nussbaum (2009) recommended the preferred ranges of body joint angles for drivers in the US, based on the Maximum Comfort and Minimal Discomfort (MCMD) method using comfort and discomfort rating scales (Corlett and Bishop, 1976; Borg, 1990; Kyung, Nussbaum, and Babski-Reeves, 2008). This study utilized an adjustable vehicle mockup and two actual vehicles (a sedan and a sports utility vehicle [SUV]).

Multiple studies have examined how various personal factors (age, gender, stature, ethnic group, weight, etc.) or vehicle attributes (steering wheel position, seat cushion angle, seat height, etc.) affect preferred driving postures and/or interior component settings as the pertinent knowledge may guide addressing the needs of diverse driver groups: Parkin, Mackay, and Copper (1995) investigated the effects of age and gender on a set of driver-steering wheel distance measures using various actual vehicles. The driver-steering wheel distances were found to be shorter for females than males, possibly due to the inherent gender-associated differences in stature. Park et al. (2000) examined the gender and stature effects on preferred driving postures and interior component settings. Shorter subjects on average sat closer to the steering wheel with more heightened cushion levels. Females were found to sit closer to the steering wheel than males. Also, Park et al. (2000) identified some postural differences between two ethnic groups (Korean and Caucasian driver groups) in preferred driving postures. McFadden, Powers, Brown, and Walker (2000) examined the effects of gender, height, age and weight on a set of driver-steering wheel distance measures. The participants drove actual vehicles of different classes. Taller drivers were found to have larger driver-steering wheel distances. The driver-steering wheel distances were found to be shorter for female and also for older drivers. These observations seem attributable to the gender-associated stature differences and age-related changes in statue. Heavier drivers had smaller driver-steering wheel distances, which appears to reflect the change in girth associated with increased body weight. Reed, Manary, Flannagan, and Schneider (2000) examined the effects of various vehicle attributes (steering wheel position, seat cushion angle and seat height) and also the gender differences utilizing a reconfigurable vehicle mockup. Gender was found to have no effect on driving postures when controlling for stature. Hanson, Sperling, and Akselsson (2006) examined the gender and stature effects using a highly adjustable vehicle mockup that provides seat, steering wheel and pedal adjustment ranges much larger than provided by existing vehicles. Gender and stature were found to significantly affect preferred interior component settings. However, no such effects were found on preferred driving posture (joint angles). Kyung and Nussbaum (2009) examined the effects of age, gender and stature on preferred driving postures. The study found that younger drivers ($20 \leq$ age ≤ 35) had greater right elbow and left hip angles than older subjects (age ≥ 60), females had a greater left elbow angle and shorter drivers had a greater left ankle angle.

Some studies attempted to predict driving postures or vehicle interior component settings: Reed, Manary, Flannagan, and Schneider (2002) made prediction model for driving postures using regression models. Vogt, Mergl, and Bubb (2005) offered new concepts to predict vehicle interior component settings for interior layout design using Computer-Based, Anthropometric Human Model for Passenger Simulation (RAMSIS). Kyung, Nussbaum, and Babski-Reeves (2010) classified the various driving postures into three postural strategies using a statistical clustering approach.

Obese individuals presently represent a major part of the US population. According to the National Center for Health Statistics in 2010, the percentages of overweight ($25.0 \leq$ body mass index [BMI] < 30.0), obese ($30.0 \leq$ BMI <40) and extremely obese ($40.0 \leq$ BMI) for U.S. adults aged 20 years and over are 34.2%, 33.8%, and 5.7%, respectively. This means that approximately 40% of the U.S. adult population is currently obese or extremely obese. Overweight people have a great chance to eventually become obese. The prevalence of overweight and obesity is expected to continue in the near future.

Despite substantial past automotive ergonomics research, preferred driving postures and interior component settings of obese individuals are not well understood at this point of time. Very few existing vehicle ergonomics studies have provided preferred posture/interior settings data of obese individuals or have investigated the obesity effects. McFadden et al. (2000) examined the effect of body weight on the driver-steering wheel distance. However, this study does not appear to have examined a sufficiently large number of obese individuals.

Given the current prevalence of overweight and obesity in the US population and its likely continuation in the near future, the lack of data/knowledge on the obese population's preference on driving posture and interior component settings is problematic − it hampers adequately addressing the needs of a large portion of the general population. The long-term goal of this research, therefore, is to provide data/knowledge for accommodating obese individuals through vehicle interior design. As an initial effort towards this long-term goal, the aim of this study was to empirically identify the obesity effects on preferred driving postures and vehicle interior component settings. In this study, a preferred driving posture is defined as a self-selected, most preferred posture found in a highly flexible vehicle environment. This study examined preferred settings of the following interior components: seat horizontal and vertical positions and steering wheel displacement and tilt angle.

The main hypotheses of the present study (H1~H4) were as follows:

H1) obese drivers place their seats farther away from gas pedal than non-obese,

H2) obese drivers have greater steering wheel tilt angles than non-obese,

H3) obese and non-obese individuals do not differ in their preferred driving postures (joint angles)

H4) obese and non-obese drivers do not differ in their hip joint center position (horizontal and vertical distance from gas pedal to right great trochanter)

H1 and H2 were based on the fact that obese individuals generally occupy more space than non-obese due to fat deposits in different body parts, i.e., exterior difference between obese and non-obese group may affect vehicle interior dimension. Obesity was also known to reduce the joint ranges of motion (RoMs) for certain body joints and motions (Park, Ramachandran, Weisman, and Jung, 2010). H3 and H4 were based on the observation of Hanson et al. (2006) − no gender and stature effects were found on preferred driving postures. Thus, this study hypothesized that internal linkages (joint angles, hip joint center position) may not be affected by personal factors (gender, stature, obesity, etc.), i.e., joint angles and hip joint position may not be affected by obesity.

A human subjects experiment was conducted to test the above hypotheses. A total of 44 participants participated in this study. The participants were classified by two obesity levels; non-obese ($18.5 \leq BMI < 30$) and extremely obese ($BMI \geq 40$). The extremely obese and non-obese group had similar gender compositions and stature characteristics. This study chose to employ a highly flexible vehicle mock-up that has much larger adjustable ranges of steering wheel configuration and seat position than provided by currently existing real vehicles, in a manner similar to Hanson et al. (2006). This is to determine preferred driving postures and interior settings under minimal environmental constraints/assumptions. While not being able to reflect the current automobile interior design trends, such preference data obtained with minimal environmental constraints/assumptions would better represent individuals' perceptions of ideal driving postures, and thus, better serve as a guide for future vehicle design efforts.

Chapter 2

Experimental methods

2.1. Subjects

Forty-four individuals 20 years or older participated in this study. All of the subjects had a valid driver's license and normal or corrected to normal vision in both eyes. None of them exhibited any obvious musculoskeletal disorders.

Obesity factor was considered in recruiting the participants. The obesity level factor had 2 factor levels: non-obese and extremely obese. Each factor level was defined in terms of the body mass index (BMI). Non-obese was defined as BMI between 18.5 and 30 kg/m^2. This corresponds to the normal weight and overweight according to the World Health Organization (2000) definitions. Extremely obese was defined as BMI 40 kg/m^2 or higher corresponding to the class III obesity (morbidly obese). The extremely obese and non-obese group had similar gender compositions and stature characteristics.

The summary of participant groups is shown in Table 1. In addition, ANOVA for BMI and height were conducted to confirm distinct obesity level and similar height distribution in each group. ANOVA revealed that significant obesity effect was found on BMI ($p<0.001$) and no obesity effect was found on height ($p=0.980$), i.e., Non-obese and Extremely obese groups for BMI were significantly different; on the other hand, height between Non-obese and Extremely obese was not significantly different.

Table 1. Summary of two participant groups

Classification	Non-obese ($18.5\ kg/m^2 \leq BMI < 30\ kg/m^2$)	Extremely obese ($BMI \geq 40\ kg/m^2$)
Male	10	10
Female	13	11
Total	**23**	**21**
Body mass (kg) Mean (SD)	73.79 (11.74)	129.59 (18.99)
BMI (kg/m^2) Mean (SD)	25.9 (2.8)	45.6 (4.5)
Height (cm) Mean (SD)	168.7 (8.9)	167.9 (10.2)

2.2. Adjustable Vehicle Mock-up

A generic, adjustable vehicle interior mockup was utilized to empirically obtain individuals' preferred interior component settings and driving postures. The mock-up consists of: a base platform, gas and brake pedals, a seat, a steering wheel and a gearshift (Figure 1, Table 2). It does not include other typical vehicle elements, such as a roof, a windshield aperture, an instrument panel, etc. The seat, steering wheel and gearshift are all adjustable. The seat has four adjustable degrees of freedom: seat horizontal position, seat vertical position, seat pan angle and seat back angle. The steering wheel is a telescopic type and has two degrees of freedom: steering wheel column displacement (the distance between the center point of the steering wheel and the base point of the steering wheel column) and steering wheel tilt angle. The gearshift has two degrees of freedom: horizontal and vertical positions. The gas and brake pedals are not adjustable.

This study examined individuals' preferred settings of the seat and steering wheel. Seat configurations were represented using four variables: seat horizontal and vertical positions, and seat pan and back angles (Figure 1, Table 2). Seat horizontal position, denoted as Seat X, was defined as the horizontal distance from the ball of foot (BoF) reference point to the seat pivot point. The BoF reference point is defined as the center position of the gas pedal surface when the pedal is not depressed. The seat pivot point is the center of the hinge joint that joins the seat back rest and the rest of the seat. Seat vertical position, Seat Z, was similarly defined as the vertical distance from the BoF to the seat pivot point. Seat pan angle was defined as the horizontal tilt of the seat pan surface. Seat back angle was defined as the angle between the long axis of the back rest and the vertical line.

Steering wheel configurations were represented using two variables: steering wheel column displacement and steering wheel tilt angle (Figure 1, Table 2). Steering wheel column displacement was defined as the distance between the steering wheel center and the hinge joint at the base of the steering wheel column. The steering wheel tilt angle was defined as the angle between the long axis of the steering wheel column and the horizontal line.

The vehicle mockup used in this study was highly adjustable. For all the adjustable interior components, the adjustment ranges were at least twice larger than those provided by existing vehicles of different types and classes. These large adjustment ranges allow emulating various types of vehicle interior configurations. Also, the absence of particular roof, windshield aperture and instrument panel geometries enable human participants to determine preferred interior settings and driving postures under minimal environmental influences or assumptions. In other words, the mockup is suitable for identifying human preferences purely from the postural standpoint. The vehicle mockup is similar to the mockup utilized by Hanson et al. (2006) – both of the mockups are highly adjustable. A difference, however, is that the vehicle mockup in Hanson et al. (2006) was equipped with adjustable pedals while the mockup used in this study has fixed pedals. Although some actual vehicles are equipped with adjustable pedals, they are rather uncommon features.

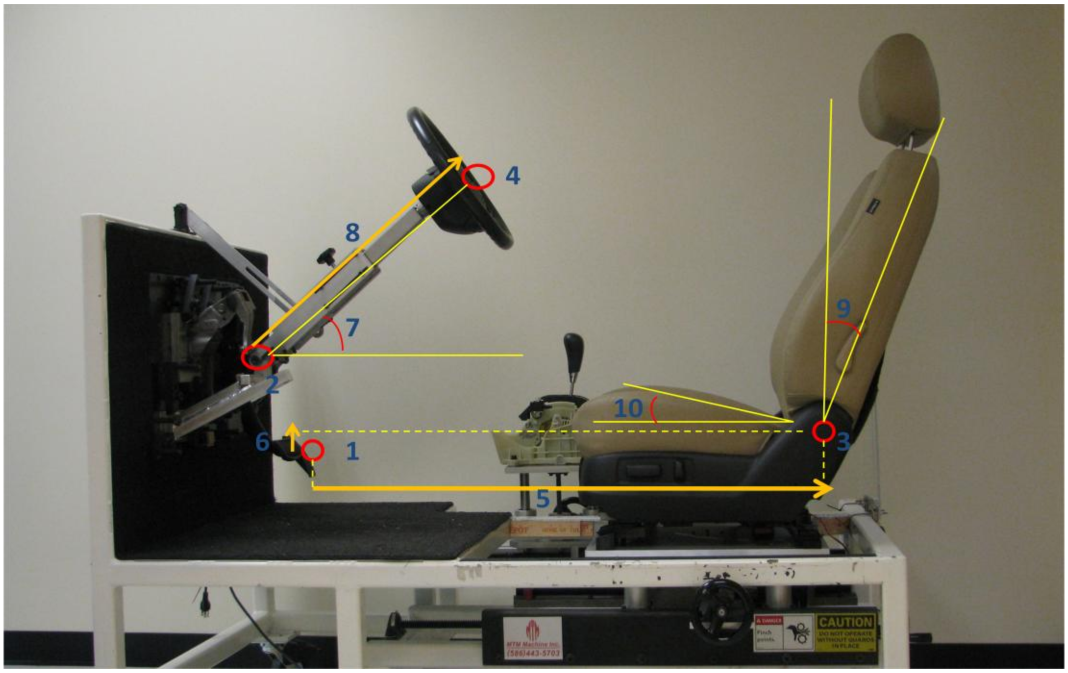

Figure 1. Vehicle Mock-up

Table 2. Description of Mock-up

1	Ball of Foot Reference Point (BoF)	6	Seat Z (SZ)
2	Steering Wheel Tilt Pivot Point	7	Steering Wheel Tilt Angle (SWA)
3	Seat Pivot Point	8	Steering Wheel Column Displacement (SWD)
4	Center of Steering Wheel	9	Seat Back Angle (SBA)
5	Seat X (SX)	10	Seat Pan Angle (SPA)

2.3. Experimental Procedure

Prior to the experimental trial, the purpose and procedures of the present study were fully explained to the participants and an informed consent was obtained from each participant. The research protocol was reviewed as approved by the Auburn University Institutional Review Board (IRB). Each subject changed into appropriate testing attire that consists of tight short pants, a tight sleeveless shirt and athletic shoes (Figure 2). Also, body mass and height were measured to calculate their BMI. After that, 41 reflective markers were attached to each subject's anatomical landmarks. This was for recording driving postures using a 10-camera VICON Motion Capture System. The marker placement protocol is graphically described in Figure 2, and more details of description of skin markers are in Appendix E. The marker placement protocol is a modification of the widely used Plug-in-Gait Marker Placement Scheme (LifeMOD/BodySIM™ Biomechanics Modeler). One notable deviation from the Plug-in-Gait Marker Placement Scheme is the use of the greater trochanter markers. The Plug-in-Gait Marker Placement Scheme uses anatomical locations of the anterior superior iliac spine (ASIS) and posterior superior iliac spine (PSIS) to estimate the pelvis position and orientation and also the hip joint centers. However, this method was not suitable for this experiment as the ASIS and PSIS markers were often obstructed by the driver seat and the fat tissues in the stomach area, and thus, couldn't be seen by the VICON cameras. Thus, the ASIS and PSIS markers were replaced with two markers directly placed upon the left and right greater trochanter landmark. Weinhandl and O'Connor (2010) showed that the markers placed on the greater trochanter landmarks accurately allow estimating the hip joint center locations.

The participants performed a 20 minutes long simulated driving task in the vehicle mockup. They were instructed to hold the steering wheel with both hands and place the right foot on the gas pedal while performing the simulated driving task. No instruction was given regarding the position of the left foot. A dynamic road scene was projected onto a large screen in front of the vehicle mockup as a visual cue. At the beginning of the driving task, the four seat configuration variables (Seat X, Seat Z, Seat Back Angle, Seat Pan Angle) and the two steering wheel configuration variables (Steering Wheel Tilt Angle and Steering Wheel Column Displacement) were set to random levels. The participants were instructed to freely adjust the six variables at any time during the driving task until finding the most preferred settings.

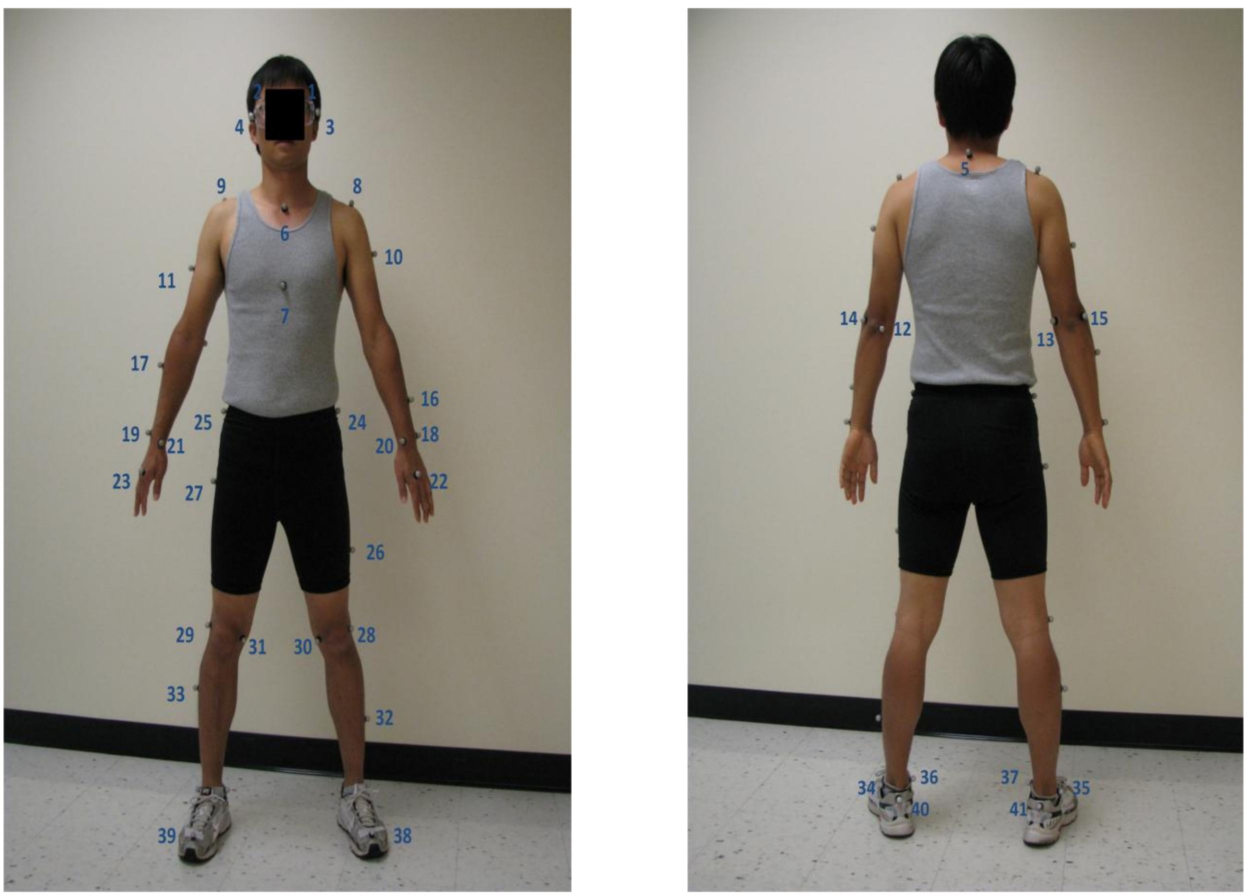

Figure 2. Locations of Skin Markers

At the completion of the 20 minute long driving task, the six variables representing the self-selected, most preferred interior settings were measured and recorded by the experimenter using tape measures and protractors mounted at different locations in the vehicle mockup. Also, the VICON Motion Capture System was used to capture the body-attached reflective markers in the most preferred driving posture. The VICON NEXUS software program was used to identify the reflective markers, calculate their 3-D coordinates, and finally, construct the stick figure linkage system (Figure 3). The most preferred driving posture was represented as a set of twelve joint angles defined in the sagittal plane from the 3-D marker position data. Moreover, hip joint center position (Hip X and Z) was calculated by horizontal and vertical distance from right great trochanter to gas pedal. The hip joint center position was used to measure driver-gas pedal distance. Definition of the joint angle and hip joint center position are provided in Figure 4 and Table 3. The angles used and their definitions are similar to those used by Reed, Manary, and Schneider (1999), and Kyung and Nussbaum (2009).

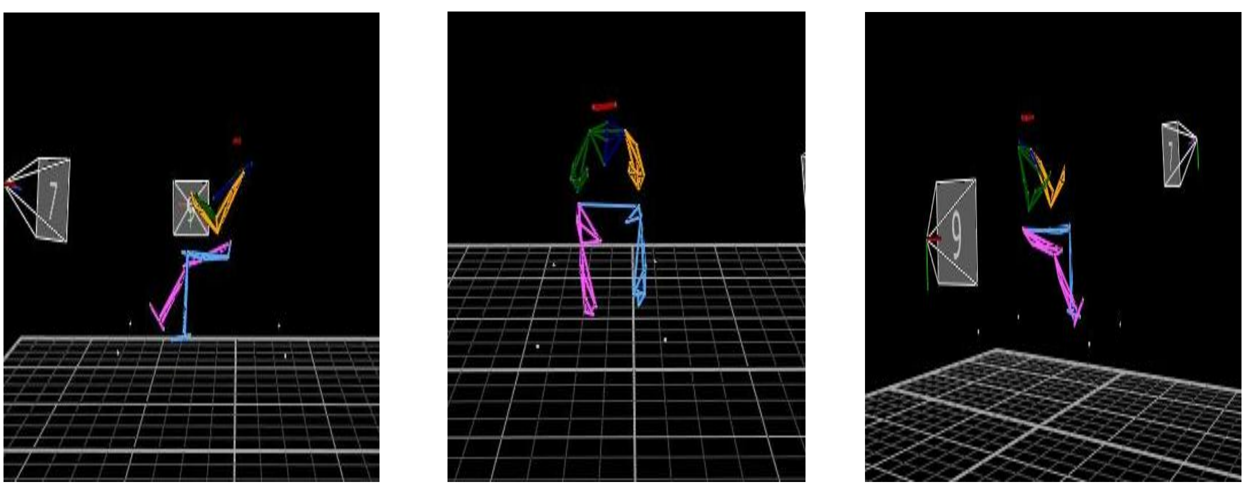

Figure 3. VICON Stick Figures

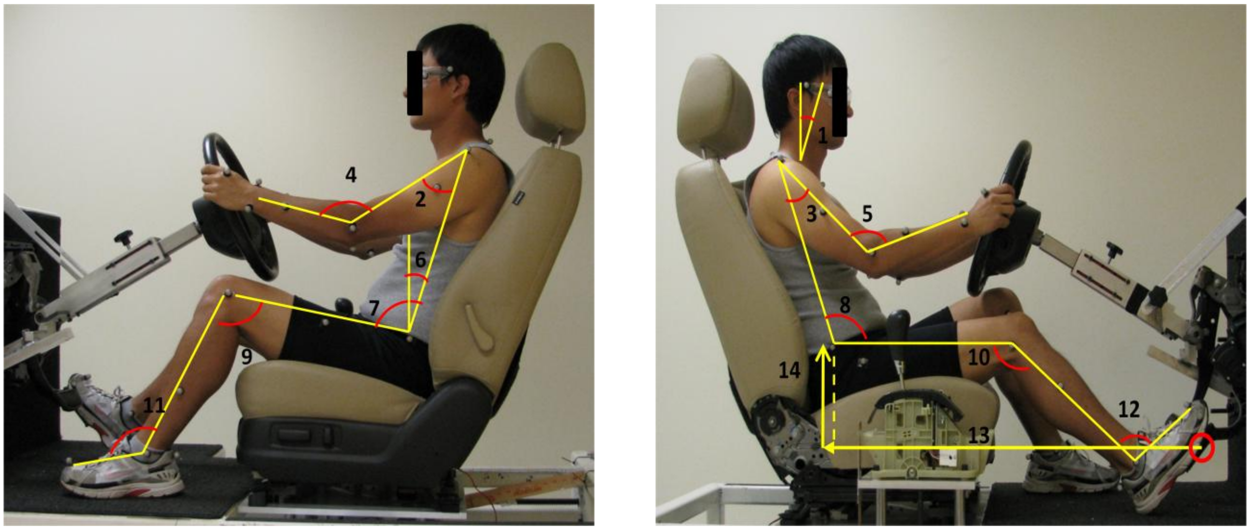

Figure 4. Definition of Joint angles and Hip joint center position

Table 3. Description of Joint angles and Hip joint center position

Joint angle	Joint center	Adjacent joints
Neck (1)	Lower neck joint (middle point between C7 and Clavicle)	Upper neck (middle point between RFH, LFH,RBH, and LBH), Vertical line
*Shoulder (2, 3) (LS: Left shoulder, RS: Right shoulder)	Shoulder joint (top of acromion process)	Elbow and hip joints
*Elbow (4, 5) (LE: Left elbow, RE: Right Elbow)	Elbow joint (lateral epicondyle of elbow)	Wrist (middle point between thumb side of wrist and pinky side of wrist) and shoulder joints
Torso (6)	Middle point of Hip joint (great trochanter)	Middle point of shoulder joint, vertical line
*Hip (7, 8) (LH: Left hip, RH: Right hip)	Hip joint (great trochanter)	Knee and shoulder joints
*Knee (9, 10) (LK: Left knee, RK: Right knee)	Knee joint (lateral epicondyle of knee)	Hip and ankle joints
*Ankle (11, 12) (LA: Left ankle, RA: Right ankle)	Ankle joint (lateral malleolus of ankle)	Knee joint, second toe
Hip X (13)	Horizontal distance from Ball of Foot reference point to right great trochanter	
Hip Z (14)	Vertical distance from Ball of Foot reference point to right great trochanter	

Note: based on Reed et al. (1999), Kyung & Nussbaum (2009)
*Angles defined bilaterally

2.4. Statistical method

Statistical analyses were conducted to examine the obesity effects on preferred interior settings (seat and steering wheel configurations), driving postures (body joint angles), and hip joint center position (horizontal and vertical distance from gas pedal to right great trochanter). Obesity level was defined as independent variables. Obesity level had two factor levels: non-obese ($18.5 kg/m^2 \leq BMI < 30 kg/m^2$) and extremely obese ($BMI \geq 40 kg/m^2$). The dependent variables are as follows: interior component settings (Seat X, Seat Z, Seat back angle, Seat pan angle, Steering wheel tilt angle and Steering wheel column displacement), joint angles (Neck, Shoulder, Elbow, Hip, Torso, Knee and Ankle) and Hip joint center position (Hip X and Hip Z).

A correlation analysis (Pearson's r) was performed to identify correlations among the dependent variables. A MANOVA (Multivariate Analysis of Variance) was conducted to assess the effects of obesity level on the overall dependent variables. Subsequently, a series of one-way ANOVAs (Analysis of Variance) were conducted to examine the effects of obesity level on each dependent variable. The Minitab statistical software program was used to conduct all statistical analyses. The α-level was set at 0.05 for all statistical analyses.

Chapter 3

Results

3.1. Correlation analysis

The results of the correlation analysis are provided in Table 4 - only statistically significant ($p \leq 0.05$) correlations are presented. As can be seen from Table 4, many pairs of dependent variables had significant correlations, which suggested that a MANOVA could be conducted on the entire set of the dependent variables.

3.2. MANOVA

The MANOVA on the entire set of the dependent variables identified a statistically significant difference between the extremely obese and non-obese groups ($p=0.014$). This indicates that overall, extreme obesity affected preferred driving postures, interior component settings and hip joint center position.

Table 4. Correlation coefficients (Pearson's r) at $p \leq 0.05$

	SX	SZ	SWA	SWD	SBA	SPA	Neck	LE	LS	LH	Torso	LK	LA	RE	RS	RH	RK	RA	Hip X	Hip Z
SX	1																			
SZ	–	1																		
SWA	–	–	1																	
SWD	.39	–	(-) .42	1																
SBA	–	–	–	–	1															
SPA	–	–	–	–	–	1														
Neck	–	–	–	–	–	–	1													
LE	.52	–	–	–	–	–	–	1												
LS	–	–	–	–	–	–	–	.51	1											
LH	–	–	–	–	–	–	–	–	(-) .33	1										
Torso	–	–	–	.34	.39	–	–	–	(-) .56	.57	1									
LK	.43	–	–	–	–	–	.30	–	–	.47	–	1								
LA	.43	–	–	.30	.30	–	–	.43	–	–	–	.60	1							
RE	.60	–	–	–	–	–	–	.83	.46	–	–	.42	.43	1						
RS	–	–	.33	–	(-) .33	–	–	–	.78	–	(-) .49	–	–	.45	1					
RH	–	–	–	–	–	–	–	–	(-) .45	.64	.61	–	–	–	(-) .57	1				
RK	–	–	–	–	–	–	–	–	–	.31	–	–	–	–	–	.62	1			
RA	.42	(-) .32	–	–	–	–	–	.55	–	–	–	.30	.35	.58	–	–	–	1		
Hip X	.79	–	–	.49	–	.33	–	.39	–	–	–	–	.37	.48	–	–	–	.42	1	
Hip Z	–	.38	–	–	–	–	–	–	–	.46	–	–	–	(-) .32	–	.45	–	(-) .38	–	1

3.3. ANOVAs

Following the MANOVA, an ANOVA was performed to examine and characterize the obesity effect on each of the dependent variables. The ANOVAs revealed that extreme obesity significantly affected only part of the dependent variables (Table 5). The dependent variables significantly affected by extreme obesity are: Seat X (SX), Steering wheel tilt angle (SWA), Steering wheel column displacement (SWD), Seat back angle (SBA), Left elbow angle (LE), and Right elbow angle (RE). The extremely obese group had larger SX (+38.2 mm), larger SWA (+5.5°), smaller SWD (-21.7 mm), smaller SBA (-3.9°), larger LE (+13.0˚) and larger RE (13.3˚) than non-obese subjects. Out of the twelve body joint angles, only the RE and LE were found to be significantly affected by extreme obesity. There were no significant group differences in hip joint center position.

Table 5. ANOVA results and mean difference

	Non-obese	Extremely obese	Mean difference (Extremely obese − Non-obese)	p-value
SX (mm)	1010.9	1049.1	**38.2**	**0.031***
SZ (mm)	103.6	100.0	- 3.6	0.541
SWA (˚)	30.4	35.9	**5.5**	**P < 0.001***
SWD (mm)	618.6	596.9	**- 21.7**	**0.013***
SBA (˚)	19.5	15.6	**- 3.9**	**0.019***
SPA (˚)	9.1	8.9	- 0.2	0.781
Neck (˚)	22.4	24.5	2.1	0.161
LE (˚)	114.4	127.4	**13.0**	**0.015***
LS (˚)	34.8	39.6	4.8	0.207
LH (˚)	103.6	106.7	3.1	0.265
Torso (˚)	17.3	16.3	− 1.0	0.554
LK (˚)	110.1	119.0	8.9	0.052
LA (˚)	119.9	122.5	2.6	0.480
RE (˚)	112.1	125.4	**13.3**	**0.006***
RS (˚)	33.9	37.9	4.0	0.347
RH (˚)	106.1	106.4	0.3	0.926
RK (˚)	123.9	126.6	2.7	0.464
RA (˚)	92.9	97.6	4.7	0.232
Hip X (mm)	844.8	839.8	− 5.0	0.792
Hip Z (mm)	225.1	235.5	10.4	0.408

Note: * indicates significant at $p \leq 0.05$

Chapter 4

Discussion

As shown in Table 5, no significant obesity level effects were found for most of the body joint angles considered: the neck, two shoulder, two hip, torso, two knee and two ankle joints were not significantly affected by obesity level. The two elbow joint angles were the only exceptions. Extreme obesity was found to increase the elbow joint angles. The absence of obesity effects on most of the body joints indicates that at the internal linkage (skeleton) level, preferred driving postures did not significantly differ between the two participant groups, except for the lower arms posture.

Obesity level significantly affected neither of the two hip joint center positions (Hip X and Hip Z) (Table 5). This finding is consistent with the observed absence of obesity level effects on the body joint angles in the lower body. The two participant groups did not significantly differ in stature (Table 1), which suggests that they would be anthropometrically similar in the lower body length dimensions. Given such anthropometric similarity, the absence of significant angular differences would result in no statistically significant differences in the hip joint center position.

In contrast to the results from the joint angles and hip joint center positions analyses described above, obesity level was found to affect many of the variables that represent preferred interior component settings (Table 5). The extremely obese group was found to place the seat farther away from the fixed BoF position (Seat X), tilt the steering wheel more forward away from the driver body (Steering Wheel Tilt Angle) and use smaller steering wheel column displacements (Steering Wheel Column Displacement) than non-obese (Table 5). Also, the extremely obese group had smaller seat back angles.

Given the lack of significant group differences in most of the body joint angles and the hip joint center positions, the observed significant obesity level effects on the seat position and steering wheel configuration seem to reflect primarily the obesity-associated body volume increases, especially in the abdomen, buttock, thigh and back areas, and thus, the needs for larger clearances. When the hip joint center position is fixed at a particular point in space with respect to a fixed BoF position, obesity-associated volume increase in the buttock and back areas would result in a more rearward position of the seat from the BoF position. Similarly, obese individuals would require more clearances between the steering wheel and their bodies due to the volume increases in the abdomen and thigh areas, and therefore, would have to tilt the steering wheel more forward. Forward tilting without adjusting the steering wheel column displacement moves the steering wheel forward and upward. It is thought that the decrease in the steering wheel column displacement was for offsetting the increase in the vertical position of the steering wheel due to the forward tilting. Also, the significantly smaller seat back angle and larger elbow angles for the extremely obese group seem due to the requirement for extended arm reach in the forward direction.

All things considered, hip joint center position and most of the joint angles were not affected by external difference between extremely obese and non-obese individuals; on the other hand, external difference between extremely obese and non-obese group affected interior component settings. Therefore, the results showed that driving postures of the two groups had similarity. During driving, drivers move lower body restrictively because of driving work in narrow space between gas pedal and seat – drivers should place right (left) foot on gas or brake pedal in narrow space between pedals to seat. If drivers are not able to push gas (brake) pedal sufficiently, they cannot move (stop) vehicle quickly. Therefore, drivers first adjust their seat to sufficiently push brake and gas pedal when they get into vehicles. The adjustment of seat maintains their lower body similarly between two groups. Also, drivers are likely to maintain their torso and neck within certain range of joint angle because of visibility, i.e., they have to see outside traffic signal, other cars, and people through windshield and mirror. The behaviors of driving work make the two groups maintain similar driving postures in lower body, torso, and neck. On the other hand, drivers move their arms and hands flexibly because drivers may choose various manipulations of steering wheel – they place their hands anywhere on steering wheel to operate steering wheel. In addition, drivers are able to place either hand on steering wheel. The driving work in steering wheel makes drivers move their arms and hands freely. Therefore, elbow angles had no similarity between the two groups.

Kee and Karwowski (2003) showed elbow had the smallest relative discomfort index (RDI) of joint motion than other joints (shoulder, neck, lower back, hip, ankle, and wrist) in the sitting posture. The results also supported to the difference of elbow angles between the two groups. Moreover, comparing elbow and shoulder, shoulder had greater RDI than elbow. Thus, when extremely obese drivers reach their hands on steering wheel, they did not choose greater shoulder angle but stretched elbows (larger elbow angles).

This study found obesity effects on preferred driving postures and vehicle interior component settings. Also, it provided new direction for future vehicle design – considering obesity effects for vehicle interior design is necessary. The contribution was significant because previous study for vehicle ergonomics did not consider obesity effects importantly. Many obese people might feel uncomfortable during driving current vehicles since automobile companies have been making vehicles fit for non-obese people. Obese population will be expected to be a major part of vehicle consumers. If automobile companies consider obese drivers and make more flexible vehicle component settings or changing shape of interior component (e.g., highly adjustable seat and steering wheel, changing shape of steering wheel, and etc.), the design accommodates various individuals' preferences. Also, it may positively influence consumers' purchasing decisions.

This study found obesity effects. However, this study had some limitations which future studies need to investigate. First, this study used static vehicle mock-up. Drivers may change driving postures in dynamic vehicle mock-up because different environment (speed, vibration, noise, etc.) may affect sense of equilibrium and preference. Second, this study did not consider various driving situations (night, weather, road condition, etc.). For instance, drivers have difficulty in driving when raining. The difficulty may influence driving postures. Third, this study did not consider long-term driving. If people drive their vehicles for a long time (e.g., over 3 hours), musculoskeletal fatigues may affect driving postures. Finally, this study did not investigate other personal factors (age, gender, stature, etc.) and interaction effect among personal factors. Therefore, future studies need to investigate various situations and factors mentioned above.

Chapter 5

Conclusions

Differences between extremely obese and non-obese drivers were obtained. First, extremely obese drivers needed more space from steering wheel to seat because their fat body – extremely obese drivers had great Seat X, greater Steering wheel tilt angle and smaller steering wheel column displacement. Second, hip joint center position (horizontal and vertical distance from gas pedal to right great trochanter) was not different between extremely obese and non-obese individuals. Third, most of the driving postures were not affected by obesity level. Finally, this study suggested new direction for future vehicle design − considering obesity effects for vehicle interior design is necessary.

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Appendices

Appendix A

ANOVA Table for BMI and Height by Minitab Statistical Software

General Linear Model: BMI, Height versus Obesity

Factor	Type	Levels	Values
Obesity	fixed	2	0, 1

Analysis of Variance for BMI, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Obesity	1	4270.8	4270.8	4270.8	307.53	0.000
Error	42	583.3	583.3	13.9		
Total	43	4854.1				

S = 3.72655   R-Sq = 87.98%   R-Sq(adj) = 87.70%

Unusual Observations for BMI

Obs	BMI	Fit	SE Fit	Residual	St Resid
43	54.5935	45.6428	0.8132	8.9507	2.46 R
44	53.2538	45.6428	0.8132	7.6111	2.09 R

R denotes an observation with a large standardized residual.

Analysis of Variance for Height, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Obesity	1	0.06	0.06	0.06	0.00	0.980
Error	42	3818.27	3818.27	90.91		
Total	43	3818.33				

S = 9.53473   R-Sq = 0.00%   R-Sq(adj) = 0.00%

Unusual Observations for Height

Obs	Height	Fit	SE Fit	Residual	St Resid
24	149.000	168.305	2.081	-19.305	-2.07 R

33	188.800	168.305	2.081	20.495	2.20 R

R denotes an observation with a large standardized residual.

Grouping Information Using Tukey Method and 95.0% Confidence for BMI

Obesity	N	Mean	Grouping
1	21	45.6	A
0	23	25.9	B

Means that do not share a letter are significantly different.

Grouping Information Using Tukey Method and 95.0% Confidence for Height

Obesity	N	Mean	Grouping
0	23	168.4	A
1	21	168.3	A

Means that do not share a letter are significantly different.

Appendix B

Correlation Analysis by Minitab Statistical Software

Correlations: SX, SZ, SWA, SWD, SBA, SPA, Neck, LE, ..., Hip Z

	SX	SZ	SWA	SWD	SBA	SPA	Neck	LE	LS
SZ	-0.065								
	0.674								
SWA	0.060	0.292							
	0.697	0.054							
SWD	0.385	0.001	-0.417						
	0.010	0.995	0.005						
SBA	-0.011	-0.008	-0.264	0.245					
	0.942	0.957	0.084	0.109					
SPA	0.233	0.044	-0.114	0.259	0.078				
	0.127	0.776	0.461	0.089	0.614				
Neck	0.181	0.016	-0.066	0.096	0.108	-0.019			
	0.239	0.919	0.670	0.534	0.487	0.901			
LE	0.524	-0.117	0.217	-0.034	0.077	-0.089	0.208		
	0.000	0.450	0.157	0.828	0.621	0.566	0.176		
LS	0.124	0.123	0.214	-0.092	-0.185	-0.202	0.070	0.514	
	0.422	0.426	0.163	0.554	0.228	0.188	0.651	0.000	
LH	0.071	0.129	0.077	0.169	-0.118	-0.019	0.172	0.102	-0.325
	0.649	0.402	0.621	0.273	0.447	0.900	0.265	0.510	0.031
Torso	0.093	-0.137	-0.169	0.340	0.389	0.039	-0.077	0.114	-0.559
	0.547	0.375	0.272	0.024	0.009	0.800	0.620	0.462	0.000
LK	0.427	-0.164	-0.066	0.204	-0.101	0.122	0.301	0.279	0.124
	0.004	0.286	0.672	0.184	0.513	0.432	0.047	0.066	0.424
	SX	SZ	SWA	SWD	SBA	SPA	Neck	LE	LS
LA	0.432	-0.243	-0.151	0.302	0.298	0.279	0.026	0.429	0.144
	0.003	0.112	0.329	0.046	0.049	0.067	0.868	0.004	0.351
RE	0.604	-0.209	0.203	0.024	-0.045	0.020	0.278	0.827	0.457

	0.000	0.173	0.187	0.876	0.774	0.897	0.068	0.000	0.002
RS	0.096	0.198	0.327	0.044	-0.328	-0.040	-0.031	0.271	0.779
	0.536	0.197	0.030	0.776	0.030	0.795	0.840	0.075	0.000
RH	0.090	-0.081	-0.201	0.033	0.099	-0.201	0.104	0.039	-0.449
	0.563	0.603	0.192	0.834	0.522	0.191	0.502	0.803	0.002
RK	0.216	0.057	-0.155	-0.060	-0.188	-0.155	0.179	0.137	-0.026
	0.160	0.712	0.315	0.698	0.223	0.315	0.246	0.376	0.866
RA	0.420	-0.317	0.104	0.158	0.134	0.182	0.164	0.546	0.293
	0.005	0.036	0.501	0.306	0.386	0.238	0.288	0.000	0.054
HIP X	0.789	-0.043	-0.212	0.490	0.217	0.329	0.267	0.389	0.156
	0.000	0.783	0.167	0.001	0.157	0.029	0.079	0.009	0.311
HIP Z	-0.028	0.377	0.297	-0.180	-0.136	-0.130	0.097	-0.229	-0.238
	0.856	0.012	0.051	0.241	0.380	0.400	0.530	0.134	0.120

	LH	Torso	LK	LA	RE	RS	RH	RK	RA
Torso	0.573								
	0.000								
LK	0.446	-0.002							
	0.002	0.990							
LA	0.092	0.224	0.597						
	0.554	0.143	0.000						
RE	0.037	-0.001	0.416	0.431					
	0.811	0.996	0.005	0.003					
RS	-0.196	-0.486	0.106	0.036	0.447				
	0.202	0.001	0.492	0.817	0.002				
RH	0.635	0.606	0.133	-0.032	-0.059	-0.569			
	0.000	0.000	0.389	0.834	0.703	0.000			

	LH	Torso	LK	LA	RE	RS	RH	RK	RA
RK	0.306	0.026	0.293	0.017	0.211	-0.110	0.621		
	0.044	0.869	0.054	0.911	0.170	0.475	0.000		
RA	-0.055	-0.055	0.297	0.350	0.577	0.083	-0.052	-0.030	

	0.721	0.721	0.050	0.020	0.000	0.593	0.737	0.846	
HIP X	-0.197	-0.099	0.268	0.372	0.478	0.147	-0.148	0.109	0.418
	0.201	0.524	0.078	0.013	0.001	0.342	0.337	0.483	0.005
HIP Z	0.462	0.097	-0.056	-0.241	-0.316	-0.167	0.449	0.234	-0.383
	0.002	0.530	0.719	0.114	0.037	0.279	0.002	0.127	0.010

	HIP X
HIP Z	-0.172
	0.263

Cell Contents: Pearson correlation
P-Value

Appendix C

MANOVA table by Minitab Statistical Software

General Linear Model: SX, SZ, ..., Hip Z versus Obesity

MANOVA for Obesity
s = 1   m = 9.0   n = 10.5

	Test		DF		
Criterion	Statistic	F	Num	Denom	P
Wilks'	0.30569	2.612	20	23	0.014
Lawley-Hotelling	2.27126	2.612	20	23	0.014
Pillai's	0.69431	2.612	20	23	0.014
Roy's	2.27126				

Appendix D

ANOVA table by Minitab Statistical Software

General Linear Model: SX, SZ, ... , Hip Z versus Obesity

Factor	Type	Levels	Values
Obesity	fixed	2	0, 1

Analysis of Variance for SX, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Obesity	1	16042	16042	16042	4.95	0.031
Error	42	136070	136070	3240		
Total	43	152112				

S = 56.9190 R-Sq = 10.55% R-Sq(adj) = 8.42%

Unusual Observations for SX

Obs	SX	Fit	SE Fit	Residual	St Resid
2	1161.49	1010.88	11.87	150.61	2.71 R
26	896.49	1010.88	11.87	-114.39	-2.05 R
28	1160.49	1049.11	12.42	111.38	2.01 R

R denotes an observation with a large standardized residual.

Analysis of Variance for SZ, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Obesity	1	139.4	139.4	139.4	0.38	0.541
Error	42	15411.8	15411.8	366.9		
Total	43	15551.2				

S = 19.1559 R-Sq = 0.90% R-Sq(adj) = 0.00%

Unusual Observations for SZ

Obs	SZ	Fit	SE Fit	Residual	St Resid
5	42.592	103.575	3.994	-60.983	-3.26 R

14	148.392	103.575	3.994	44.817	2.39 R
34	158.392	103.575	3.994	54.817	2.93 R

R denotes an observation with a large standardized residual.

Analysis of Variance for SWA, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Obesity	1	327.95	327.95	327.95	18.07	0.000
Error	42	762.05	762.05	18.14		
Total	43	1090.00				

S = 4.25958   R-Sq = 30.09%   R-Sq(adj) = 28.42%

Unusual Observations for SWA

Obs	SWA	Fit	SE Fit	Residual	St Resid
10	22.0000	30.3913	0.8882	-8.3913	-2.01 R
34	41.0000	30.3913	0.8882	10.6087	2.55 R

R denotes an observation with a large standardized residual.

Analysis of Variance for SWD, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Obesity	1	5141.4	5141.4	5141.4	6.65	0.013
Error	42	32463.4	32463.4	772.9		
Total	43	37604.8				

S = 27.8018   R-Sq = 13.67%   R-Sq(adj) = 11.62%

Unusual Observations for SWD

Obs	SWD	Fit	SE Fit	Residual	St Resid
2	707.295	618.556	5.797	88.739	3.26 R
8	688.295	618.556	5.797	69.739	2.56 R

10	716.295	618.556	5.797	97.739	3.59 R

R denotes an observation with a large standardized residual.

Analysis of Variance for SBA, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Obesity	1	167.19	167.19	167.19	5.97	0.019
Error	42	1176.69	1176.69	28.02		
Total	43	1343.89				

S = 5.29306   R-Sq = 12.44%   R-Sq(adj) = 10.36%

Unusual Observations for SBA

Obs	SBA	Fit	SE Fit	Residual	St Resid
26	9.0000	19.5217	1.1037	-10.5217	-2.03 R
27	3.0000	15.6190	1.1550	-12.6190	-2.44 R
37	2.0000	15.6190	1.1550	-13.6190	-2.64 R

R denotes an observation with a large standardized residual.

Analysis of Variance for SPA, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Obesity	1	0.466	0.466	0.466	0.08	0.781
Error	42	249.278	249.278	5.935		
Total	43	249.744				

S = 2.43623   R-Sq = 0.19%   R-Sq(adj) = 0.00%

Unusual Observations for SPA

Obs	SPA	Fit	SE Fit	Residual	St Resid
1	1.0000	9.0870	0.5080	-8.0870	-3.39 R
5	3.0000	9.0870	0.5080	-6.0870	-2.55 R

R denotes an observation with a large standardized residual.

Analysis of Variance for Neck, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Obesity	1	49.75	49.75	49.75	2.04	0.161
Error	42	1024.78	1024.78	24.40		
Total	43	1074.53				

S = 4.93959   R-Sq = 4.63%   R-Sq(adj) = 2.36%

Unusual Observations for Neck

Obs	Neck	Fit	SE Fit	Residual	St Resid
7	12.0931	22.3866	1.0300	-10.2935	-2.13 R
8	35.4643	22.3866	1.0300	13.0777	2.71 R

R denotes an observation with a large standardized residual.

Analysis of Variance for LE, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Obesity	1	1835.1	1835.1	1835.1	6.37	0.015
Error	42	12100.8	12100.8	288.1		
Total	43	13936.0				

S = 16.9740   R-Sq = 13.17%   R-Sq(adj) = 11.10%

Unusual Observations for LE

Obs	LE	Fit	SE Fit	Residual	St Resid
1	153.083	114.435	3.539	38.648	2.33 R
26	70.769	114.435	3.539	-43.666	-2.63 R

R denotes an observation with a large standardized residual.

Analysis of Variance for LS, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Obesity	1	252.5	252.5	252.5	1.64	0.207

Error	42	6467.5	6467.5	154.0		
Total	43	6720.0				

S = 12.4092   R-Sq = 3.76%   R-Sq(adj) = 1.47%

Unusual Observations for LS

Obs	LS	Fit	SE Fit	Residual	St Resid
41	5.5130	39.6316	2.7079	-34.1187	-2.82 R

R denotes an observation with a large standardized residual.

Analysis of Variance for LH, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Obesity	1	110.10	110.10	110.10	1.28	0.265
Error	42	3616.79	3616.79	86.11		
Total	43	3726.89				

S = 9.27977   R-Sq = 2.95%   R-Sq(adj) = 0.64%

Unusual Observations for LH

Obs	LH	Fit	SE Fit	Residual	St Resid
16	129.408	106.720	2.025	22.687	2.51 R

R denotes an observation with a large standardized residual.

Analysis of Variance for Torso, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Obesity	1	11.05	11.05	11.05	0.36	0.554
Error	42	1305.72	1305.72	31.09		
Total	43	1316.76				

S = 5.57570   R-Sq = 0.84%   R-Sq(adj) = 0.00%

Unusual Observations for Torso

Obs	Torso	Fit	SE Fit	Residual	St Resid
39	3.2995	16.3137	1.2167	-13.0142	-2.39 R
41	29.9193	16.3137	1.2167	13.6056	2.50 R

R denotes an observation with a large standardized residual.

Analysis of Variance for LK, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Obesity	1	872.5	872.5	872.5	4.02	0.052
Error	42	9125.2	9125.2	217.3		
Total	43	9997.7				

S = 14.7400   R-Sq = 8.73%   R-Sq(adj) = 6.55%

Analysis of Variance for LA, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Obesity	1	69.5	69.5	69.5	0.51	0.480
Error	42	5732.9	5732.9	136.5		
Total	43	5802.3				

S = 11.6832   R-Sq = 1.20%   R-Sq(adj) = 0.00%

Unusual Observations for LA

Obs	LA	Fit	SE Fit	Residual	St Resid
26	79.598	119.938	2.436	-40.339	-3.53 R
27	94.534	122.453	2.549	-27.919	-2.45 R

R denotes an observation with a large standardized residual.

Analysis of Variance for RE, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Obesity	1	1942.3	1942.3	1942.3	8.33	0.006
Error	42	9795.8	9795.8	233.2		

Total	43	11738.0

S = 15.2720   R-Sq = 16.55%   R-Sq(adj) = 14.56%

Unusual Observations for RE

Obs	RE	Fit	SE Fit	Residual	St Resid
26	76.759	112.124	3.184	-35.365	-2.37 R

R denotes an observation with a large standardized residual.

Analysis of Variance for RS, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Obesity	1	173.4	173.4	173.4	0.90	0.347
Error	42	8062.5	8062.5	1 92.0		
Total	43	8235.8				

S = 13.8551   R-Sq = 2.11%   R-Sq(adj) = 0.00%

Unusual Observations for RS

Obs	RS	Fit	SE Fit	Residual	St Resid
39	70.7740	37.8788	3.0234	32.8952	2.43 R

R denotes an observation with a large standardized residual.

Analysis of Variance for RH, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Obesity	1	0.63	0.63	0.63	0.01	0.926
Error	42	3045.46	3045.46	72.51		
Total	43	3046.08				

S = 8.51533   R-Sq = 0.02%   R-Sq(adj) = 0.00%

Unusual Observations for RH

Obs	RH	Fit	SE Fit	Residual	St Resid
29	123.348	106.370	1.858	16.978	2.04 R

35	85.486	106.370	1.858	-20.884	-2.51 R

R denotes an observation with a large standardized residual.

Analysis of Variance for RK, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Obesity	1	79.5	79.5	79.5	0.55	0.464
Error	42	6110.1	6110.1	145.5		
Total	43	6189.6				

S = 12.0615   R-Sq = 1.28%   R-Sq(adj) = 0.00%

Unusual Observations for RK

Obs	RK	Fit	SE Fit	Residual	St Resid
4	90.007	123.886	2.515	-33.879	-2.87 R
33	99.132	126.577	2.632	-27.445	-2.33 R
35	102.173	126.577	2.632	-24.404	-2.07 R

R denotes an observation with a large standardized residual.

Analysis of Variance for RA, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Obesity	1	242.6	242.6	242.6	1.47	0.232
Error	42	6940.8	6940.8	165.3		
Total	43	7183.4				

S = 12.8552   R-Sq = 3.38%   R-Sq(adj) = 1.08%

Unusual Observations for RA

Obs	RA	Fit	SE Fit	Residual	St Resid
2	124.752	92.851	2.680	31.901	2.54 R
19	127.534	97.552	2.805	29.982	2.39 R

R denotes an observation with a large standardized residual.

Analysis of Variance for HIP X, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Obesity	1	277	277	277	0.07	0.792
Error	42	165232	165232	3934		
Total	43	165509				

S = 62.7224   R-Sq = 0.17%   R-Sq(adj) = 0.00%

Unusual Observations for HIP X

Obs	HIP X	Fit	SE Fit	Residual	St Resid
2	978.514	844.777	13.079	133.736	2.18 R
24	710.949	839.754	13.687	-128.806	-2.10 R
26	698.527	844.777	13.079	-146.250	-2.38 R

R denotes an observation with a large standardized residual.

Analysis of Variance for HIP Z, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Obesity	1	1173	1173	1173	0.70	0.408
Error	42	70552	70552	1680		
Total	43	71725				

S = 40.9854   R-Sq = 1.64%   R-Sq(adj) = 0.00%

Unusual Observations for HIP Z

Obs	HIP Z	Fit	SE Fit	Residual	St Resid
14	337.746	225.123	8.546	112.623	2.81 R
18	309.546	225.123	8.546	84.423	2.11 R

R denotes an observation with a large standardized residual.

Grouping Information Using Tukey Method and 95.0% Confidence for SX

Obesity	N	Mean	Grouping
1	21	1049.1	A
0	23	1010.9	B

Means that do not share a letter are significantly different.

Grouping Information Using Tukey Method and 95.0% Confidence for SZ

Obesity	N	Mean	Grouping
0	23	103.6	A
1	21	100.0	A

Means that do not share a letter are significantly different.

Grouping Information Using Tukey Method and 95.0% Confidence for SWA

Obesity	N	Mean	Grouping
1	21	35.9	A
0	23	30.4	B

Means that do not share a letter are significantly different.

Grouping Information Using Tukey Method and 95.0% Confidence for SWD

Obesity	N	Mean	Grouping
0	23	618.6	A
1	21	596.9	B

Means that do not share a letter are significantly different.

Grouping Information Using Tukey Method and 95.0% Confidence for SBA

Obesity	N	Mean	Grouping
0	23	19.5	A
1	21	15.6	B

Means that do not share a letter are significantly different.

Grouping Information Using Tukey Method and 95.0% Confidence for SPA

Obesity	N	Mean	Grouping
0	23	9.1	A
1	21	8.9	A

Means that do not share a letter are significantly different.

Grouping Information Using Tukey Method and 95.0% Confidence for Neck

Obesity	N	Mean	Grouping
1	21	24.5	A
0	23	22.4	A

Means that do not share a letter are significantly different.

Grouping Information Using Tukey Method and 95.0% Confidence for LE

Obesity	N	Mean	Grouping
1	21	127.4	A
0	23	114.4	B

Means that do not share a letter are significantly different.

Grouping Information Using Tukey Method and 95.0% Confidence for LS

Obesity	N	Mean	Grouping
1	21	39.6	A
0	23	34.8	A

Means that do not share a letter are significantly different.

Grouping Information Using Tukey Method and 95.0% Confidence for LH

Obesity	N	Mean	Grouping
1	21	106.7	A
0	23	103.6	A

Means that do not share a letter are significantly different.

Grouping Information Using Tukey Method and 95.0% Confidence for Torso

Obesity	N	Mean	Grouping
0	23	17.3	A
1	21	16.3	A

Means that do not share a letter are significantly different.

Grouping Information Using Tukey Method and 95.0% Confidence for LK

Obesity	N	Mean	Grouping
1	21	119.0	A
0	23	110.1	A

Means that do not share a letter are significantly different.

Grouping Information Using Tukey Method and 95.0% Confidence for LA

Obesity	N	Mean	Grouping
1	21	122.5	A
0	23	119.9	A

Means that do not share a letter are significantly different.

Grouping Information Using Tukey Method and 95.0% Confidence for RE

Obesity	N	Mean	Grouping
1	21	125.4	A
0	23	112.1	B

Means that do not share a letter are significantly different.

Grouping Information Using Tukey Method and 95.0% Confidence for RS

Obesity	N	Mean	Grouping
1	21	37.9	A
0	23	33.9	A

Means that do not share a letter are significantly different.

Grouping Information Using Tukey Method and 95.0% Confidence for RH

Obesity	N	Mean	Grouping
1	21	106.4	A
0	23	106.1	A

Means that do not share a letter are significantly different.

Grouping Information Using Tukey Method and 95.0% Confidence for RK

Obesity	N	Mean	Grouping
1	21	126.6	A
0	23	123.9	A

Means that do not share a letter are significantly different.

Grouping Information Using Tukey Method and 95.0% Confidence for RA

Obesity	N	Mean	Grouping
1	21	97.6	A
0	23	92.9	A

Means that do not share a letter are significantly different.

Grouping Information Using Tukey Method and 95.0% Confidence for HIP X

Obesity	N	Mean	Grouping
0	23	844.8	A
1	21	839.8	A

Means that do not share a letter are significantly different.

Grouping Information Using Tukey Method and 95.0% Confidence for HIP Z

Obesity	N	Mean	Grouping
1	21	235.5	A
0	23	225.1	A

Means that do not share a letter are significantly different.

Appendix E

Description of Skin Markers

Point #	Name	Position	Point #	Name	Position
1, 2	Left/Right Forehead (LFH, RFH)	On glasses	20, 21	Left/Right thumb side of wrist (LTW, RTW)	Epicondyle on thumb side of wrist
3, 4	Left/ Right Back head (LBH, RBH)	On glasses	22, 23	Left/Right Finger (LFIN, RFIN)	Knuckle of index finger
5	C7	Lower posterior neck & vertebrae that sticks out when neck is flexed forward	24, 25	Left/Right great trochanter (LGT, RGT)	Pivot point of hip, boney lateral protrusion of femur head
6	Clavicle (CLAV)	Between under neck and upper chest	26	Left thigh (LTH)	Point closer to knee in line with LGT and LLK
7	Sternum (STRN)	Bottom of sternum where ribs meet in center of chest	27	Right thigh (RTH)	Point closer to hip in line with RGT and RLK
8, 9	Left/Right shoulder (LSH, RSH)	Top of acromion process	28, 29	Left/Right Lateral knee (LLK, RLK)	Lateral epicondyle of knee
10	Left upper arm (LUARM)	Point closer to shoulder in line with LSH and LLE	30, 31	Left/Right medial knee (LMK, RMK)	Medial epicondyle of knee
11	Right upper arm (RUARM)	Point closer to elbow in line with RSH and RLE	32	Left lower leg (LLLEG)	Point closer to ankle in line with LLK and LLAN
12, 13	Left/Right medial elbow (LME,RME)	Medial epicondyle of elbow	33	Right lower leg (RLLEG)	Point closer to knee in line with RLK and RLAN
14, 15	Left/Right lateral elbow (LLE, RLE)	Lateral epicondyle of elbow	34, 35	Left/Right lateral ankle (LLAN, RLAN)	Lateral malleolus of ankle
16	Left lower arm (LLARM)	Point closer to hand in line with LME and LTW	36, 37	Left/Right medial ankle (LMAN,RMAN)	Medial malleolus of ankle
17	Right lower arm(RLARM)	Point closer to elbow in line with RME and RTW	38, 39	Left/Right toe (LTOE,RTOE)	Second toe
18, 19	Left/Right pinky side of wrist (LPW, RPW)	Epicondyle on pinky side of wrist	40, 41	Left/Right Heel (LHL, RHL)	Heel

Note: based on Plug-in-Gait Marker Placement (LifeMOD/BodySIM™ Biomechanics Modeler)