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Effects of Obesity on Slip-Related Falls among Young Adults during Gait

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Abstract

Falls present serious medical, health, and societal challenges to not only the frail elderly or individuals with mobility disorders; but also the active and vigorous older adults. Slip-related falls account for about 40% of all falls among older adults. Individuals with obesity are subject to an elevated risk of falls associated with muscle weakness, abnormal body mass distribution, and postural instability. Dynamic gait stability has been identified as a key factor leading to falls after a slip during gait. Despite individuals with obesity suffer higher risk of falls compared to their lean counterparts, no study has investigated how the dynamic stability differs between obese and lean individuals during unperturbed (normal walking) or perturbed (gait slip) walking, and how obesity affects slip-related falls. The overall purpose of this study was to examine whether and to what extent the dynamic gait stability during unperturbed and perturbed gait, as well as the risk of falls in responding to an unexpected slip induced during walking differ between young lean and obese individuals. Forty-six young adults including 23 lean and 23 obese participated in the study. Participants were informed that they would be performing normal walking initially and would experience a simulated slip later without knowing when and how that would happen while walking on the treadmill. After approximately five normal walking trials, all subjects were exposed to the identical and unexpected slip with the perturbation level of 12 m/s^2. Compared with the lean group, individuals with obesity exhibited comparable dynamic stability during normal walking possibly due to their cautious gait pattern. In response to the novel slip, individuals with obesity were less stable at the recovery foot touchdown in comparison with lean individuals. As a result, more people with obesity fell compared to their lean counterparts ($p < 0.01$, 78.3% vs. 40%, odds ratios = 18.9). The findings from this study could provide evidences that individuals with obesity have high risk of falls due

to the less effective control of dynamic stability upon a slip induced in gait, and could be applicable to train older adults with obesity to reduce their risk of falls.

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1. Introduction

1. 1. Falls

Falls are a serious health concern among older adults worldwide. In the United States (U.S.), more than 33% of older adults (aged 65 years and older) fall annually, which resulted in nearly 16,000 deaths in 2005 (Centers for Disease Control and Prevention, 2008). Falls are the second cause of physical injuries like sprains, fractures, bruises, contusions, brain trauma and even death (Corso, Finkelstein, Miller, Fiebelkorn, & Zaloshnja, 2006). Psychologically, falls can also lead to a fear of falling which is associated with a loss of mobility and reduced confidence (Ogden, Carroll, Kit, & Flegal, 2014; Rubenstein & Josephson, 2006). Furthermore, falls exert a heavy economic burden on individuals, families, and our public health system (e.g. in the U.S., 19 billion dollars were used in the treatment of fall-related injuries in 2000) (Corso et al., 2006). Not only the obvious injuries to older adults who experiences falls, but also incidence of falls among older adults influences their families for spending time and effort to take care of the fallers (Centers for Disease Control and Prevention, 2008). In addition, among females aged 75 years or older, the rate of falls leading to injuries continuously increased from 1985 to 2000 (Corso et al., 2006). Therefore, it is urgent to develop training paradigm towards preventing falls among older adults.

1. 2. Effects of obesity on falls

Obesity has become a significant health problem in the U.S. (Wyatt, Winters, & Dubbert, 2006). According to an investigation by The National Health and Nutrition Examination Survey, the prevalence of obesity in 2007-2008 was 32.2% and 35.5% among adult men and women, respectively (Ogden & Carroll, 2010). This prevalence of obesity continues to rise. For

instance, the obesity rates grew by 74% from 1991 to 2001 in the U.S. (Mokdad et al., 2003). Obesity is a common factor contributing to health issues. For example, obesity is closely associated with high risk of developing hypertension, high blood cholesterol, diabetes mellitus, coronary heart disease, and certain forms of cancer (Kopelman, 2000).

Obesity has also been related to various musculoskeletal disorders leading to structural and functional limitations during movement control, which cause an increased risk of falls (Hills et al., 2002; Lai, Leung, Li, & Zhang, 2008; Wearing, Hennig, Byrne, Steele, & Hills, 2006). Obesity is another increasingly serious health issue facing older adults. Based on a study by Flegal, Carroll, Ogden, and Curtin (2010), 37% of men and 34% of women aged 60 and older were considered obese. In some races, obesity could be a more serious problem. For example, 50% of African American women aged 60 years and older are obese (Flegal et al., 2010).

It has been shown that obesity could result in both functional disabilities (Jenkins, 2004) and raised risk of falls (Corbeil, Simoneau, Rancourt, Tremblay, & Teasdale, 2001; Fjeldstad, Fjeldstad, Acree, Nickel, & Gardner, 2008) among older adults. For example, a study by Fjeldstad et al (2008) reported that individuals with obesity and above the age of 50 had a higher likelihood of falls compared to the same age of their lean counterparts (obese: 27% vs. lean: 15%).

Obesity can also affect one's reaction to external perturbations, like slip or trip. Slip-related falls, accounting for about 40% of all falls among older community-dwelling individuals (Luukinen et al., 2000), frequently lead to hip fractures with catastrophic consequences (Yoon &

Lockhart, 2006). Older adults with obesity are less stable, resulting in an impaired ability to recover balance from a slip perturbation and falls (Horak, 1992). It could be challenging for individuals with obesity to take a recovery step during an unexpected slip perturbation because of the insufficient muscle strength and power to generate the necessary lower extremity movements (Madigan, Roseenblatt, & Grabiner, 2014). Wu, Lockhart and Yeoh (2012) presented that individuals with obesity have a higher vertical center of mass (COM) compared to their lean counterparts; and the high vertical COM reduces the stability based on the conventional physical law (Hall, 2012) and requires increased angular momentum to transfer the body's COM forward and vertically into the next step. As a result, the increased momentum by the greater vertical COM excursions among people with obesity requires more metabolic and mechanical energy, compared to the lean counterparts. Other studies reporting the positive correlation between body mass index (BMI) and the risk of falls among older adults, suggest that the excessive BMI could be another factor leading to falls (Corbeil et al., 2001; Fjeldstad et al., 2008).

1. 3. Obesity-related factors increasing risk of falls

Various obesity-related factors could increase the risk of falls. These factors include the increased body mass, muscle weakness, and instability (Corbeil et al., 2001; Hita-Contreras et al., 2013; Myers, Young, & Langlois, 1996). Aging is a general symptom for humans and it usually leads to a decline in muscle strength (Moreland, Richardson, Goldsmith, & Clase, 2004). Muscle weakness has been identified as a risk factor of falls for older adults. A meta-analysis by Moreland et al (2004) indicated that lower extremity weakness is significantly associated with high risk of falls among seniors (Davis, Ross, Nevitt, & Wasnich, 1999; Nevitt, Cummings, &

Hudes, 1991; Tinetti, Doucette, Claus, & Marottoli, 1995). In comparison to lean individuals, people with obesity demonstrated smaller strengths at lower limb (Moreland et al., 2004). Therefore, muscle weakness is one risk factor leading to rising fall incidences in people with obesity.

Another risk factor of falls related to obesity could be the increased body mass (Hita-Contreras et al., 2013). It was postulated that the increased body mass of people with obesity leads to great inertia and further makes a successful recovery from a perturbation difficult (Costello, Matrangola, & Madigan, 2012). To regain balance following a perturbation, one with obesity must generate sufficiently high muscle force or power on lower extremity to correct the body's posture. Costello et al (2012) concluded that the moment of inertia of the body was increased by the additional body mass among people affected by obesity. Consequently, the increased body moment of inertia requires great muscle strength or power to reestablish the balance after a perturbation (Costello et al., 2012). For example, it was suggested that larger plantar-flexor muscle force and power are required to maintain an upright position among persons with obesity than among those who are not affected by obesity (Owings, Pavol, Foley, & Grainer, 2000). The same study found that if there was not enough power in the plantar-flexor muscles, one would be more susceptible to tripping due to a stepping response issue following a large postural disturbance. Given the fact that people with obese have relatively lower muscle strength, the increased body mass further increase the risk of falls among older adults (Hita-Contreras et al., 2013).

Additionally, the abnormality of body fat distribution is another independent risk factor for falls (Hita-Contreras et al., 2013). A cross-sectional and observational study by Hita-Contreras et al (2013) investigated the association of body weight and body fat distribution with postural balance in women with aged 50 to 65 years. The results from this study exhibited that postural instability was significantly associated with weight gain and increased central adiposity distribution types, suggesting that abnormal body fat distribution could be a factor leading to risk of falls.

Older adults with obesity have a decreased capacity of sensorimotor function, resulting in an increased susceptibility to falls (Stelmach & Worringham, 1985). In relation to a balance at standing position, obese individuals who have less plantar sensitivity indicated increased postural sway (Wu & Madigan, 2014). The result from the same study indicated that the impaired foot plantar sensitivity among obesity could be a factor leading to their impaired balance during quiet standing. The impaired sensation of plantar mechanoreceptors, which is a sensory receptor for controlling human balance through the detection of the body position, may provide less feedback to regulate the body to tilt posteriorly and anteriorly. As a result, the central nervous system may be unable to extract the exact body position cue indicating the direction and the amplitude of the whole-body inclination. Thus, the decreased plantar sensitivity among obesity could result in the increased postural sway (Teasdale et al., 2013; Wu & Madigan, 2014) and a higher risk of falls (Teasdale et al., 2013).

Corbeil et al (2001) reported that postural instability originated from the additional mass, muscular atrophy, muscle weakness, and abnormal distribution of fat mass cause many

disadvantages in ambulation among individuals affected by obesity. An assessment of postural stability during quiet standing is fundamental and most common method for an estimation of body balance among obese older adults (Madigan et al., 2014). From this method, obesity appeared to be significantly associated with the decreased postural stability as measured by larger sway amplitude and sway velocity at sagittal plane (Hita-Conterras et al., 2013). In this notion, the anterior-posterior postural instability enabled the location of COM to shift excessively (Corbeil et al., 2001). This excessive excursion of COM among older adults would be fragile to display their COM closer to their boundary of stability when exposed to daily postural stress and perturbation, consequently resulting in greater risk of falls.

The results from the aforementioned studies represented that muscle weakness, the increased adiposity distribution types, the less perceptual sensitivity of plantar sole of the foot, and the postural instability among obesity may position people with obesity at a higher likelihood of falls compared to lean individuals.

1. 4. Slip-related falls in obesity

1. 4. 1. Gait pattern among people with obesity

Obesity affects the way that people walk. For instance, it changes the durations of double stance phase (the time duration that both feet remain in contact with the ground) and single stance phase (the time duration that one foot remains in contact with the ground), the step length, step width, and joint angle during walking. Individuals with obesity usually adopt a “cautious gait” pattern. Specifically, obese adults walked with wider step width than their lean counterparts at their self-selected walking pace (Wu et al., 2012). Spyropoulos, Pisciotta, Pavlou, Cairns, and Simon

(1991) reported that individuals with obesity were inclined to take a greater step width that increases the base of support (BOS), improves the dynamic stability of the body, and reduces the chance of balance loss during gait.

Obese adults tend to walk slowly with short stride (Hulens, Vansant, Claessens, Lysens, & Muls, 2003; Wearing et al., 2006), long stance phase, short swing phase, and prolonged double support phase (Spyropoulos et al., 1991). These adaptive modifications to the gait pattern were also interpreted as underlying movement instability in obesity (Wearing et al., 2006). Another study comparing gait stability between obese and lean prepubertal boys indicated that individuals with obesity had greater percentage of gait cycle in double stance phase than that of their lean counterparts during walking with their self-selected velocity, which could be a compensatory mechanism in response to the instability during obese gait (McGraw, McClenaghan, Williams, Dickerson, & Ward, 2000).

In contrast to the findings from the self-selected velocity of the obese, DeVita and Hortobágyi (2003) reported that, at an identical velocity (1.5 m/s), obese participants produced greater swing time, shorter stance time, greater step length, more frequent step rate compared to their walking with self-selected gait speed, resulting in the diminished gait stability on increased walking speed among obesity. Nevertheless, when obese participants walked with the identical velocity (1.5 m/s) in order to compare gait stability with their lean counterparts, the results indicated that obese participants had shorter swing time and longer stance time on gait patterns. The findings from DeVita and Hortobágyi (2003) exhibited that individuals with obesity had cautious gait patterns to keep their stability on their self-selected gait speed, and their cautious gait patterns

among obesity more and more revealed on the comparison to their lean counterparts at the identical velocity.

In the same study, Devita and Hortobágyi (2003) reported that people with obesity also exhibited a more erect or upright walking pattern when walking at a same velocity (1.5 m/s) as their lean counterparts. In detail, individuals with obesity represented less hip flexion during stance phase, less maximum knee flexion in early stance phase, less knee flexion during stance phase, and more ankle plantarflexion during stance phase. These biomechanical gait parameters among individuals with obesity could be viewed as reflections of the instability during obese gait (Devita & Hortobágyi, 2003).

1. 4. 2. Dynamic gait stability

Stability generally is defined as one's ability to resist loss of balance from perturbations while maintaining an upright posture. In static situations like when a person stands still, one has to confine the projection of the body's COM within the BOS; otherwise, a loss of balance would occur (the static feasible stability region (FSR), Figure 1) (Borelli, 1680). However, the static FSR has been shown insufficient when applied to a dynamic situation. For example, even though the projection of the COM is behind the BOS at liftoff of the trailing foot during gait, the person would not lose his or her balance. In order to examine the stability in dynamic situations, the combination of the horizontal velocity and position of the COM relative to the BOS was considered a key factor for the measurement of dynamic stability (Pai, 2003; Pai & Patton, 1997).

Pai and Patton (1997) adopted an inverted pendulum model assisted by an optimization algorithm to determine the set of feasible COM velocity-position combinations for movement termination. Forward falls would initiate if the COM velocity-position combinations exceeded the upper boundary of the dynamic FSR (FSR with a diagonal band in Figure 1). Conversely, backward falls initiated if the COM velocity-position combination drops below the lower boundary (FSR with a diagonal band in Figure 1). If the combination of horizontal COM velocity-position is located inside the FSR after a perturbation, the person would keep his or her balance without changing the BOS (Pai & Patton, 1997). On the other hand, if the combination of horizontal COM velocity-position is not located in the FSR, the person will have no option but to experience a loss of balance, usually by stepping (Pai & Patton, 1997).

Yang and his colleagues (2008) have extended the definition of the FSR for the movement termination developed by Pai and Patton (1997) to gait situation by using a 7-link bipedal human model. The seven-link model included an upper body segment which was a combination of head, arms, and trunks, and the remaining segments were made up of each right and left thigh, shank, and foot. On the other hand, the two-link model of Pai and Patton (1997) was one model segment represented the placement of the feet and the other segment represented the rest of the body. The 7-link model enabled the accuracy of the instantaneous COM motion state (the combination of horizontal position and velocity of COM) to be figured out during gait patterns. According to the study by Yang, Anderson, and Pai (2007), even though greater minimal horizontal COM velocity was required to prevent a backward balance loss in walking, the feasible stability boundary against backward balance loss in gait in general produced a similar result to the one created by the movement termination published by Pai and Patton (1997).

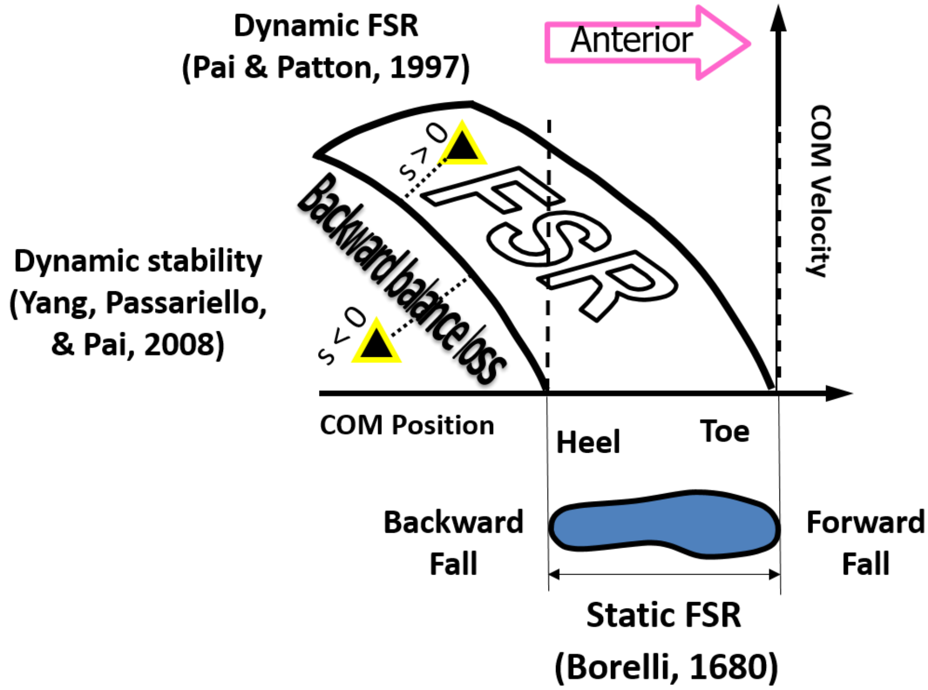

Figure 1.
The Feasible Stability Region (FSR) under both static and dynamic situations. In static situation, the projection of the body's COM has to be located in the BOS for maintaining the stability (Static FSR). However, in dynamic situation, the COM motion state (the combination of COM velocity and COM position in relation to the BOS) has to be located within the dynamic FSR (FSR with a diagonal band) to maintain the stability. The triangle signal (▲) represents the COM motion state. Two arrows indicate the direction that the COM motion state would travel (i.e., *x*-coordinates represent the COM anteroposterior position and the positive *y*-coordinates indicate COM forward velocity). Dynamic stability (*S*) is calculated as the shortest distance from the COM motion state to the corresponding boundary of the dynamic FSR). Zero value of the dynamic stability means that the COM is directly above the posterior border of the FSR, and negative and positive values imply that the COM motion state is below and above to the lower border of the dynamic FSR, respectively. Position and forward velocity of the COM relative to the BOS were dimensionless variables as normalized to foot length and $\sqrt{g \times bh}$, respectively, where g is the gravitational constant and bh is the body height.
Borelli, 1680; Pai & Patton, 1997, Yang, Passariello, & Pai, 2008

The instantaneous dynamic gait stability (S in Figure 1), which is a key factor leading to slip-related falls, was defined as the shortest distance from the COM motion state to the

corresponding boundary of the FSR (Yang, Bhatt, & Pai, 2009). If the COM motion state is located below the boundary (i.e. the stability value is negative), instability will increase, which leads to the backward balance loss due to the insufficient forward COM velocity. Conversely, if the COM motion state is located above the boundary (i.e. the stability value is positive), stability will increase which leads to less likelihood of backward balance loss because the sufficient COM velocity enables the COM motion state to be located inside the FSR.

Human ambulation can be implemented by continuous and repeated minute COM excursions. However, excessive COM excursions during walking leads to loss of balance which results in a fall. To reduce the excursion of the COM during walking, Inman & Eberhart (1953) suggested that the movement of pelvic rotation, pelvic tilt, and lateral pelvic displacement must be minimized while knee and hip flexion, knee and ankle interaction must to be maximized. One study suggested that obese individuals yielded greater hip abduction during the latter half of the double stance phase and reduced ankle plantar flexion during the entire gait cycle (Spyropoulos et al., 1991). From this research, it was hypothesized that the relative excess range of dorsiflexion of the ankle during the double stance phase resulted from the reduced hip flexion coupled with a shorter stride length.

Although dynamic gait stability has been closely related to slip-related falls, no studies have investigated the differences in the COM dynamic stability between the obese and their lean counterparts during walking. It remains unknown whether the dynamic stability control is similar or different between people with obesity and their lean counterpart.

1. 4. 3. Mechanisms of inducing slip

Understanding what causes slip-precipitated ambulation accident is challenging because there are multiple factors involved including the interacting environmental and human behavior. Redfern et al (2001) explained the cause of slips. One fundamental principle is the relationship between the friction required by the pedestrian and the friction available at the surface of the walkway. Second, a slip incidence is originated when the heel did not come to a stop with heel contact. The force interactions between the pedestrians' shoe and the ground surface are probably the most critical biomechanical parameters influencing slip perturbation. For example, if the shear forces generated from a particular step exceed the friction forces between the shoe and the ground surface, the slip perturbation will be inevitable (Redfern et al., 2001). Kinematics of the foot at touchdown (TD) also play an important role in leading to slip perturbation (Redfern et al., 2001). Slip of the heel naturally occurs during most steps, resulting in less than 1 cm of slip distance, and these micro-slips occur without any notice of the walker. However, as the slipping distance increase, this slipping action of the heel is noticed by the pedestrian and falls (Redfern et al., 2001).

Based on these fundamental principles, the stability in obese individuals during slip-induced ambulation has been investigated by using either low-friction surfaces or moveable platforms (Redfern et al., 2001). In some previous research, water oil, floor polish, and ice were used to apply the slippery condition with low-friction between shoe and ground surface interface (Gronqvist, 1995; Manning & Jones, 2001); other previous research in relation to slip-induced conditions, moveable platforms releasing a low-friction between shoe and the platforms were employed (Bhatt, Wening, & Pai, 2006; Parijat & Lockhart, 2012). Although these two types of

methods are easy to apply and cost-effective, they have weaknesses. Specifically, they are hard to control the perturbation level between subjects or even between trials with subject. Without controlling the perturbation intensity, it could introduce some confounding factors, which affect the results. To examine the mechanisms of slip-related falls, a standardized platform, which has the capability to provide an identical slip perturbation among subjects, is highly desired.

Treadmill (TM) is being widely employed in clinical or rehabilitation fields, primarily due to its inherent advanced features. Specifically, a TM requires less space but can provide a sufficient number of steps (Shimada, Obuchi, Furuna, & Suzuki, 2004). In the field of fall prevention research, an instrumented TM is relatively more convenient and less demanding of experimental equipment to generate the slip perturbation compared with the two aforementioned approaches inducing slip perturbation (Shimada et al., 2004).

The TM is able to produce a real-life external slip perturbation within a confined space in a highly-controllable manner. A special TM, ActiveStep (Simbex, Lebanon, NH), induces a slip at a certain moment during walking by suddenly changing the belt speed and direction. This TM has been used in fall prevention studies and various TM-slip training programs (Yang, Bhatt, & Pai, 2013). More importantly, this TM enables all subjects to have an identical slip perturbation with minimizing the potential influences of encountering factors (i.e. an ununiformed exposure level to potential fall hazards, an inconsistent circumstance of falls, and falls collection approach) (Han & Yang, 2015). Shimada et al (2004) also suggested that the unexpected slip perturbation program on the TM might be used as a training method to reduce risk of falls. However, before the slip-induced TM can be deployed as an instrument for fall prevention, it

must be certain that the stability control is similar between overground and TM walking. Therefore, in this study, a special TM was employed to induce an identical slip perturbation for all subjects.

1. 5. Purpose and hypotheses

Research related to the differences in kinematic and kinetic parameters during gait between young lean and obese individuals have been studied (Costello et al., 2008; Fjeldstad et al., 2008; Hita-Contreras et al., 2013; Wu et al., 2012). However, most of the studies concerning falls in people with obesity tackled indirectly this issue by examining other measurements, such as balance recovery on standing posture and gait analysis. No study has been conducted to directly investigate dynamic stability and fall incidences during an unexpected slip induced during walking among people with obesity. Therefore, the effects of obesity on slip-related falls are still not completely clear. As does how the dynamic gait stability control is similar or different between people affected by obese and their lean counterparts during both unperturbed (or normal walking) or perturbed (gait slip) gait.

Therefore, the overall purpose of this study was to examine if and to what extent the risk of falls and dynamic stability in response to an unexpected slip-induced walking on a TM differ between young obese and young lean individuals. In detail, this study was conducted:

1) to determine the between-group (lean vs. obese) differences in COM velocity, COM position, dynamic stability control, and trunk angle at TD of the leading foot during normal walking;

2) to examine if and to what extent the risk of falls in responding to an unexpected slip-induced walking on a TM differs between the two groups; and

3) to determine the differences in the four variables between groups at TD of the recovery foot after slip onset.

Along with the purpose, three hypotheses were testified:

1) individuals with obesity have comparable dynamic gait stability during normal TM walking compared to their lean counterparts;

2) people with obesity would exhibit significantly higher risk of falls in comparison to their lean counterparts when they are exposed to an unexpected slip perturbation during gait on the TM; and

3) individuals with obesity would be less stable than their lean counterparts upon the unexpected slip perturbation during gait on the TM.

2. Methods

2. 1. Participants

Young adults between 18 and 45 years were recruited from the University of Texas at El Paso and local residents via massive e-mail and recruitment flyers. All participants were free of any clinically significant history of musculoskeletal disorders, neurological disorders, orthopedic conditions, or cardiovascular conditions. To be enrolled in this study, participants were either lean or obese. The classifications of lean and obese in terms of BMI and body fat percentage are listed in Table 1 (American College of Sports Medicine, 2014). Subjects who did not meet the criteria as listed in Table 1 were considered overweight and excluded from the study. The body fat percent (Fat%) was measured by a bioelectric impedance analysis (BIA) machine (TBF-310 01A). Fifty-seven subjects were initially screened. Among them, 11 subjects (five males and six females) were classified as overweight. Therefore, forty-six subjects were included in this study. Among them, 23 were lean and the remaining 23 obese young adults, respectively (Table 2).

Table 1. The classifications of lean and obese groups
Two measurements: BMI and Fat% were used to determine whether a participant is a lean or obese. A participant was classified as obese when the BMI is not less than 30 kg/m^2 and the Fat% is not less than a threshold (25% for male and 30% for female). To be classified to the lean group, one's BMI must be lower than 25 kg/m^2 and the body fat percent must be below a per-set threshold value (25% for male and 30% for female)

Gender	Lean		Obese	
	BMI (kg/m^2)	Fat%	BMI (kg/m^2)	Fat%
Female	< 25	< 30	≥ 30	≥ 30
Male	< 25	< 25	≥ 30	≥ 25

Table 2. The demographic information in mean ± SD for both groups

Groups	Age (years)	Gender (female)	Height (m)	Mass (kg)	BMI (kg/m^2)	Fat (%)
Lean (n = 23)	23.9 ± 4.4	16	1.63 ± 0.09	58.4 ± 13.2	21.8 ± 2.8	20.8 ± 5.8
Obese (n = 23)	24.9 ± 5.7	8	1.70 ± 0.10	102.9 ± 17.6	35.1 ± 3.9	37.3 ± 6.0

Prior to the experiment, participants were instructed to wear comfortable clothing and shoes (i.e. shorts and a T-shirt, preferably tight fitting clothing) in order for them to move without limitations and to facilitate attachment of experimental equipment. The study was conducted at the Stanley E. Fulton Biomechanics and Motor Behavior Laboratory at the University of Texas at El Paso. All subjects were informed about the procedures and written consent was obtained prior to the experiment. The study was approved by the University of Texas at El Paso Institutional Review Board.

2. 2. Experimental protocol

After walking over ground five times on a 14-m walkway for warm up, all subjects in both groups were instructed to step on the TM (ActiveStep, Simbex, NH). They were informed that they would be performing normal walking initially and a "slip-like" movement on the TM "later" without knowing when and how that would happen while walking on the TM. They were also told to keep looking forward during walking, and to try to recover their balance without grabbing onto the harness on any slip incidence, and to continue walking.

After three normal walking trails without slip perturbation on the TM at the speed of 1.2 m/s, subjects were instructed that "from now on, you may or may not be slipped during each trial". Following another two normal walking trails, participants were exposed to a slip perturbation. The slip trial began with a ramp up (Figure 2b), followed by a steady state with a backward-moving belt speed of -1.2 m/s. After 10 to 12 regular steps in the slip trial, approximately 80-120 ms later than the TD of the leading foot, the top belt suddenly accelerated forward within 0.2 seconds without the subjects' knowledge. The abruptly reduced backward speed (1.2 m/s) in sagittal plane led to a forward displacement of the subjects' BOS relative to their COM. Such a sudden change in the belt speed generated a slip perturbation (Yang et al., 2013), which was unannounced and difficult to predict. The perturbation level was the same for all subjects as the acceleration was 12 m/s^2 with the slip distance of 0.24 m, providing a standardized framework to induce slips and falls (Figure 2c). Following the slip perturbation, the belt speed returned to -1.2 m/s within 3 seconds, and then continued at a steady speed of -1.2 m/s within 3 seconds until the belt stopped. Full body kinematics data from 26 retro-reflective markers placed on the subjects' body were gathered using an 8-camera motion capture system (Vicon, UK) at 120 Hz.

For all trials on the TM, a full body safety harness, connected by shock-absorbing ropes at the shoulders to an overhead arch, was employed to protect the subjects while imposing negligible constraint to their movement (Yang & Pai, 2011) (Figure 2a). The slackness of the ropes connecting the harness to the arc was precisely adjusted. This was achieved by ensuring the ropes were just fully stretched when subjects stood in the rear of the treadmill belt with knees flexed at 45 degrees (Figure 2b).

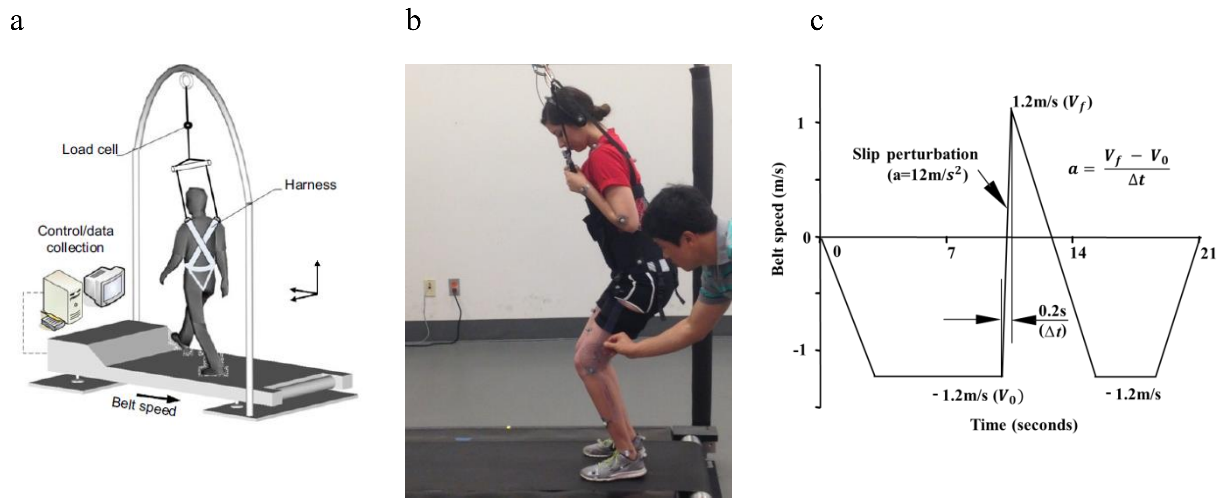

Figure 2.
Experimental setting and slip perturbation profile. (a) Schematics of the treadmill implemented to produce slip perturbation (Yang et al., 2013). A full body safety harness, connected by shock-absorbing ropes at the shoulders to an overhead arch, was employed to protect the subjects while imposing negligible constraint to their movement (Yang & Pai, 2011). (b) The slackness of the ropes connecting the harness to the arc was precisely adjusted. This was achieved by ensuring the ropes were just fully stretched when subjects stood in the rear of the treadmill belt with knees flexed at 45 degrees. (c) The slip perturbation occurred about ten to twelve steps post the belt ramped up to its stabilized speed of -1.2 m/s (negative means the belt moving backward), and then abruptly accelerated to 1.2 m/s within 0.2 s after approximately 80-120 ms later than the TD of the leading foot. Following the perturbation, the belt speed returned to -1.2 m/s within 3 s, and then continued at a steady speed of -1.2 m/s within 3 s until the belt stopped.

2. 3. Data reduction and event identification

A load cell (Transcell, Technology Inc., Buffalo Grove, IL) connecting to the ropes in series measured the force exerted on the ropes. The load cell force was recorded at 600 Hz and synchronized with the motion capture system and the video recording. The force from the load cell was used to determine the outcomes (fall or recovery, Figure 3) of each slip trial. The slip trial was classified as a fall if the peak load cell force exceeded 30% body weight; otherwise, the slip trial would be a recovery (Yang & Pai, 2011). The criterion distinguishing whether an individual falls or not during the slip-induced TM conducted by the peak load cell force was

regarded as the gold standard for determining the slip outcomes, confirmed through visual observation of a recorded video (Yang et al., 2009; Yang & Pai, 2011). Marker paths were low-pass filtered at marker-specific cut-off frequencies (ranging from 4.5 to 9 Hz) using fourth-order, zero-lag Butterworth filters (Winter, 2005). Locations of joint centers, heels, and toes were computed from the filtered marker positions.

The four outcome measurements in the slip trial included COM position, COM velocity, dynamic gait stability, and trunk angle were calculated at two events: the TD of the leading foot before the slip onset (pre-onset TD) and the recovery TD of the trailing foot after slip onset (post-onset TD). These two events were identified based on the feet kinematics (Figure 4a & b). Specifically, the time of the TD was determined when the vertical velocity of the heel marker was below 0.05 m/s.

The body COM displacement was computed using gender-dependent segmental inertial parameters (de Leva, 1996) and its velocity was calculated as the first order displacement with respect to time. The two components of the COM motion state, i.e. its position and velocity were calculated relative to the rear of BOS (i.e. the leading heel) and normalized by foot length (l_{BOS}) and $\sqrt{g \times bh}$, respectively, where g is the gravitational acceleration and bh is the body height. Dynamic stability was calculated as the shortest distance from COM motion state to the limit of stability (Yang et al., 2009). Trunk angle was calculated between the trunk segment and the vertical axis (Figure 5). Positive trunk angle represented that the trunk leaned backward with respect to the vertical axis.

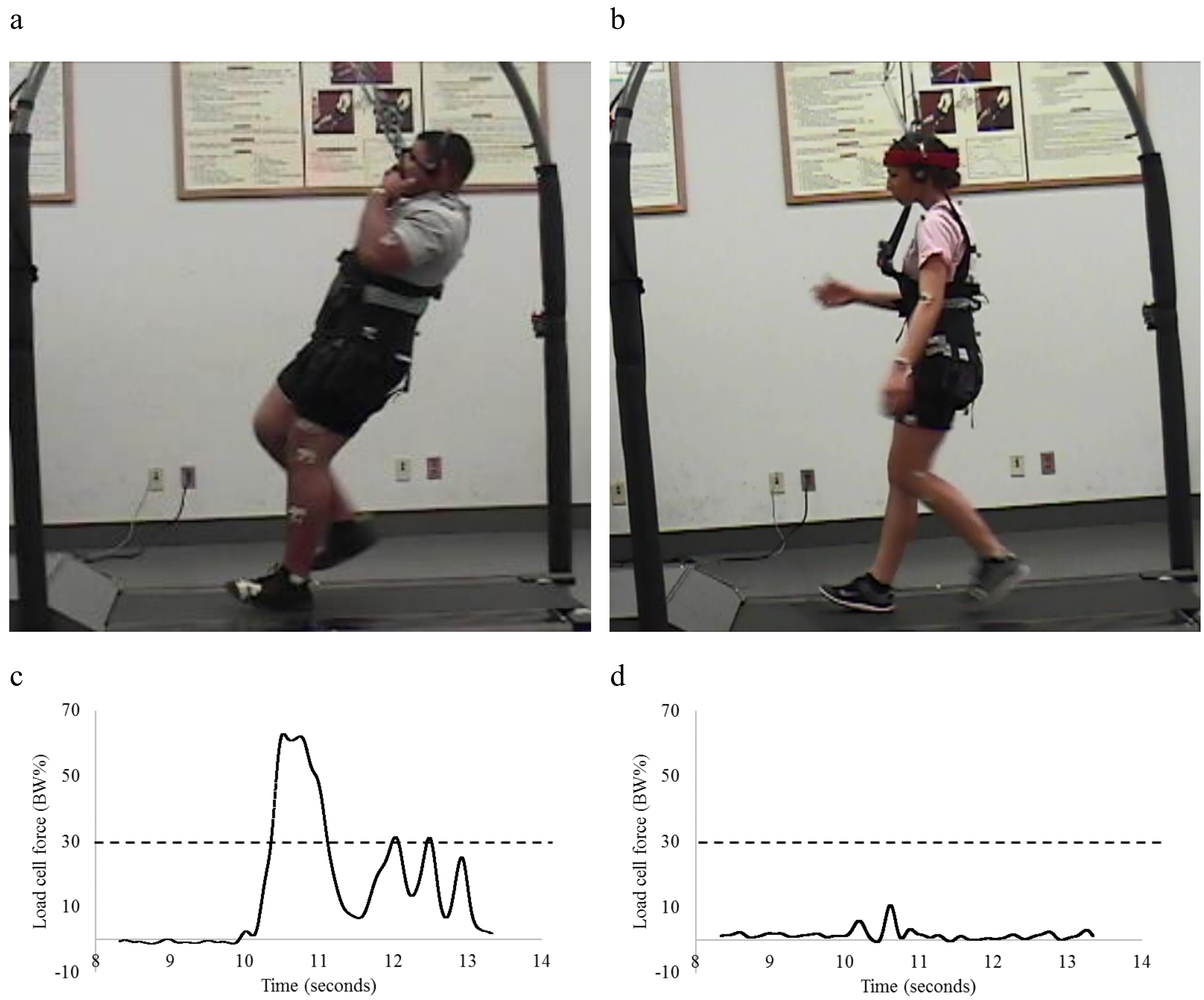

Figure 3.
Pictures indicated two possible outcomes: (a) fall was defined as the peak load cell force was greater than 30% of body weight or equal, and (b) recovery was considered the peak load cell force was less than 30% of body weight. Two plots (c and d) indicated the time history of load cell force during slip trial. Subject in (a) lost his balance and fell backward without successful recovery stepping after slip onset. Approximately, 63% (> 30%) of his body weight was assisted by the harness post slip onset (c). On the other hand, subject in (b) was able to reestablish her balance with successful recovery step after slip onset. The peak load cell force during slip trials was 11% (< 30%) of her body weight.

To examine the differences in spatiotemporal parameters between the two groups, five kinematic gait variables were calculated: the step length (the farthest anteroposterior distance from one heel's TD to another heel's TD), step width (the shortest mediolateral distance between both feet at TD) normalized to the body height (*bh*) (Figure 5), durations of double support phase (the time duration of both feet in contact with the TM) and the single support phase (the time duration of one foot in contact with the TM), and the foot angle which is the angle between the subjects' sole and the ground surface, where a flat foot corresponded to zero degrees (Figure 5).

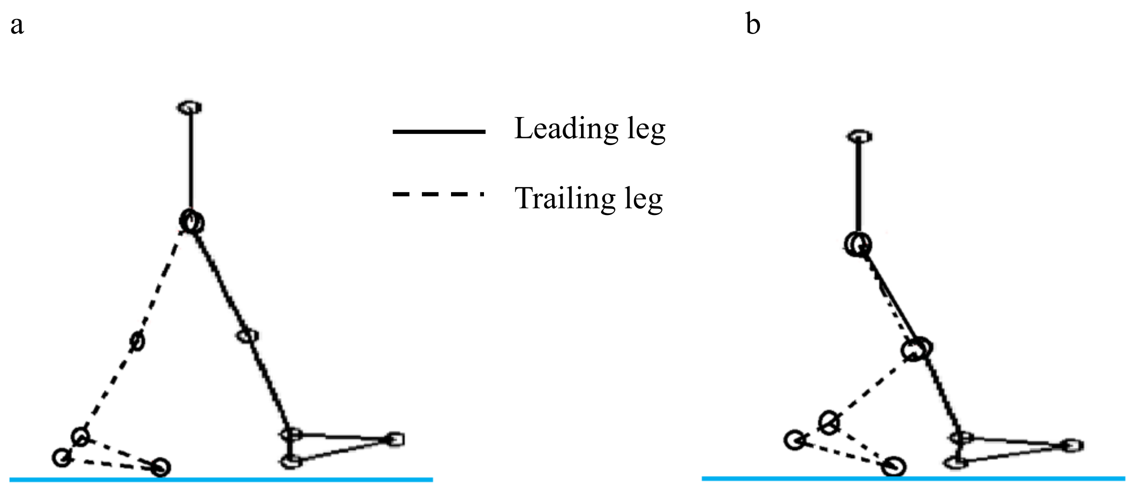

Figure 4.
The identification of the timing for (a) the pre-onset TD and (b) the post-onset TD. (a) indicated the timing for TD of the leading leg (the solid line) before slip onset. The five kinematic gait variables (step length, step width, double support phase, single support phase, and foot angle) and the four stability variables (COM position, COM velocity, dynamic stability, and trunk angle) were calculated at the pre-onset TD after slip onset. (b) indicated the timing for TD of the trailing leg (the dashed line). The four stability variables were calculated at the post-onset TD. These two events were identified when the vertical velocity of the heel marker was below 0.05 m/s.

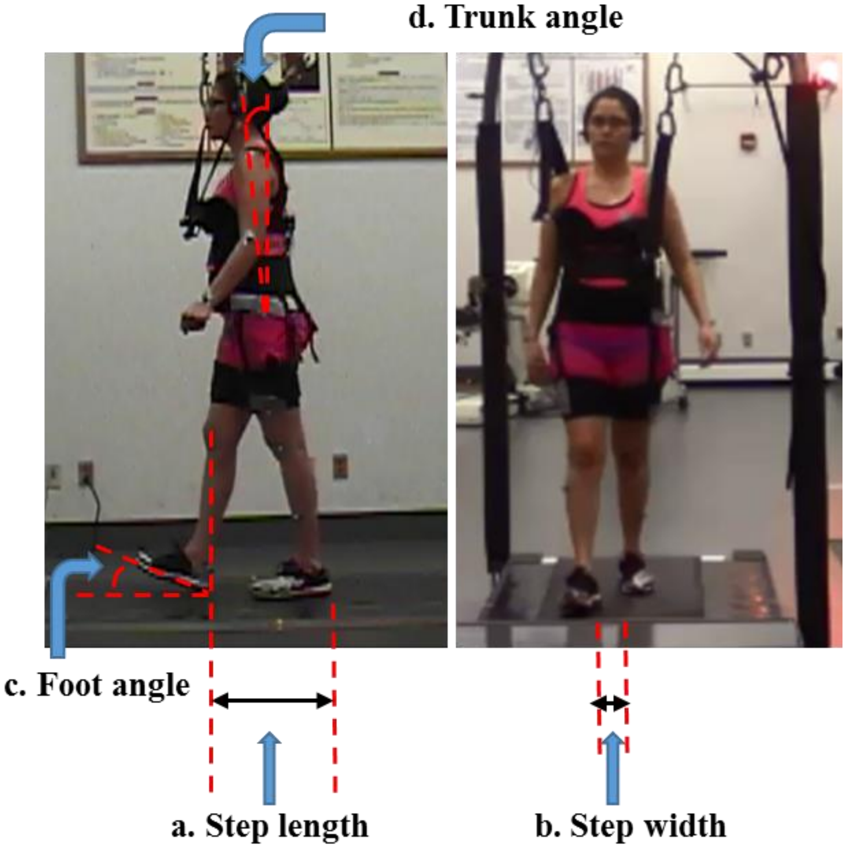

Figure 5.
Definitions of step length, step width, foot angle, and trunk angle. (a) Step length, (b) step width, and (c) foot angle were calculated at the pre-onset TD. (d) Trunk angle was measured both at pre- and post-onset TD. The step length was calculated as the farthest anteroposterior distance from one heel's TD to another heel's TD at the pre-onset TD, and it was normalized to the body height (*bh*). Step width was the shortest mediolateral distance between both feet, and it was normalized to the body height (*bh*). Foot angle (degrees) was the angle between the subjects' sole and the ground surface, where a flat foot corresponded to zero degrees. The trunk angle (degrees) was the angle between the trunk segment and the vertical axis. Positive trunk angle represented that the trunk leaned backward with respect to the vertical axis.

2. 4. Statistical analysis

To identify the group-differences in kinematic gait variables (step length, step width, double support phase, single support phase, and foot angle) at the pre-onset TD, analysis of covariance after controlling the effect of participants' gender (ANCOVA) was applied. Logistic regression

analysis was used to examine the fall incidence for the two groups. The dependent variable is the binary slip outcome (recovery or 0 vs. fall or 1). The predictors were groups (lean vs. obese) and gender (male vs. female). ANCOVA was also used to examine the differences in COM position, COM velocity, dynamic stability, and trunk angle at the timing for two events (the pre-onset TD and the post-onset TD) between the two groups. In addition, a Pearson correlation analysis was used to determine whether there was any relationship between the trunk angle and COM position at the post-onset TD. All statistics were performed using SPSS 22.0 (IBM, NY), and a significance level of $p < 0.05$ was implemented.

3. Results

Data from three lean subjects were lost due to a technical error. Therefore, statistical analyses were performed for 43 participants (lean group = 20, obese group =23).

3. 1. Stability prior to slip perturbation

One of five gait kinematic variables before slip perturbation exhibited between-group differences after controlling for the effect of participants' gender (Table 3, Figure 6). Specifically, individuals with obesity had wider step width (0.072 ± 0.024 vs. 0.052 ± 0.025 *bh*, $p < 0.05$) but similar step length (0.372 ± 0.022 vs. 0.388 ± 0.025 *bh*, $p > 0.05$) (Figure 6). No between-group differences in the durations of the double support phase (seconds, $p > 0.05$), single support phase (seconds, $p > 0.05$), or the foot angle (degrees, $p > 0.05$) were observed (Table 3).

Table 3. Comparisons of gait kinematic variables between lean and obese groups
Three gait kinematic variables (mean ± SD) were calculated from the last double stance phase at the pre-onset TD. Double support phase (the time duration of both feet in contact with the TM) and single support phase (the time duration of each foot in contact with the TM) were investigated. Foot angle was calculated by the angle between the subjects' sole of the leading leg and the ground surface.

	Double support phase (seconds)	Single support phase (seconds)	Foot angle (degrees)
Lean (n = 20)	0.158 ± 0.018	0.302 ± 0.132	18.977 ± 5.512
Obese (n = 23)	0.164 ± 0.031	0.316 ± 0.107	19.957 ± 5.634

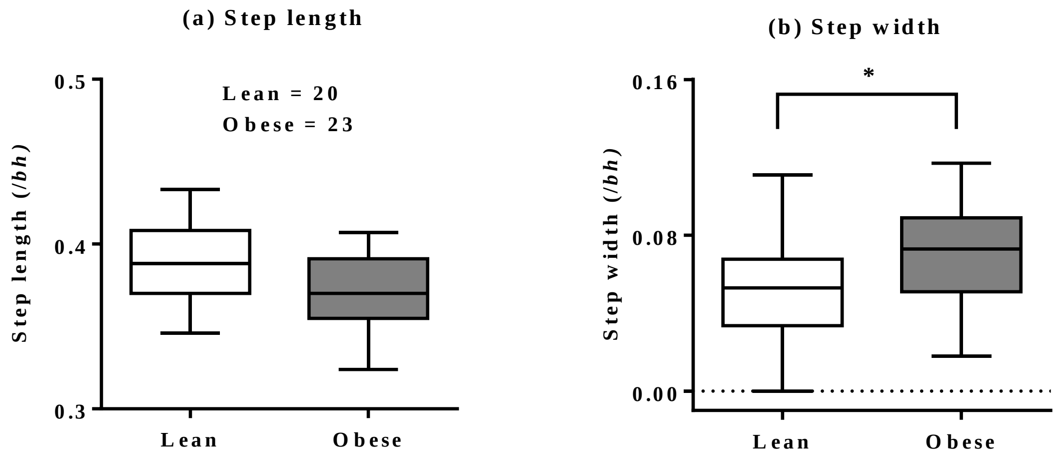

Figure 6.
Comparisons of (a) step length (the farthest anteroposterior distance from one foot's TD to another foot's TD) and (b) step width (the shortest mediolateral distance between both feet) were calculated from the last double stance phase at pre-onset TD, and were normalized to the body height (*bh*). Within the white (lean group) and black (obese group) boxes, the horizontal lines represented the median of (a) step length and (b) step width, respectively. The top and bottom of the boxes represented the upper and lower quartile, respectively. The distance between the top of the boxes and the top of the whiskers indicated the range of the top 25% of scores; similarly, the distance between the bottom of the boxes and the end of the bottom whiskers indicated the range of the lowest 25% of scores. *: $p < 0.05$

At pre-onset TD, the between-group differences in three stability variables and trunk angle were investigated after controlling the effect of participants' gender. The instantaneous COM position relative to the BOS (lean vs. obese; -0.856 ± 0.152 vs. -0.791 ± 0.135, $p > 0.05$) and the COM velocity (lean vs. obese; 0.253 ± 0.041 vs. 0.269 ± 0.045, $p > 0.05$) were not affected by obesity (Figure 7a & b). Furthermore, individuals with obesity exhibited similar dynamic stability as lean individuals before slip onset (-0.122 ± 0.052 vs. -0.156 ± 0.060, $p > 0.05$) (Figure 7c). No significant between-group difference in trunk angle was observed (lean vs. obese; -0.289 ± 3.466 vs. 0.374 ± 3.667 degrees, $p > 0.05$) (Figure 7d).

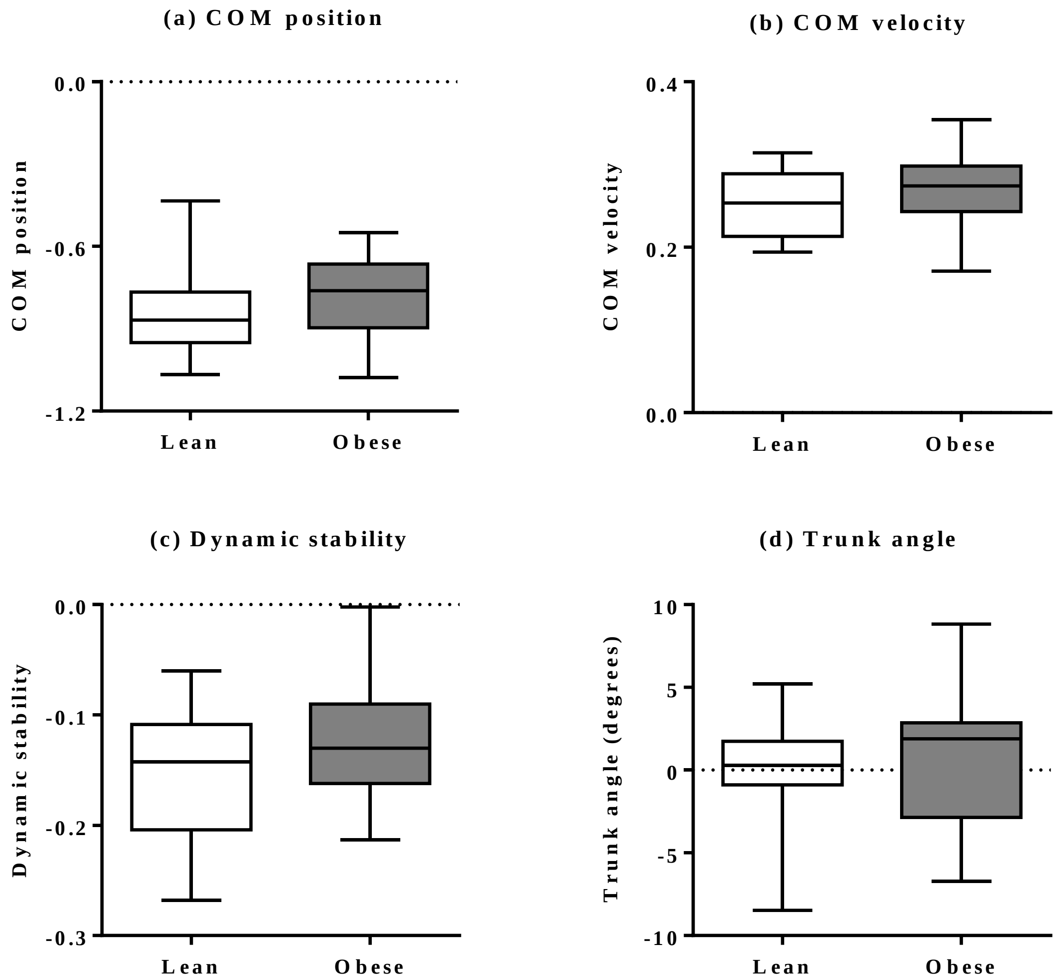

Figure 7.
Comparisons of (a) COM position, (b) COM velocity, (c) dynamic stability, and (d) trunk angle at the pre-onset TD between lean and obese groups. Within the white (lean group) and black (obese group) boxes, the horizontal lines represented the median of (a) COM position, (b) COM velocity, (c) dynamic stability, and (d) trunk angle, respectively. The top and bottom of the boxes represented the upper and lower quartile, respectively. The distance between the top of the boxes and the top of the whiskers indicated the range of the top 25% of scores; similarly, the distance between the bottom of the boxes and the end of the bottom whiskers indicated the range of the lowest 25% of scores.

3. 2. Fall incidence in response to the slips

When exposed to an identical slip on the TM, all subjects experienced a backward balance loss. Logistic regression showed that incidence of fall in responding to the slip onset was significantly affected by obesity ($p < 0.01$) after controlling the effect of participants' gender. Specifically, individuals with obesity compared to their lean counterparts were significantly more likely to fall after slip onset (odds ratios = 18.9; 95% confidence interval = [2.11, 169.11]). Eighteen out of 23 (78.3%) subjects in the obese group fell while only eight of 20 fell (40%) in the lean group ($p < 0.01$, Figure 8).

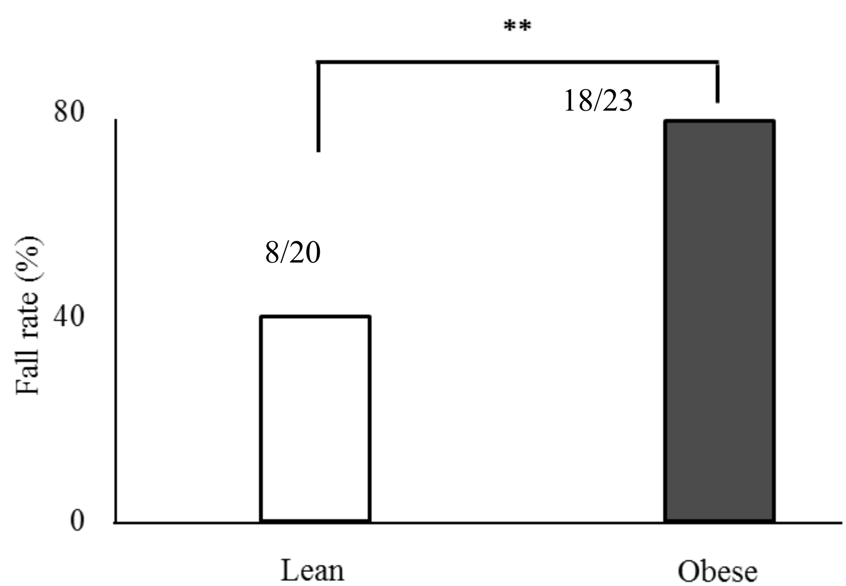

Figure 8.
The comparison of fall rate between lean and obese groups. A slip trial classified as a fall if the peak load cell force exceeded 30% body weight; otherwise, the slip trial was defined as a recovery (Yang & Pai, 2011). **: $p < 0.01$

3. 3. Stability post slip perturbation

At the post-onset TD, individuals without obesity placed their COM more anterior to the BOS compared to those with obesity (-0.145 ± 0.376 vs. -0.450 ± 0.170, $p < 0.01$) (Figure 9a). However, individuals with obesity exhibited similar COM velocity with their lean counterparts (-0.280 ± 0.032 vs. -0.264 ± 0.073, $p > 0.05$) (Figure 9b). Individuals without obesity were more stable than those affected by obesity at the post-onset TD (-0.309 ± 0.235 vs. -0.488 ± 0.093, $p < 0.01$) (Figure 9c). The trunk angle showed marginal difference between the two groups ($p = 0.068$, Figure 9d). Individuals without obesity displayed less backward-lean trunk in comparison with those affected by obesity (0.587 ± 5.156 vs. 3.194 ± 3.390 degrees, $p = 0.068$). The COM position relative to the BOS was strongly and inversely associated with the trunk angle at the post-onset TD ($r = -0.336$, $p < 0.05$) (Figure 10).

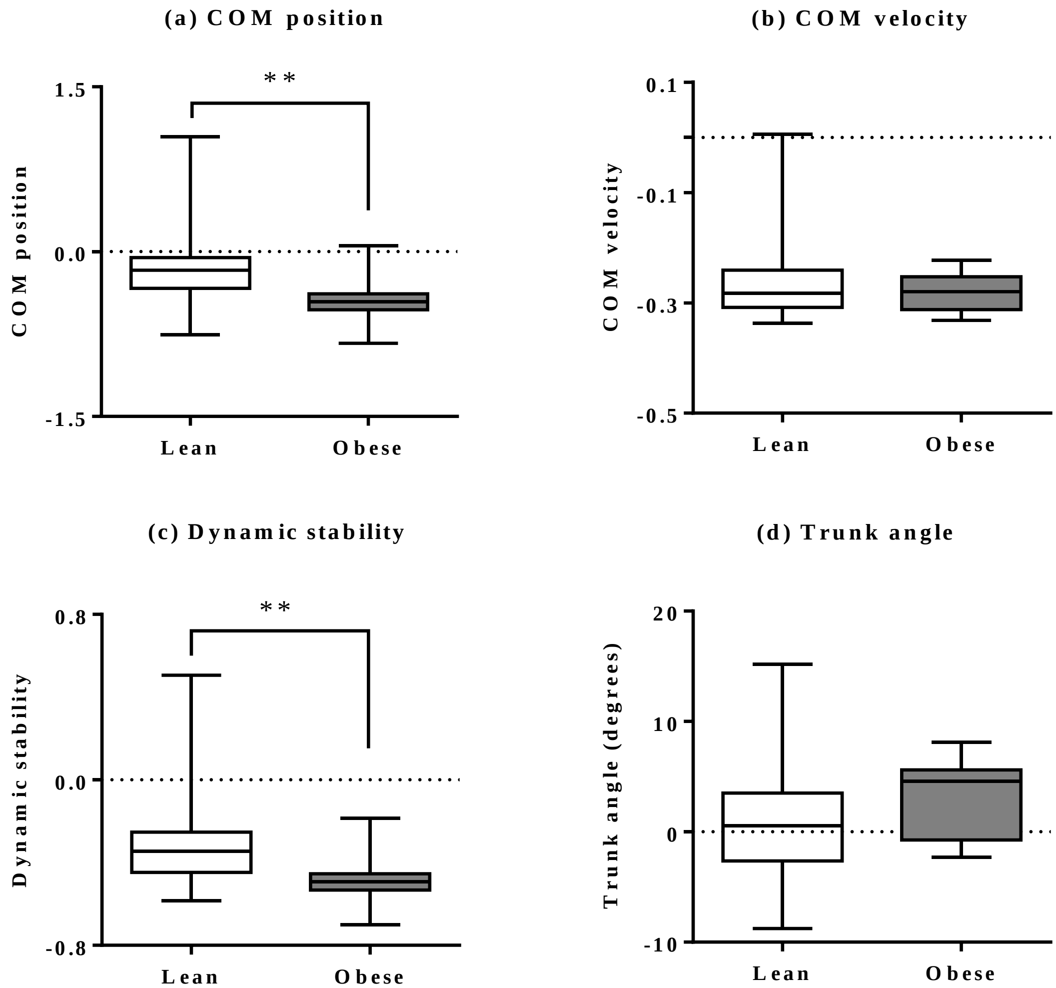

Figure 9.
Comparisons of (a) COM position, (b) COM velocity, (c) dynamic stability, and (d) trunk angle at the post-onset TD between lean and obese groups. Within the white (lean group) and black (obese group) boxes, the horizontal lines represented the median of (a) COM position, (b) COM velocity, (c) dynamic stability, and (d) trunk angle, respectively. The top and bottom of the boxes represented the upper and lower quartile, respectively. The distance between the top of the boxes and the top of the whiskers indicated the range of the top 25% of scores; similarly, the distance between the bottom of the boxes and the end of the bottom whiskers indicated the range of the lowest 25% of scores. **: $p < 0.01$

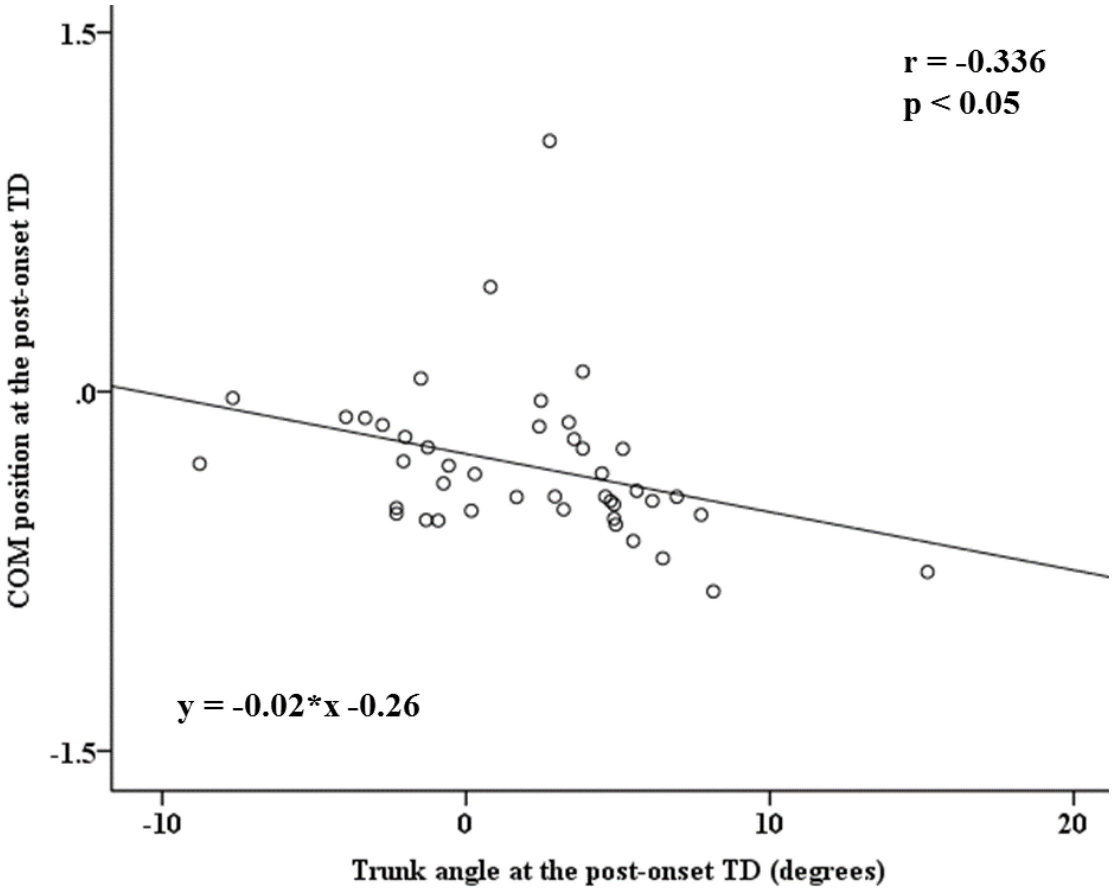

Figure 10.
Correlation test was implemented between COM position relative to the BOS and trunk angle (degrees) at the post-onset TD.

4. Discussion

The overall purpose of this study was to examine if and to what extent the risk of falls and dynamic stability in responding to an unexpected slip induced during walking on a TM differ between young obese and young lean individuals. The results from the present study revealed that both lean and obese individuals have comparable dynamic gait stability during normal walking as indicated by the stability at the pre-onset TD. However, individuals with obesity fell much more than their lean counterparts due to their impaired dynamic stability control when in response to the post-onset TD.

4. 1. Stability control during normal walking

The first hypothesis was that obese populations would have comparable dynamic gait stability as their lean counterparts at the pre-onset TD. This hypothesis was accepted as no significant between-group differences at the pre-onset TD. In the current study, both obese and lean persons showed similar COM position and COM velocity relative to the BOS, leading to a comparable dynamic stability (Figure 7).

The pre-onset TD can present a participants' normal walking. Literature suggested that obese person has structural and functional limitation on movement control due to higher musculoskeletal disorders, sensorimotor dysfunction, and abnormal body fat distribution compared to their lean counterparts (Corbeil et al., 2001; Hills et al., 2002; Hita-Contreras et al., 2013; Myers, et al., 1996). These limitations among individuals with obesity led to less stable while walking. Such a notation was not in agreement with the result of the present study. In the

present study, dynamic stability was comparable between groups as reflected by the similar COM position and velocity at the pre-onset TD (Figure 7).

The possible attributor to the comparable stability could be the cautious gait pattern by individuals with obesity. During normal walking, persons with obesity attended to walk with a wider step width in comparison with those without obesity. Therefore, the compensatory effect from the cautious gait pattern could enable individuals with obesity to have comparable dynamic gait stability during normal walking. In present the study, significant between-group difference in step width ($p < 0.05$) was investigated (Figure 6), which is in agreement with the changes in gait kinematics of obese population observed in the previous studies (Spyropoulos et al., 1991; Wu et al., 2012).

4. 2. Fall incidence in response to an unexpected slip

The second hypothesis was that individuals with obesity would be more prone to fall than their lean counterparts and was supported by our results. The fall rate among the obese group was higher than that among their lean counterparts (odds ratios = 18.9; 95% confidence interval = [2.11, 169.11]), and the between-group difference in fall rate was similar to previous studies (Hills et al., 2002; Lai et al., 2008; Wearing, et al., 2006; Fjeldstad et al., 2008).

However, our results not verified but extended the findings from previous studies. Most of previous studies adopted either the traditional self-report method to collect real-life falls or indirect study designs (Costello et al., 2012; Fjeldstad et al., 2008; Hita-Contreras et al., 2013; Wu et al., 2012). The self-reported data often lacks information on the specific details (like types

and circumstances of falls) of the actual falls, which could vary considerably from person to person. The indirect methods were widely implemented to analyze the risk of fall by collecting 1) COM movement pattern during balance recovery on standing posture; 2) kinematics and kinetics gait patterns (i.e. center of pressure, stance time, walking velocity, step length, and step width) from normal walking; or 3) data from Berg Balance test, Timed-Up-and-Go, and sit-to-stand test, which are correlated with risk of falls. On the other hand, in the present study, a special TM was used to control for the incidence of fall and level of the exposure to fall hazards, resulting in all subjects being experienced the identical slip perturbation at a standard platform. Therefore, the results from this present study strongly presents that people with obesity fall more under the circumstance of the identical slip-induced TM.

Previous studies concerning the risk of fall investigated among elders, however, no studies were investigated the outcomes (fall vs. recovery) from slip-induced TM between individuals with obesity and without obesity among young adults. Rosenblatt and Grabiner (2012) studied the relationship between obesity and falls among healthy adults aged 55 years and older resulting in higher fall rate among individuals with obesity after a laboratory-induced trip. Surely the trip-induced fall is directly related to the forward balance loss, on the other hand, the slip-induced fall is related to the backward balance loss. Nevertheless, this previous study (Rosenblatt & Grabiner, 2012) provided obvious evidence that obese individuals had a reduced performance to recover from the dynamic perturbation. One factor leading to falls at slip-induced TM walking can be insufficient muscle strength and power. Specifically, a research concerning the relationship between muscle power and incidence of fall exhibited that people who had greater knee isokinetic power capabilities had less incidence of fall from an unexpected slip during gait

(Han & Yang, 2015). Due to the relative muscle weakness (normalized to the body mass), individuals with obesity have shown a challenging recovery step during an unannounced slip occurrence (Madigan et al., 2014). These disadvantages from obesity eventually disturb their lower extremity movement posteriorly post slip perturbation.

4. 3. Stability control after slip onset

The third hypothesis was that individuals with obesity would less stable than their lean counterparts at the post-onset TD. Our results verified this hypothesis because significant between-group differences in the dynamic gait stability at the post-onset TD was detected. COM dynamic gait stability at the post-onset TD largely contributed to the higher fall rate among individuals with obesity. In the current study, a significant between-group difference was observed in the COM position ($p < 0.01$, Figure 9c). As a result of further COM position from the rear of BOS among obese group, obese group was more instable than the lean group, by indicating lower dynamic stability level among obese group (obese vs. lean; -0.488 ± 0.093 vs. -0.309 ± 0.235, $p < 0.01$, Figure 9d). From a biomechanics perspective, less posterior COM excursions and faster COM velocity on sagittal plane with respect to the BOS during slip perturbation were obvious factors to increasing stability (You, Chou, Lin, & Su, 2001). Dynamic stability (as well as COM position and COM velocity) at the post-onset TD played a pivotal role in preventing incident of fall (Yang et al., 2011). In other words, people with obesity have less ability to display their COM forward-shifted post slip onset, thereby representing less dynamic stability.

The greater fall rate among people with obesity may be related to their impaired ability to control the dynamic stability. Particularly, obese people had difficulty in shifting COM anteriorly during a slip-induced fall. Trunk angle could be a key reason of the differences in COM position and dynamic stability control between the two groups, resulting in incidence of fall when implementing slip perturbation. In the present study, individuals with obesity appeared more backward-lean trunk at the post-onset TD although indicating a marginal significant difference between two groups ($p = 0.068$, Figure 9d). Consequently, more excessive trunk-leaning backward symptom among individuals with obesity at the post-onset TD led their COM to locate further from the rear of BOS. In the context of slip perturbation, the anteroposterior position of COM was considerably influenced by the trunk angles as the trunk comprises nearly 50% of total body weight (Winter, 2005). Relatively, individuals with obesity have more body mass than do their lean counterparts, thus a same amount of backward lean of the trunk segment would result in a more backward COM position relative to its BOS further reducing the dynamic stability.

The correlation between COM position and trunk angle at the post-onset TD investigated in the present study, resulting in a negative association between COM position and trunk angle ($r = -0.336$, $p < 0.05$, Figure 10). As subjects' COM posteriorly displays further from the rear of BOS, it appears that the subjects lean backward more against vertical line. This aspect consequently influences on less stable at the post-onset TD. Although no studies have studied the relationship between anteroposterior COM position and trunk angle at recovery TD post slip, Crenshaw, Rosenblatt, Hurt, and Grabiner (2012) have evaluated the correlation between stability control (the COM position) and trunk flexion angle when imposing trip-induced fall, resulting in parallel to the results of the present study. Trunk angle of the second recovery step had the largest

negative correlation with stability measures (the anteroposterior distance between the body COM and the stepping limb toe) at trip-induced fall on a TM (Crenshaw et al.,2012).

The joint torque capacities of the lower limb are considered key factors because they allow a person to react quickly to have compensatory stepping (Lanza, Towse, Caldwell, Wigmore, & Kent-Braun, 2003). Relatively, less muscle strength among obesity could be an important factor to explain that individuals with obesity could not effectively control their trunk movement, further leading to more instability (Han & Yang, 2015). Although no study has studied about biomechanical mechanisms how muscle strength induces a quick recovery stepping, and how it impacts on the trunk movement after slip perturbation, the effective recovery TD after slip onset could be an essential capability for participants' trunk to less leaning backward from the vertical line and preventing incidence of falls when slip-induced circumstances occur.

4. 4. Limitations and future directions

This study had several limitations. First, as a first study of obesity's effect on slip-related falls, only young healthy adults (aged 18 to 45 years) were recruited. Given that a large slip perturbation was used in this study, it would be unsafe to begin this line of research with older adults. However, this study did gather important information regarding the application of this protocol to older adults with obesity. Second, although muscle strength and power at lower extremity are significant factors preventing falls after slip onset, they were not analyzed in the present study. Third, all subjects walked at the identical gait speed of 1.2 m/s instead of their self-selected speed. In many previous studies, individuals with obesity had slower walking speed compared to their lean counterparts (Hulens et al., 2003; Wearing et al., 2006). Therefore,

the pre-set walking speed may exert some potential effect on the walking pattern of subjects. However, the precisely-controlled common speed between groups provided the opportunity of isolating the potential effects of various speeds among subjects on our findings. Fourth, the onset of slip perturbation during a gait cycle was unable to be precisely controlled due to the technical difficulty. The sudden changes in the belt speed and direction occurred approximately 80 to 120 ms later than the TD of the leading foot. Therefore, the slip could occur anytime with a 40-ms time window. Such a variation could also influence our results. Finally, the footwear was not controlled in the present study. Future studies are needed to investigate these issues.

4. 5. Conclusions

In summary, individuals with obesity had the cautious walking pattern with wider step width, enabling them to walk with comparable dynamic gait stability as lean subjects. However, when exposed to an unexpected slip during gait, individuals with obesity were more prone to falls than were the lean individuals, due to their impaired control of dynamic stability. Such impairment was primarily resulted from the less-effective control of the trunk movement. This study could provide some insights into the mechanisms of obesity increasing the rate of slip-related falls in young adults. Further, the findings from this study can lay a foundation for designing effective fall prevention training programs targeting individuals with obesity.

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Curriculum Vitae

Jae Eun Kim earned a Bachelor's degree in Physical education from Inha University, South Korea in February 2006. He received the middle and high school teacher certification with highest score conferred by the Minister of Education of South Korea in 2006. Throughout his instructor career, Jae Eun learned teaching and training methods by working as a high school teacher as well as a director of a high school athletic team. Jae Eun received his first Master degree in Education from Inha University in August 2009. During his master period, he assisted extensively with several studies, which dealt with assessment of physical fitness for schoolchildren, middle and high school athletic students. In 2013, Jae Eun joined the Master Program of Kinesiology at the University of Texas at El Paso and switched his focuses to Biomechanics. He has mainly studied dynamic gait stability and its application in fall prevention. He also had opportunities to work on fall prevention studies in older adults and people with multiple sclerosis. During his study as a student pursuing a 2nd master degree, he gave several presentations at national and international scientific conferences meetings. In February 2015, he received an award of the 3rd place of the research poster presentation at the annual meeting of the Texas Chapter of the American College of Sports Medicine. Jae Eun will graduate in December 2015.

Publications

1. Kim, J., Yang, F., Munoz, J., (2016). Effect of obesity on dynamic stability control during slip-related falls among young adults. *Annals of Biomedical Engineering* (In preparation).
2. Yang, F., Kim, J., Munoz, J., (2015). Adaptive gait responses to awareness of a slip during treadmill walking. *Annals of Biomedical Engineering* (Under review).

3. Kim, J., Munoz, J., Villa, C., & Yang, F. (2015). Effect of obesity on stability control during gait-slip perturbation in young adults. *South Central Society of Biomechanics Conference,* March 6-7*,* 2015.

4. Munoz, J., Kim, J., Sanchez, M., & Yang, F. (2015). Vibration training could reduce risk of falls among young adults with obesity. *South Central Society of Biomechanics Conference,* March 6-7, 2015.

5. Kim, J., Munoz, J., Villa, C., & Yang, F. (2015). Effect of obesity on stability control among young adult in responding to a simulated slip induced in gait. In *International Journal of Exercise Science: Conference Proceedings* (Vol. 2, No. 7, p. 22).

6. Munoz, J., Kim, J., Sanchez, M., & Yang, F. (2015). Effect of vibration training on reducing risk of falls among young adults with obesity. In *International Journal of Exercise Science: Conference Proceedings* (Vol. 2, No. 7, p. 21).

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