Preliminary Study of Obstacle Clearance and Compensatory Movements in Individuals with High Body Mass Index

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This study investigated the effect of obstacles of different heights on task performance and compensatory movements of six individuals with a body mass index (BMI) ≥ 30kg/m^2. Obstacle heights were increased from 36cm to 66cm in 5cm increments using a method of limits. Video-based task analysis was used to develop a conceptual model of obstacle clearance and compensatory movements in response to the postural challenge of increasing obstacle heights. Results from the task analysis were used to identify temporal and kinematic performance measures of dynamic balance and postural control. Changes in obstacle clearance performance and compensatory movements may indicate heightened fall risk and could be mitigated by accessible design and assistive support features in the environment.

INTRODUCTION

The prevalence of obesity (BMI ≥ 30kg/m^2) was 39.8% among U.S. adults in 2015-2016, which was a 9.1% increase compared to the prevalence in 1999-2000 (Hales, Carroll, Fryar, & Ogden, 2017). About 5% of U.S. adults are morbidly obese (Sturm, 2007), defined by the CDC as individuals with a BMI ≥ 40kg/m^2, and this rate is also in an increasing trend.

Individuals with higher BMI experience greater risk of mobility impairment, activity limitations, and comorbidities compared to people with lower BMI (de Leon, Hansberry, Bienias, Morris, & Evans, 2006). Compared with individuals with lower BMI (BMI < 30kg/m^2), the odds ratios for the risk of falling is 1.12 in an obese population with BMI 30.0–34.9kg/m^2, and 1.50 in the morbidly obese population (Himes & Reynolds, 2012). The higher risk of falls in individuals with high BMI may result from decreased postural control (Benetti, Bacha, Garrido Junior, & Greve, 2016) and an anterior shift in center of mass due to the excessive distribution of body fat in the abdominal area (Corbeil, Simoneau, Rancourt, Tremblay, & Teasdale, 2001).

Maintaining postural balance is more challenging when standing on one leg. Durations of single leg stance are encountered in many daily activities such as in walking (Drought, Murray, & Kory, 1964), staircase climbing (Nadeau, McFadyen, & Malouin, 2003), negotiating a level (e.g., sidewalk) and clearing obstacles such as stepping over a door threshold or stepping into a bathtub. The need for a prolonged single leg stance during bathtub ingress and egress may be a potential contributing factor to the high prevalence of nonfatal bathroom falls. The CDC reported 189,850 cases of nonfatal bathroom falls in 2008 (CDC, 2011). Nearly 12% of the nonfatal bathroom injuries occurred when entering or exiting the bathtub (CDC, 2011).

Single leg stance while simultaneously stepping over an obstacle with the raised foot places unique demands on postural control. Most studies on postural balance in individuals with high BMI have either measured their postural stability during the static biped standing (Pataky, Armand, Muller-Pinget, Golay, & Allet, 2014) or one-legged stance test (Apovian et al., 2002). However, these tests do not represent naturalistic situations of obstacle clearance where the dynamic shift of the center of mass is involved during a single leg stance.

The purpose of this study was to develop a conceptual understanding of obstacle clearance and movement strategies in individuals with high BMI involving a prolonged single leg stance with dynamic movement. This would provide a framework for describing different types of stepping and compensatory movements used during obstacle clearance tasks, and to identify potential performance measures concerning dynamic balance and postural control during this task.

METHODS

Study Participants

Six participants (3 male, 3 female) with a BMI ≥ 30kg/m^2 were recruited in this study. Average (± S.D.) BMI was 44.3 ± 12.5 kg/m^2 (range: 31.9 – 63.3 kg/m^2). Sampling for this preliminary study was targeted to obtain a diverse range of BMI values. Participants were screened with questions on health condition to ensure that they are able to walk and climb staircases independently. Participants provided written informed consent prior to data collection. The study was approved by the university's institutional review board.

Experiment Procedure

A laboratory experiment was conducted that involved participants stepping over a simulated obstacle of incrementally increasing height. The obstacle comprised of rectangular blocks (1.0m length x 0.1m width) constructed from light-weight cardboard material that stack vertically (Figure 1). The base obstacle (minimum height) had a height of 36cm (14"). The height of the obstacle was increased in 5cm (2") increments by adding cardboard blocks on top of the base obstacle. The maximum height used in this study was 66cm (26"). A method of limits starting from the minimum height was used for determining the maximum height that the participant could clear successfully (i.e., without knocking down the cardboard blocks).

Participants were asked to step over the obstacle without contacting or knocking down the obstacle. Participants could self-select their preferred side or leading leg and could approach the obstacle from either the lateral or anterior direction. Participants had to maintain their approach direction and leading leg for all subsequent trials. Clearance space was provided on both sides of the obstacle and one end of the obstacle was located against a vertical wall, which participants were allowed to use for support at any time during the trial if they chose to.

All of the obstacle clearance trials were video-recorded using two cameras located in-line and perpendicular to the obstacle to capture a side (Figure 1) and frontal (Figure 4) view of the task. The frontal view was used for detecting hand contact with the wall. Hierarchical task analysis (Annett, 2003) was used to analyze the video data using the software program ELAN v5.1 (The Language Archive).

Figure 1. Images showing a participant stepping over the obstacle at the height of 36cm (left, minimum height) and 0.66m (right, maximum height).

RESULTS

Task Analysis

Stepping and compensatory movements were identified by a video-based task analysis. Figure 2 describes the overall steps identified in the completion of one trial along with a timeline. For successful trials, participants showed four stepping movements consisting of the leading leg liftoff, leading leg touchdown, trailing leg liftoff, and trailing leg touchdown. Liftoff was defined as the first instant either foot is entirely off the ground prior to stepping over the obstacle. Touchdown was defined as the first instant any part of the foot (e.g., heel or toe) touches the ground on the opposite side of the obstacle. This sequence of stepping movements would be consistent, excluding any situation of hopping or jumping over the obstacle. The latter was not observed in any of the observed trials.

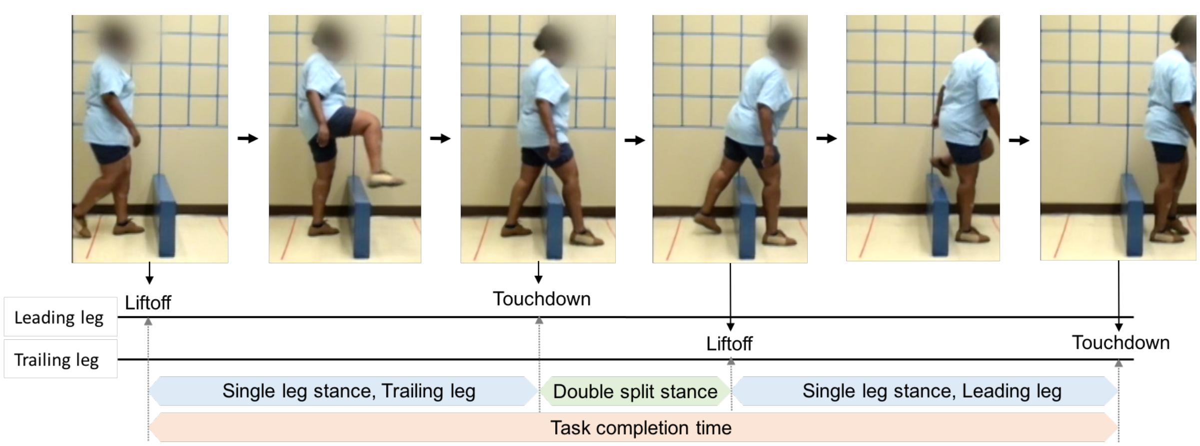

Figure 2. Example of aligned stepping over task with timeline showing images and key events for the leading leg (right leg in this case) and trailing leg (left leg) with an obstacle height of 36cm.

The main goal of the obstacle clearance task was to clear both legs to the opposite side of the obstacle without knocking down the blocks. Thus, the task can be divided into two sub-goals, namely, clearing the obstacle with the leading leg (1. in Figure 3) and then with the trailing leg (2. in Figure 3). At a more detailed level, the participant needs to raise their leading leg (1.1), clear the obstacle (1.2), lower the leading leg (1.3), and then touch the ground (1.4). The same sequence of events was repeated for the trailing leg (2.1, 2.2, 2.3, and 2.4).

Participants also adopted compensatory movements to maintain their balance and control posture during the task. In this preliminary study, we only focused on the compensatory movements performed by either one or both legs or one or both hands across the participants. Table 1 summarizes three types of compensatory movements identified for the leg(s) (i.e., shuffle, hover, and pivot) and two movements for the hands(s) (i.e., contact the wall, and lift the leg with hand, Figure 4).

Table 1. List and definitions of compensatory movements by leg(s) and hand(s) identified from the task analysis.

Compensatory movements *by leg(s)*	
Shuffle	Participant's foot is lifted off and down to the ground with a vertical displacement which is not associated with the actual stepping over motion.
Hover	Participant's foot is off the ground during the stepping over movement but showing a paused hovering motion.
Pivot	Participant's foot is rotated on the ground about the vertical axis of the shank. Part of the foot (e.g., heel or toe) can be lifted but not entirely off from the ground.
Compensatory movements *by hand(s)*	
Contact the wall	Participant contacts or braces against the wall with either the right or left hand or both hands together
Lift the leg	Participant use their hand to lift the swinging leg.

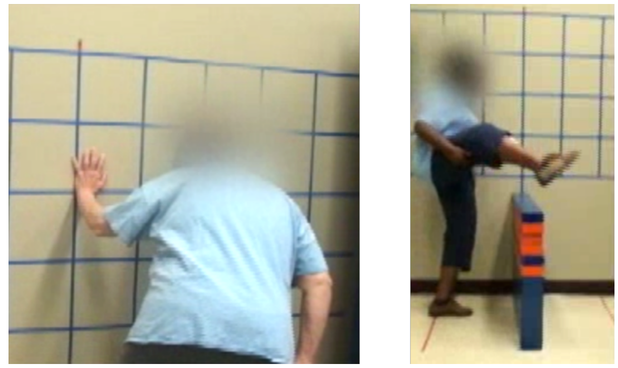

Figure 4. Images showing two different types of compensatory movements performed by participants: (a) contact the wall with the left hand, and (b) lift the swinging leg (leading leg in this case) with the right hand.

Compensatory movements were identified under each stepping movement (Figure 5). During the lifting of the leading leg (1.1) event, participant can either use their leg(s) (1.1.1) or hand(s) (1.1.2) to maintain their balance. They could either hover the leading leg (1.1.1.1), pivot the trailing leg (1.1.1.2), or contact the wall (1.1.2.1) with their hand(s). When they contact the block (1.1.3) and eventually knock down the block (1.1.3.1), the trial is terminated as a failure. While the upper hierarchy (1.1 to 2.4) was sequential, subtasks in the lower hierarchy (1.1.1 to 2.4.3) represent selections where one or more tasks can occur during the upper task.

Similar compensatory movements were found with the next steps (1.2, 1.3, and 1.4), but the only difference was the use of hand to lift the leading leg (e.g., in Figure 4) during the clearance of the obstacle task (1.2). Subtasks for 2.1, 2.2, 2.3, and 2.4 were identical with 1.1, 1.2, 1.3, and 1.4, respectively, but performed with the contralateral side.

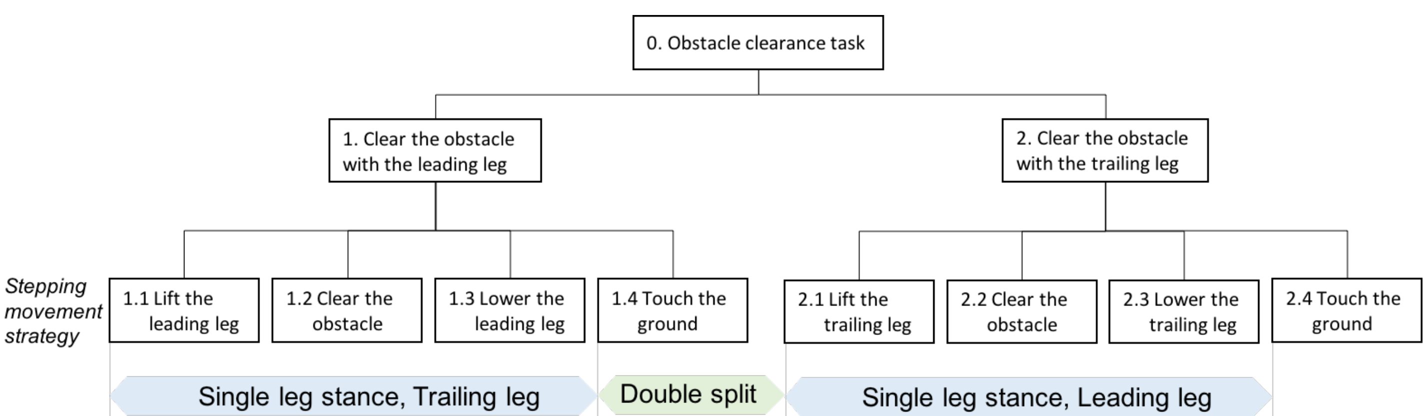

Figure 3. Task analysis of obstacle clearance task with the sequence of movements and timeline identified from the video-based analysis.

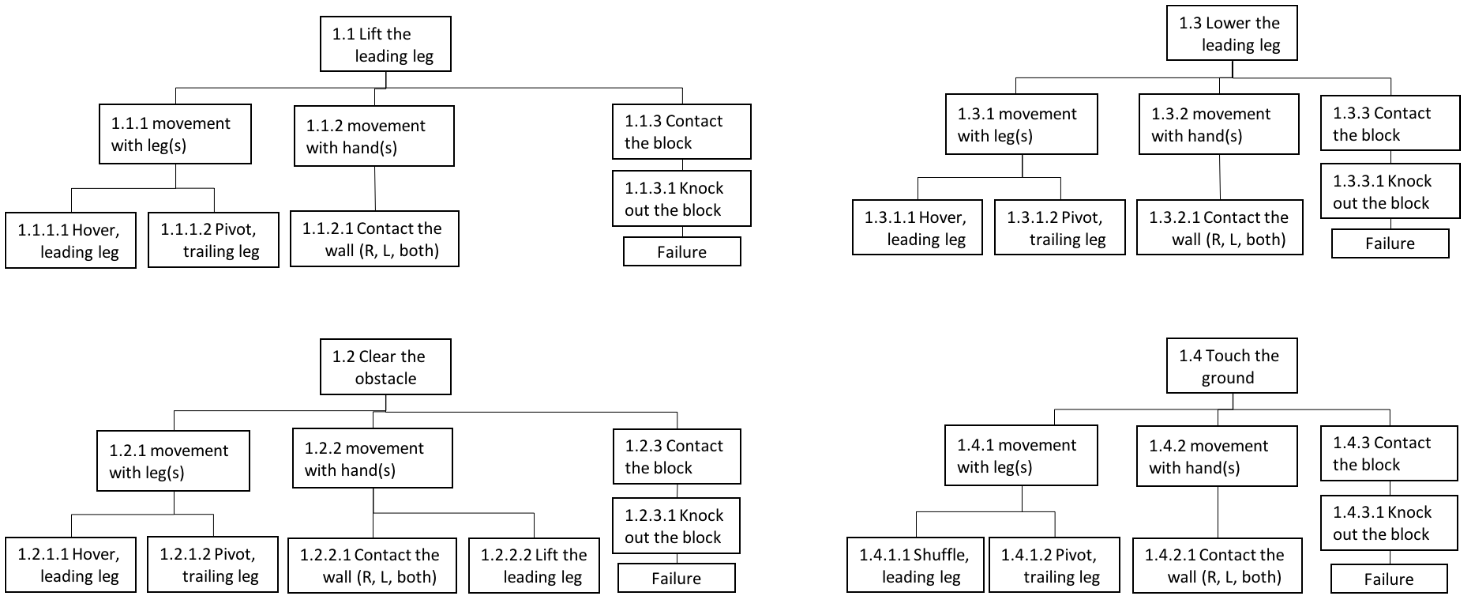

Figure 5. Further expansion of sub-tasks 1.1, 1.2, 1.3, and 1.4 depicted in Figure 3.

Performance Measures

Potential performance measures for assessing the postural stability during the obstacle clearance were identified as an outcome of the task analysis. This includes temporal parameters such as task completion time, single stance duration for the leading and trailing leg, and double split stance duration (Figure 2).

In terms of the compensatory movements, potential performance measures identified include the frequency counts and durations of shuffle, hover, pivot, hands contacting the wall, and use of the hands to raise the leg over the obstacle. Increasing trends in the count and duration of such movements will indicate that a perceived loss of balance or postural control leading to the need for greater external assistance in maintaining or regaining balance.

Figure 6 shows an example of one such performance measures, task completion time (s), from the video-based analysis. Preliminary results indicate an increasing task completion time with an increase in obstacle height. Also, the use of compensatory movements increased with increasing obstacle heights.

DISCUSSION AND CONCLUSIONS

This study was performed as an initial step to develop a conceptual model of obstacle clearance with different obstacle heights. Video-based hierarchical task analysis helped identify stepping movement sequences and compensatory movement strategies performed during the task. These findings are intended to form the basis for a quantitative and objective assessment of dynamic balance and postural control in individuals with high BMI.

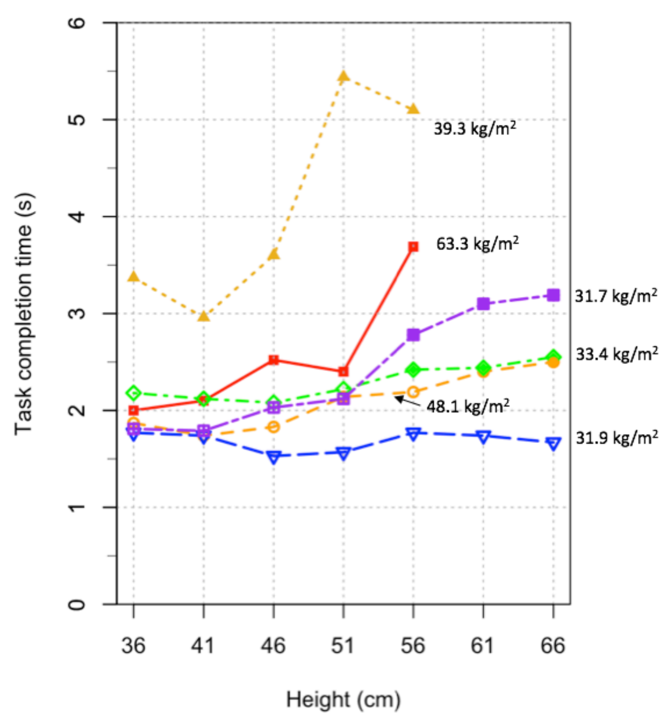

Figure 6. Line graphs showing the task completion time (s) by participant (n=6) at different obstacle height (m) conditions. Filled markers indicate the participant used compensatory movement(s) during that trial.

Further work can also inform guidelines on acceptable height limits for obstacles found in the daily environment (e.g., bathtub). Movement preferences and compensatory strategies (e.g., use of the wall for support) can provide useful guidance to accessibility standard developers, interior designers, and architects when deciding on the placement of assistive features (e.g., grab bars and handholds).

The current analysis was limited to identifying movements with the legs and hand that can be easily observed from videos. Other postural movements such as in the torso and pelvis may also be used in maintaining balance (i.e., torso flexion/extension or hip rotation). Future work aims to investigate postural kinematics at the torso and hips using motion capture to obtain more refined insights into these strategies for maintaining dynamic balance and postural control.

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