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Automatic recognition of falls in gait-slip training: Harness load cell based criteria

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ABSTRACT

Over-head-harness systems, equipped with load cell sensors, are essential to the participants' safety and to the outcome assessment in perturbation training. The purpose of this study was to first develop an automatic outcome recognition criterion among young adults for gait-slip training and then verify such criterion among older adults. Each of 39 young and 71 older subjects, all protected by safety harness, experienced 8 unannounced, repeated slips, while walking on a 7 m walkway. Each trial was monitored with a motion capture system, bilateral ground reaction force (GRF), harness force, and video recording. The fall trials were first unambiguously indentified with careful visual inspection of all video records. The recoveries without balance loss (in which subjects' trailing foot landed anteriorly to the slipping foot) were also first fully recognized from motion and GRF analyses. These analyses then set the gold standard for the outcome recognition with load cell measurements. Logistic regression analyses based on young subjects' data revealed that the peak load cell force was the best predictor of falls (with 100% accuracy) at the threshold of 30% body weight. On the other hand, the peak moving average force of load cell across 1 s period, was the best predictor (with 100% accuracy) separating recoveries with backward balance loss (in which the recovery step landed posterior to slipping foot) from harness assistance at the threshold of 4.5% body weight. These threshold values were fully verified using the data from older adults (100% accuracy in recognizing falls). Because of the increasing popularity in the perturbation training coupling with the protective over-head-harness system, this new criterion could have far reaching implications in automatic outcome recognition during the movement therapy.

1. Introduction

An estimated 25% to 35% of adults aged 65 years and older fall each year (Tinetti, 2003). Slip-initiated falls account for about one quarter of all falls (Holbrook, 1984) and frequently cause hip fracture (Kannus et al., 1999). A better understanding of the mechanisms underlying slip-related falls will undoubtedly be a crucial step towards the prevention of such injuries. Real slip and fall reproduction in a lab environment is important to investigate the mechanisms behind slip-related falls (Lockhart, 2008; Pai and Bhatt, 2007; Redfern et al., 2001) as well to produce perturbation training for fall prevention (Pai and Bhatt, 2007; Pai et al., 2010). A widely-used method to reproduce real falls or balance loss is the gait-slip experiments. During these tests, subjects walk on a contaminated surface (Cham and Redfern, 2002; Lockhart et al., 2003; Troy et al., 2008; You et al., 2001), on a motorized force plate (Ferber et al., 2002; Tang and Woollacott, 1998), on a movable platform (Bhatt et al., 2006; Troy and Grabiner, 2006), or on a stroller (Marigold and Patla, 2002). To ensure the participants' safety, a harness system is essential during these experiments or in perturbation training that employ repeated slips (Pai and Bhatt, 2007; Pai et al., 2010).

Accurate classification of the slip outcome (fall vs. recovery) is critical to the proper assessment of the effectiveness of fall prevention training. Besides fall and recovery, harness assistance should be unambiguously classified (Brady et al., 2000; Pavol et al., 1999; Yang et al., 2009). False identification of a trial as a fall could lead to over or underestimating of the effect sample size or the training effect itself. When the harness system is set properly, visual inspection of the video recording can be used as a gold standard to judge falls in responding to a slip (Beschorner and Cham, 2008; Lockhart et al., 2003; Troy et al., 2008; Yang et al., 2009). A trial is usually categorized as a fall, if the subject's overall body posture is clearly and unambiguously in a falling mode that is only terminated when all the slack in the safety harness is taken away. However, this identification approach is time consuming, and is dependent upon the availability of the video recording. While the falling body posture and an actual fall can be unambiguously recognizable with visual inspection of video replay, such human cogitation and intelligence cannot be easily emulated at the present time for automatic identification with mathematical algorithm nor computer programming.

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