Proceedings of the ASME 2019
International Mechanical Engineering Congress and Exposition
IMECE2019
November 11-14, 2019, Salt Lake City, UT, USA

IMECE2019-11889

THE NATURAL SIT-TO-STAND-WALK OF THE FRAIL

Dorothy Taylor
University of Utah
Salt Lake City, Utah, USA

Andrew Merryweather
University of Utah
Salt Lake City, Utah, USA

Janice Morse
University of Utah
Salt Lake City, Utah, USA

Bob Wong
University of Utah
Salt Lake City, Utah, USA

ABSTRACT

Sit-to-stand-walk (STW) is a complex task that sequentially transitions an individual from sitting through standing to walking. In this study we evaluate the unrestricted, natural pattern of movement of the STW task from a hospital bed of 21 (5 Female, 16 Male) frail (MFS>55) adults (68.0±11.2 years) with a total of 144 unique trials. Bed height (low, medium, high) and bed rail condition (no rails, Hill-Rom®, Stryker®), were varied, generating 9 potential trial types per participant. A new STW phase, Stand Preparation, is defined specifically for the frail that occurs just prior to the Flexion Momentum Phase, also named here as the Stand Initiation Phase. In conjunction with the newly defined Stand Preparation Phase, movements used by the frail to maintain or regain balance during STW task are newly defined as corrective behaviors (CBs). These include hand, foot, leg and torso CBs. In 144 unique STW trials, 678 hand and foot CBs were observed and recorded. The most frequent CB type was the hand CB (335), followed by the foot CB (316). A coding system for use in the kinematic analysis of the natural STW task was developed that identifies CBs through visual observation. In addition, a 3D biomechanical model was generated from collected marker position data and will be used in future biomechanical analyses with the visually observed CB data. The Stand Initiation Phase contained the most CBs. Significant factors included bed height and phase, as well as their interaction (all with p-values≤0.006). This is the first study to establish a more accurate and complete STW of the frail elderly, as well as to define CBs employed during their natural STW. The dataset from this coding system, along with the newly established STW phases of the frail, are currently being used for further analyses to determine the exact timing and position of fall initiations during STW of the frail.

Keywords: sit-to-walk, sit-to-stand, sit-to-stand-walk, frail, fall

1. INTRODUCTION

As the frail elderly population continues to increase, falls among the frail are becoming a major public health concern worldwide. [1,2] Recent fall research has identified the sit-to-stand-walk (STW) task as a high-risk task where falls are most likely to occur among the frail elderly. [3-7] As a result, an understanding of the STW process in frail individuals, including the elderly, would have substantial impact on overall injury and lifespan, and is therefore a research area of high interest.

STW is a complex task that sequentially transitions an individual from sitting through standing to walking. The task of STW for healthy subjects has been previously described by Kerr in four phases: flexion momentum, extension, unloading, and stance. [8-10] Healthy adults tend to perform the STW in one smooth motion. As they stand, around the point of seat-off, they are able to use the horizontal momentum to carry them through to gait initiation; they continue to move upward and forward simultaneously.

However, distinct differences between the STW process in healthy and frail individuals have been reported. For example, Buckley, et. al. reported that the frail perform various movements before they even initiate standing that have not been observed in healthy subject studies. [11-12, 18] These preparatory movements vary depending on the type of STW strategy employed, but include things such as scooting to the edge of the bed/chair, bouncing, and grasping and/or applying force with one or both hands to support rising. In addition to these preparation movements, the frail do not have a continuous motion from seat-off to gait. Rather, the frail rise to stand and then stop forward motion prior to initiating gate. [11-15] Hence, the frail perform the STW task in two distinct sequential tasks: first, sit-to-stand (STS), followed by a distinct pause and then gait initiation (GI). [11] Such key differences between observed healthy and frail individuals indicate that the STW process must be separately studied in frail individuals.

Previous analyses of STW processes observed subjects as they performed an experimentally prescribed STW task; they were instructed to rise with hands crossed over their chest and both feet resting parallel on the floor. [8-9] However, in more natural, spontaneous STW processes, individuals have their hands and feet free to engage in behaviors to promote balance that were not included in these previous studies. Hence, it is also of high utility to track the STW process under less scripted conditions.

We have designed a series of experiments that observe the unscripted natural STW processes in subjects during egress from a hospital bed, as they rise and begin walking. Both motion capture position data and visual observation data were recorded for future analyses of individual motions during the STW process. No instructions were given to the patients about what motions or supports they should use; hence, the study can be used to describe the spontaneous movements individuals use in their natural STW process.

Here we present analyses through video observation of unscripted STW of frail individuals. We also observed corrective behaviors (CBs) not previously described. For frail individuals, such motions could help compensate for both lack of muscle strength needed for rising and lack of balance that can otherwise lead to falls. With this new understanding, using CBs as a proxy for fall in these participants, new insights into the mechanics of fall initiation and fall risk may be obtained.

2. METHODS

2.1 Participant Selection

Participants were recruited by staff referral from the University of Utah Medical Center, the George E Whalen Medical Center (VA), and the local community.

Inclusion criteria included:

1. Morse Fall Scale score: MFS >55 for frail elderly
2. Able to stand at bedside and walk without assistance, including assistive devices for 10 feet

Exclusion criteria included:

1. Unilateral strength deficits >25%
2. Lower limb amputation
3. Medical conditions that preclude the use of the safety system for falls prevention (i.e., osteoporosis, morbid obesity)
4. Cognitive impairments that preclude giving informed consent or following simple instructions to perform bed egress

This study included 5 (23.8%) female and 16 (76.2%) male with an average age of 68.2 ± 11.2 years old. Approval was obtained from the Institutional Review Board (IRB 00107043). All subjects consented to participate in the study and to be videotaped. All participants were tethered to mitigate against a fall.

2.2 Natural STW from Hospital Bedside Setup

In order to simulate a variety of bed and rail combinations, a Hill-Rom® hospital bed was stripped and two upper side rails (Hill-Rom® and Stryker®) were retrofitted to be interchangeable with the bed. The side rails were instrumented with a multi-axis load cell (6 dof). Load cell data are used to determine the direction and magnitudes of forces being applied to the side rails by the participant.

A wooden platform was constructed along the length of the bedside with two force plates (Bertec® BP4060) installed to collect bilateral lower extremity ground reaction forces (sample rate 500 Hz). Linoleum flooring, similar to common hospital flooring, was then placed over the entire platform. A large steel frame was constructed (16'x15'x8.5') around the hospital bed and chair to secure 18 optoelectric cameras (NaturalPoint®) and 1 reference video camera.

A fall intervention safety device consisting of an iron frame (8'x8.5'x5'), with two degrees of freedom for planar translations, and a belay system was located above the bed. The belay system was connected to the patient's harness to ensure no patient would fall to the ground.

Participants rose from the bed and walked approximately 3.2 ft to a chair. A potential maximum of nine trials/participant are performed which vary the 2 parameters (bed height and side rail) each having three levels. The bed heights (low, medium, and high) were set for each subject according to their leg length. Leg length was measured from the floor to the subject's lateral condyle of the tibia. The low (LB), medium (MB), and high (HB) bed heights were calculated at 95%, 110%, and 125% of the subject's lower leg length, respectively. [20] The three rail conditions were Hill-Rom®, Stryker®, and no rail. Each unique trial, with a set bed height and rail condition, was performed in a randomized order. No assistive devices were used by the participants during the trials. Some participants were unable to complete all nine trials.

2.3 Motion Capture Data Collection

During the trials, participants wore black cycle shorts, tank top and a restraint vest. Movement was measured by optoelectric cameras recording 80 retroreflective markers placed at key anatomical landmarks on each participant. These include the sacrum, anterior superior iliac spine, knee, lateral malleolus, heel, 2nd metatarsal head, tibial wand, femoral wand, wrist, elbow, shoulder, C7 vertebrae, and clavicle. A headband secured markers on the head. A custom user interface and accompanying software was designed using Labview® (National Instruments) for analog data acquisition and synchronization with the motion tracking software (AMASS®, C-Motion Inc.).

The continuously recorded position data, along with the individual's anthropometric data, were used to define a three dimensional, 15-segment, whole-body custom skeletal model in Visual3D (C-Motion, Inc®.) Collected data were filtered with a Butterworth low-pass filter at 6 and 15 Hz, and synchronized between the 3D motion capture and the ground reaction force, respectively. All data were encrypted, and transferred via a secure RedCap server to the University of Utah College of Nursing Statistics Department and to the Merrill Engineering Building for analyses. A single video camera recorded each trial. These recordings were used when performing observational coding of key events and corrective behaviors.

2.4 New Definitions: Frailty, Stand Preparation Phase, Key Events of STW Phases, and Corrective Behaviors

Frailty is a complex subject and has been evaluated in a variety of ways depending on the context [14]. For simplicity, this study equates frailty to fall risk and uses the Morse Fall Scale (MFS) score as a measure of frailty, where frail >55 MFS. [16] All participants used for this study have an MFS>55 and, therefore, all participants are considered frail.

Based on previous studies and preliminary observations, a new STW phase for the frail is established here, named the Stand Preparation Phase. The Stand Preparation phase includes all preparatory movement prior to the torso flexion that initiates a successful stand. By defining the end of the Stand Preparation Phase in this way, the actual rise from seat-off to gait initiation can be compared between the frail and healthy individuals, including biomechanical and balance measures, as well as time.

In this study, key events that indicate the beginning and end of each STW phase were visually identified and coded. They are described here.

Stand Preparation (SP): SP is defined as the first movement, which may include feet, hands, torso, etc., following directive to begin STW. This includes any physical adjustments such as bouncing, scooting, shifting, and/or unsuccessful standing (falling back to a seated position) prior to a successful stand initiation.

Stand Initiation (SI): SI is defined as torso and lower extremity flexion that is followed by a successful rise to stand. If a participant generates torso flexion that produces bouncing or scooting, stand initiation is specified as the torso flexion just prior to a successful rise to stand.

Seat-Off (SO): SO is defined as the moment just after the buttocks leave the seat surface and the majority of the participant's body weight is supported by feet and/or hands, following stand initiation.

Gait Initiation (GI): GI is defined as the first heel off (HO) by the swing foot with forward movement and the intention to walk. Other foot movements that adjust base of support prior to gait are preparatory, and are classified as foot corrective behaviors.

In addition to the key events of STW for the frail, the authors also define additional assistive movements of the frail during STW. These movements are called corrective behaviors (CBs), and are defined here as a movement performed to maintain or regain the necessary balance needed to perform a task, such as STW. In this study, these corrective behaviors have been observed to include the use of hands, feet, legs and torso. Such balance corrections generally include making contact with surfaces, such as a hand reaching to touch or grasp a bedrail, while other corrections do not, such as raising arms or a quick movement of the torso to realign the center of mass (CoM) to be more centered within their base of support (BoS).

2.5 New Method for Coding Key Events and CBs

A detailed protocol handbook for coding CBs and key events was developed and used to train 2 coders. These coders tagged all CBs and key events that indicate all STW phases of the frail for each trial video. Table 1 includes all CB types that were coded when present. These visual observations were recorded with their respective time stamp in Adobe Premiere®. In addition, an observed fall risk phase rating (1-4, with 1 indicating the most fluid movement and 4 being the jerkiest or most unstable motion) was recorded.

Following training, both coders coded nine randomly selected trial videos. An initial IRR check was performed, with a resulting good interrater consistency (Cronbach's alpha > 0.80). [17] During the coding process, two additional checks were run to check for IRR. At the conclusion of coding, all coded trials were reviewed by an expert coder to locate and correct any typos, incorrect labeling, and any other problems prior to using the codes for calculations and analyses.

2.6 Statistical Analysis of Corrective Behaviors

The total number of CBs occurring during all STW trials and its association with bed height (low, medium, high), phase (Stand Preparation Phase, Stand Initiation Phase, Stand Phase), and the interaction between bed height and phase were analyzed by regression models using generalized estimating equation (GEE) with an independent correlation structure and an identity link function. GEE is a suitable method to analyze repeated measures within an individual (correlated outcomes) and can accommodate missing values. [20] To account for individual differences in frailty we included a participant's timed up and go (TUG) as a pre-trial measure of performance.

TABLE 1. CB CODES WITH CB NAMES AND DEFINITIONS

CB Code	CB Name	CB Definition
CBFCL/R*+	Corrective Behavior Foot Contact (L for Left *or* R for Right)	Extra step, other than normal stand or gait (indicate L or R).
CBFOL/R*+	Corrective Behavior Foot Off (L for Left *or* R for Right)	Extra step release, other than normal stand or gait (indicate L or R).
CBHCL/R*	Corrective Behavior Hand Contact (L for Left *or* R for Right)	Hand is in intentional/force applied contact with surface, other than at rest (indicate L or R).
CBHOL/R*	Corrective Behavior Hand Off (L for Left *or* R for Right)	Hand is no longer in contact with surface (indicate L or R).
GIFOL/R*	Gait Initiation Foot Off (L for Left *or* R for Right)	First step, starting at heel/foot off, after (not including) any CB Foot (indicate L or R).

*Add an 'S' to the end of a foot code if the foot does not completely leave the floor, i.e. Slides, slips or shuffles.
+Any foot movement/contact prior to stand initiation or once the subject is seated will be marked as a CBF.

3. RESULTS AND DISCUSSION

To more fully investigate movements employed by frail individuals during STW, we used both visual observation and motion capture to track spontaneous movements of 144 unique STW trials involving 21 individuals. Each unique trial, with a set bed height and rail condition, was performed in a randomized order. This study reports specifically on the visual observations of STW. We observed CBs not previously described. These behaviors of the frail reflect the need to compensate for reduced balance and/or strength to achieve a successful STW.

3.1 STW stages of frail individuals

We observed and coded all movements in each of the 144 trials. These movements included 678 CBs, with the largest number of CBs occurring prior to and during the Stand Initiation Phase. This observation is key in understanding how the frail perform the STW and led us to suggest adding a new STW phase called the Stand Preparation Phase. We also observed discontinuous vertical and horizontal motion during STW of the frail, as previously reported by Buckley, et. al. [12]. We confirmed that, unlike the continuous rise and forward movement observed by Kerr [13] in healthy individuals, frail subjects pause after finishing their upward motion prior to initiating gait. This behavior increases the duration of the Stand Phase when compared to a healthy STW.

Definitions of key events that indicate the beginning and end of each phase were described in the Methods section. Proposed STW Phases include the newly described Stand Preparation Phase (SP-SI), as well as the previously described Stand Initiation (SI-SO) and Stand phases (SO-HO) (Figure 1).

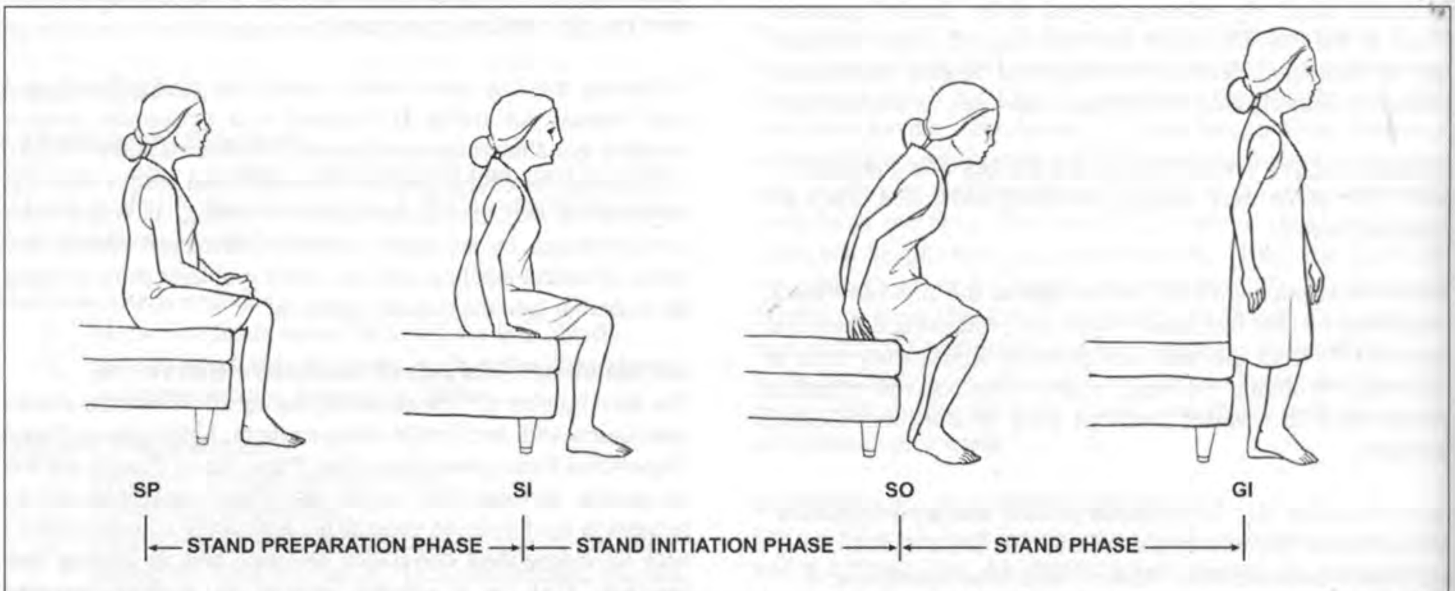

FIGURE 1. STW PHASES OF THE FRAIL WITH NEWLY PROPOSED STAND PREPARATION PHASE ©Brenden Taylor Illustration

3.2 Corrective Behaviors

Since our experimental design tracked the natural and spontaneous motions undertaken by frail individuals during the STW task, we were able to observe and quantify CBs. For frail individuals, such motions are often used to compensate for lack of strength and/or loss of balance, and include movements by hands, feet, legs, and torso. These CBs include making contact with surfaces, such as a hand reaching to touch or grasp a bedrail, while other corrections do not, such as raising arms or a quick movement of the torso to realign the center of mass (CoM) to be more centered within their base of support (BoS). Categories of CBs and the codes used to refer to them are described in more detail in the Methods section.

Since all individuals in the study can be classified as frail (MFS>55), no distinguishing correlation between MFS score (frailty) and number of CBs during STW phases can be made. However, we can draw conclusions about types and quantities of CBs per STW phase for this frail population. When the number and type of CBs are tabulated over the course of the STW process in the 144 trials, some trends emerge (Table 2).

For all 21 subjects, there were a total of 678 hand and foot CBs during the three evaluated STW phases. The greatest number of CBs occurred in the Stand Initiation Phase (343), followed closely by the Stand Preparation Phase (275), while the Stand Phase had a much lower CB count (84). Overall hand and foot CBs were similar in count (335 and 367, respectively). Whether such hand and/or foot motions would also naturally occur in healthy individuals cannot be determined, since previous studies on the STW process for healthy individuals were designed to explicitly exclude extraneous hand and foot motions.

TABLE 2. PREVALENCE OF CBS PER STW PHASE

CB Code	Stand Preparation	Stand Initiation	Stand
CBHCL	67	70	6
CBHCLS	3	2	0
CBHCR	83	69	23
CBHCRS	5	3	4
CBFCL	38	66	27
CBFCLS	22	35	3
CBFCR	36	67	17
CBFCRS	21	31	4
TOTAL = 678	275	343	84
Total Hand CBs = 335	158	144	33
Total Foot CBs = 367	117	199	51

The prevalence of total CBs as a function of bed height (Figure 2) illustrates the interaction between bed height and phase for the total average number of corrective behaviors. As expected, a low bed results in a higher number of CBs in each STW phase, particularly in the Stand Preparation and Stand Initiation phases. This suggests that the frail largely compensate for the increased effort when standing from a low bed height prior to and during rising. It was observed that a variety of strategies were employed among the frail subjects while preparing to initiate stand, such as bouncing, scooting and/or shifting, and leg and hand placement. These different strategies employ different biomechanics that will be evaluated in a future paper.

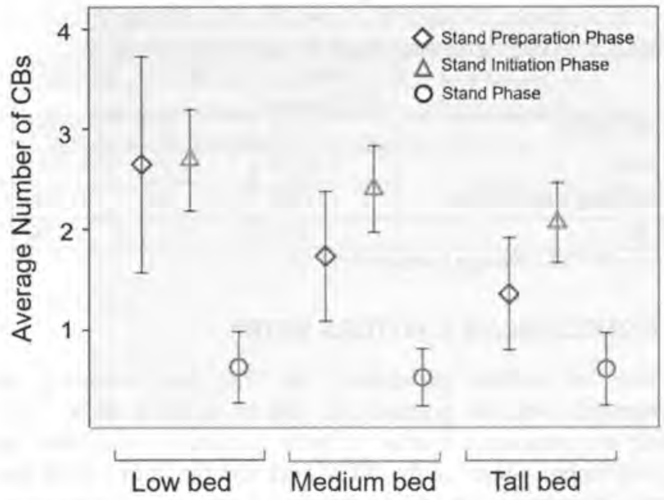

FIGURE 2. AVERAGE NUMBER OF CORRECTIVE BEHAVIORS DURING EACH PHASE OF STW, AS A FUNCTION OF BED HEIGHT. ERROR BARS REPRESENT 95% CONFIDENCE INTERVALS.

All 144 trials by 21 participants were analyzed with GEE to determine whether CB prevalence was statistically correlated with phase or bed height. Results indicate the fixed factors of bed height, phase, and their interaction were significantly related to the number of CBs (Table 3).

Estimated marginal means are included in Annex A. The estimated marginal mean in CBs is highest in the Stand Preparation and Stand Initiation Phases/Low Bed Height configuration (EMM = 2.66 and 2.7, SE = 0.61 and 0.31, respectively). The next highest measure of CBs occurred in the Stand Initiation Phase/Medium Bed Height configuration (EMM = 2.38, SE = 0.35). The least amount of variability in CBs is for the Stand Phase/Medium Bed Height configuration (EMM = 0.51, Std. Error = 0.14), followed by the Stand Phase/High Bed Height configuration (EMM = 0.61, Std. Error = 0.20). (Annex A)

Hospital beds are typically equipped with side rails. For trials with bed rails, the participants had the option of choosing to employ the raised rails as an assistive device for rising or to stabilize gait initiation. When we evaluated the significance of the presence or absence of the bed rail to the number of CBs employed, we observed no statistical correlation for any of the evaluated STW stages. In fact, only 14.3% of participants consistently employed bed rails during STW; the majority used the bed itself when employing hand CBs. As a result, employment of bed rail was not included in our model.

We also evaluated a possible link between the degree of frailty for each patient and the number of CBs employed using the Timed Up and Go test (TUG), a pre-trial measure of frailty. As shown in Table 3, TUG time is trending toward significance with the total number of corrective behaviors (p = 0.059). The STW process takes longer as the number of CBs increases.

TABLE 3. ESTIMATED FIXED EFFECTS FROM GEE: TOTAL CBS

	Wald Chi-Square	df	*p*-value
Bed Height	13.81	2	0.001
Phase	110.01	2	< 0.001
Bed Height and Phase	14.30	4	0.006
TUG	3.58	1	0.059

Covariate: TUG average (seconds)=17.59

4. CONCLUSIONS & FUTURE WORK

Unlike the healthy population, the frail use a variety of movements both to prepare for and to achieve STW. The exhibited preparation by the frail prior to rising is established as an additional phase of the STW task for the frail called the Stand Preparation Phase. Assistive movements performed by the frail during STW are classified as Corrective Behaviors (CBs) and are defined as behaviors used to maintain and/or regain balance to avoid a fall.

While previous studies have only been able to identify the STW task as a high fall risk task, we have shown the specific STW phases that have the greatest fall risk for the frail persons based on the number of CBs employed, in particular during the Stand Initiation Phase of STW. In addition, we have shown that the highest concentration of CBs employed by frail persons occurs during the Stand Initiation Phase, followed closely by the Stand Preparation Phase. The CBs used in the Stand Preparation phase possibly are used to optimize positions for standing rather than balance correction. This analysis supports the need for a new STW phase: the Stand Preparation Phase.

It is important to recall that previous studies were designed to explicitly eliminate possible hand and foot CBs, thus the assumption that normal non-frail individuals do not engage in hand CBs has not been validated. It remains to be seen whether this assumption will be born out in direct observations of normal (non-scripted) STW in non-frail individuals. We are currently involved in analyses to test the validity of this assumption.

A new method has been developed to study STW of the frail that includes both visual observation and motion capture position data. Future analyses of biomechanical measures will lead to a better understanding of strategies used by the frail during STW, including bouncing and scooting STW strategies.

These analyses and additional learning from the natural movements and adaptation strategies of the frail during STW will provide insights for rehabilitation therapy, as well as assistive product designs that can facilitate safe STW transitions during activities of daily living. In addition, interventions to reduce falls can build upon these results through use of wearable inertial sensors in natural settings that quantify movement to help assess fall risk, including changes in functional status during STW and over time. Finally, by precisely identifying the task, timing, and position of the subject when an imbalance occurs, an environment can be designed where CBs are most effective at preventing loss of balance, and thus preventing falls.

ACKNOWLEDGMENTS

This research is funded in part by grants from:
National Institute for Occupational Safety and Health
(NIOSH Training Grant Number T42/CCT810426)
Agency for Healthcare Research and Quality
(AHRQ Grant Number 1R01HS018953)

REFERENCES

[1] World Health Organization Fact Sheet. (2019) Retrieved 1 March 2019 from www.who.int/mediacentre/factsheets/fs344/en/.

[2] National Council on Aging Falls Prevention Facts. (2019) Retrieved 1 March 2019 from www.ncoa.org/news/resources-for-reporters/get-the-facts/.

[3] Rapp, K., Becker, C., Cameron, I. D., König, H. H., & Büchele, G. (2012). Epidemiology of falls in residential aged care: analysis of more than 70,000 falls from residents of Bavarian nursing homes. *Journal of the American Medical Directors Association*, *13*(2), 187-e1.

[4] Cloutier, A., Yang, J., Pati, D., & Valipoor, S. (2016). Experimental identification of potential falls in older adult hospital patients. *Journal of biomechanics*, *49*(7), 1016-1020.

[5] Oliver, D. (2002). Bed falls and bedrails—what should we do? *Age and ageing*, *31*(5), 415-418.

[6] Aziz, O., Park, E. J., Mori, G., & Robinovitch, S. N. (2012, August). Distinguishing near-falls from daily activities with wearable accelerometers and gyroscopes using Support Vector Machines. In *Engineering in Medicine and Biology Society (EMBC), 2012 Annual*

International Conference of the IEEE (pp. 5837-5840). IEEE.

[7] N. M. Peel, "Epidemiology of falls in older age," Canadian Journal on Aging, vol. 30, pp. 7-19, 2011.

[8] Chang, C. S., Leung, C. Y., Liou, J. J., & Tsai, W. W. (2010). Evaluation of key points in the sit-to-stand movement using two force platforms. *Perceptual and motor skills*, *111*(2), 496-502.

[9] Kerr, A., Durward, B., & Kerr, K. M. (2004). Defining phases for the sit-to-walk movement. *Clinical Biomechanics*, *19*(4), 385-390.

[10] Podsiadlo, D., & Richardson, S. (1991). The timed "Up & Go": a test of basic functional mobility for frail elderly persons. *Journal of the American Geriatrics Society*, *39*(2), 142-148.

[11] T. Buckley, C. Pitsikoulis, E. Barthelemy, and C. J. Hass, "Age impairs sit-to- walk motor performance," Journal of Biomechanics, vol. 42, pp. 2318-2322, 2009.

[12] T. A. Buckley, C. Pitsikoulis, and C. J. Hass, "Dynamic postural stability during sit-to-walk transitions in Parkinson disease patients," Movement Disorders, vol. 23, pp. 1274-1280, 2008.

[13] A. Kerr, D. Rafferty, K. M. Kerr, and B. Durward, "Timing phases of the sit-to- walk movement: Validity of a clinical test," Gait & Posture, vol. 26, pp. 11-16, 2007.

[14] Kerr, A., Pomeroy, V. P., Rowe, P. J., Dall, P., & Rafferty, D. (2013). Measuring movement fluency during the sit-to-walk task. *Gait & posture*, *37*(4), 598-602.

[15] Tavakol, M., & Dennick, R. (2011). Making sense of Cronbach's alpha. *International Journal of Medical Education*, *2*, 53.

[16] Buta, B. J., Walston, J. D., Godino, J. G., Park, M., Kalyani, R. R., Xue, Q. L., Varadhan, R. (2016). Frailty assessment instruments: Systematic characterization of the uses and contexts of highly-cited instruments. *Ageing Research Reviews*, *26*, 53–61. doi:10.1016/j.arr.2015.12.003

[17] Morse, J. M., Morse, R. M., & Tylko, S. J. (1989). Development of a scale to identify the fall-prone patient. *Canadian Journal on Aging/La Revue Canadienne du Vieillissement*, 8(4), 366-377.

[18] G. E. Frykberg, A. C. Åberg, K. Halvorsen, J. Borg, and H. Hirschfeld, "Temporal Coordination of the Sit-to-Walk Task in Subjects With Stroke and in Controls," Archives of Physical Medicine and Rehabilitation, vol. 90, pp. 1009-1017, 2009.

[19] Twisk, J. W. (2004). Longitudinal data analysis. A comparison between generalized estimating equations and random coefficient analysis. *European Journal of Epidemiology*, *19*(8), 769-776.

[20] Christman, M., Morse, J., Wilson, C., Godfrey, N., Doig, A., Bloswick, D., & Merryweather, A. (2015). Analysis of the influence of hospital bed height on kinematic parameters associated with patient falls during egress. *Procedia Manufacturing*, *3*, 280-287.