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The inter-observer reliability and agreement of lateral balance recovery responses in older and younger adults

Shani Batcir[a], Hadar Sharon[a], Guy Shani[b], Noa Levitsky[b], Yoav Gimmon[a], Ilan Kurz[a], Amir Shapiro[c], Itshak Melzer[a,*]

[a] Department of Physical Therapy, Faculty of Health Sciences, Ben-Gurion University of the Negev, Beer-Sheva, Israel
[b] Department of Information Systems, Faculty of Engineering Sciences, Ben-Gurion University, Beer-Sheva, Israel
[c] Department of Mechanical Engineering, Faculty of Engineering, Ben-Gurion University of the Negev, Beer-Sheva, Israel

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ABSTRACT

The purpose of this study was to evaluate the inter-observer reliability and agreement of balance recovery responses, step and multiple-steps thresholds, and kinematic parameters of stepping responses. Older and younger adults were exposed to 36 progressively challenging right and left unannounced surface translations during quiet standing. Subjects were instructed to "react naturally". Step threshold and multiple-step threshold were defined as the minimum disturbance magnitude that consistently elicited one and more than one recovery step, respectively. Fall threshold is defined as the minimum disturbance magnitude from which a fall resulted (i.e., fall into harness system or grasped one of the anchor straps of the harness, or grasped the research assistant to maintain balance). The inter-observer reliability of balance recovery responses for older adults were excellent, especially for step and multiple-step thresholds (ICC2,1 = 0.978 and ICC2,1 = 0.971, respectively; $p < 0.001$). Also kinematic parameters of stepping responses such as step recovery duration and step length were excellent (ICC2,1 > 0.975 and ICC2,1 = 0.978, respectively; $p < 0.001$), substantial reliability was found for swing phase duration (ICC2,1 = 0.693, $p < 0.001$). Younger adults showed similar ICCs. The Bland–Altman plots demonstrated excellent limits of agreement (LOA > 90%) for most kinematic step parameters and stepping thresholds. These results suggest that balance recovery responses and kinematic parameters of stepping including step threshold and multiple-step threshold are extremely reliable parameters. The measure of balance recovery responses from unexpected loss of balance is feasible and can be used in clinical setting and research-related assessments of fall risk.

1. Introduction

Falls among older adults are the leading cause of injury-related visits to emergency departments (CDC, 2016); in 2011, 65% of injuries were due to falls (DeGrauw et al., 2016). Falls are the leading cause of accidental death (CDC, 2016) and hip fractures (Lofthus et al., 2001); approximately 95% of hip fractures result from falls (Hayes et al., 1993; Parkkari et al., 1999). Inability to recover from unexpected loss of balance due to trips and slips constitutes 59% of causes of seniors' falls in the community (Berg et al., 1997). Recently, Robinovich et al. (2013) reported that falls in elderly people residing in long-term care was due to inability to recover from balance loss after incorrect weight shifting, trip or stumble, hit or bump. Age-related deterioration in the ability to recover from unexpected loss of balance is a major contributor to falls (Maki and McIlroy, 2006). Studies showed differences in balance recovery responses during standing between older and younger adults, and between fallers and non-fallers (Maki et al., 2000; Maki and McIlroy, 1997, 2005, 2006; Rogers et al., 2001). These studies demonstrated reduced step length, decreased likelihood to take a "cross-over" step, more collisions between the legs, multiple steps to recover balance, a second lateral step that follows the forward or backward step, and failure to recover equilibrium (Maki et al., 2000; McIlroy and Maki, 1996; Maki and McIlroy, 1997, 2005, 2006; Rogers et al., 2001).

Among the most commonly used clinical instruments to assess fall risk, the Timed Up and Go (Podsiadlo and Richardson, 1991), Performance Oriented Mobility Assessment (POMA) (Tinetti, 1986), Berg Balance Scale (Berg et al., 1997), BESTest (Horak et al., 2009), and MiniBESTest (Leddy et al., 2011), perturbations are provided only in the POMA and BESTest. A warning is given in POMA and in BESTest that the perturbation is expected as it is a unidirectional stepping

* Corresponding author at: Schwartz Movement Analysis & Rehabilitation Laboratory, Department of Physical Therapy, Recanati School for Community Health Professions, Faculty of Health Sciences, Ben-Gurion University of the Negev, P.O.B. 653, Beer-Sheva 84105, Israel.
E-mail address: itzikm@bgu.ac.il (I. Melzer).

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response; thus they lack a degree of ecological validity. Assessments of recovery responses following unexpected perturbation, i.e., unexpected horizontal surface translation, is increasingly being used in research on falls prevention programs (Bhatt et al., 2011; Gimmon et al., 2017; Grabiner et al., 2012; Kurz et al., 2016; Mansfield et al., 2010; Pai et al., 2010; Rosenblatt et al., 2013; Shimada et al., 2003). This evaluation has the potential to be ecologically valid since it simulates trips and slips, in safe laboratory conditions, enabling evaluation of balance recovery responses.

High test retest reliability and agreement of compensatory stepping thresholds were found in younger adults (Crenshaw and Kaufman, 2014). In the present study, we aimed to evaluate the inter-observer reliability and agreement of balance recovery responses, kinematic parameters of stepping, and step threshold. In addition, stepping threshold, multiple-step threshold, and fall threshold were also observed. The stepping threshold is defined as the minimum perturbation magnitude that consistently elicits a single recovery step in at least two consecutive perturbation magnitudes; the multiple-step threshold is defined as the minimum perturbation magnitude (in cm) that consistently elicits two or more recovery steps in at least two consecutive perturbation magnitudes; fall threshold is defined as the perturbation magnitude that resulted in unsuccessful balance recovery response (i.e., fall into the harness system). We hypothesized that the inter-observer reliability and agreement will be high for all balance recovery responses and for the 3D kinematic analysis of stepping, with the highest reliability and agreement for step threshold, multiple-step threshold, and fall threshold, which are easy to observe.

2. Methods

2.1. Participants

A convenience sample of 24 older adults (70 years or older) who live independently and 23 younger adults (20–30 years old) from a university population were recruited. Eligibility criteria were: 70 years or older, walking independently, Mini-Mental Score higher than 24. Participants were excluded if they met any exclusion criteria: (a) blindness or serious vestibular impairments (Meniere's disease, dizziness); (b) inability to ambulate independently; (c) score < 24 on the Mini-Mental State Examination (MMSE); (d) symptomatic cardiovascular disease; (e) neurological disorders such as stroke, Parkinson's disease, multiple sclerosis; (f) orthopedic acute disorders (total hip or knee replacements); (g) severe arthritis; (f) cancer under active treatment. The study was approved by the Helsinki ethics committee (Barzilai University Medical Center, Ashkelon, Israel), and prior to participation all subjects provided written informed consent.

2.2. Assessments protocol

Participants stood with their feet close together on a mechatronic device, i.e., a perturbation system composed of 2 motors controlled by a computer program that provides unexpected surface translation to anterior, posterior, right, or left directions in the horizontal plane in order to simulate unexpected loss of balance (Shapiro and Melzer, 2010). Participants were instructed to "react naturally" (i.e., no instructional constraints) to a lateral right or left unannounced surface translation that systematically increased from 1 cm to 18 cm in increments of 1 cm with increasing velocity and acceleration levels, for a maximum of 36 perturbations (see Table 1). In case the subject fell into the harness system or asked to stop the examination we did not continue to the next level of difficulty. To prevent injury, in case of falling, the subjects wore a loose safety harness that arrests falls, but allows the participant to execute balance recovery responses. A loose safety harness was used since balance reactive responses either disappeared or were extremely reduced in amplitude when the trunk was supported during postural perturbation trials (Cordo and Nashner, 1982).

Table 1
Characteristics of surface horizontal translation.

Displacement (cm)	Displacement Time (sec)	velocity (cm/sec)	Acceleration (cm/sec^2)
1	0.30	6	25
2	0.40	7	60
3	0.45	11	80
4	0.50	14	85
5	0.55	15	90
6	0.60	17	94
7	0.65	19	98
8	0.68	21	102
9	0.70	22	107
10	0.73	23	111
11	0.75	25	117
12	0.78	26	123
13	0.80	28	128
14	0.83	30	133
15	0.85	31	139
16	0.86	33	146
17	0.87	34	151
18	0.88	36	158

cm = centimeters; sec = seconds; sec/cm = centimeters per second; sec/cm^2 = centimeters per second squared.

2.2.1. Observational analysis of the balance recovery responses

Eleven balance recovery responses following right/left perturbations were identified (Fig. 1): (1) UBB – Upper body balance response without stepping or arms movement; (2) 2AL – two arms lift; (3) PDAL – perturbation direction arm lift only; (4) PODAL – perturbation opposite direction arm lift only; (5) ULSS – unloaded leg side step, i.e., performing the first step in the same direction of the platform translation; (6) LLSS – loaded leg side step, i.e., performing the first step after the perturbation in the opposite direction of the platform translation; (7) COS – cross-over step; stepping with the unloaded leg in the opposite direction of the platform translation while swinging the leg over the loaded leg; (8) Col – leg collision occurs between the swinging leg and the loaded leg; (9) Abd – abducting a leg and standing on one leg only; (10) Multiple steps is a balance response that consists of more than one step, whether moving both legs or taking a few steps with the same foot; (11) fall – a fall was considered when the subject fell into the harness or grasped one of the anchor straps of the harness, or grasped the research assistant to maintain balance. In addition, the stepping threshold, multiple-step threshold, fall threshold, number of change-of-base-of-support trials (change-of-BOS trials), number of multiple-step trials, and number of fall events during the experiment were observed.

Two physical-therapy experts blinded to each other's observations and analysis, separately analyzed the balance recovery responses through full-test video clips for a total of 1437 trials (627 in older adults and 810 in younger adults). Each trial was dichotomously evaluated for each of the eleven strategies (i.e., when a given strategy appeared, it was marked by 1, and if not it was marked by 0).

2.2.2. Kinematic analysis of the stepping responses

If the trials resulted in a recovery stepping response a 3D kinematic analysis was performed separately by the two examiners using a program written especially for this project in C# (Microsoft 2000). The 3D kinematic data were collected through motion capture, the Ariel Performance Analysis System (APAS, Ariel Dynamics Inc.; CA, USA). Two video cameras were mounted at a 45° angle between each camera and the subject's standing position, at a height of 2.5 m and 7 m in front of the perturbation system. The two video cameras simultaneously recorded the motion of 8 reflective markers with a sampling frequency of 60 Hz. The markers were placed at (1) the anterior midpoint of the ankle joints, (2) Anterior Superior Iliac Spines, (3) acromion processes, and (4) radial styloid processes. Views from both cameras were mapped onto a 3D coordinate system using an internal direct linear