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Application of motion analysis system in pre-impact fall detection

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Abstract

The purpose of this study is to investigate unique features of body segments in fall and activities of daily living (ADL) to make automatic detection of fall in its descending phase before the impact. Thus, fall-related injuries can be prevented or reduced by deploying feedback systems before the impact. In this study, the authors propose the following hypothesis: (1) thigh segment normally does not go beyond certain threshold angle to forward and sideways directions in ADL and (2) even if it does, the angular characteristics measured at torso and thigh differ from one another in ADL whereas in the case of fall, they become congruent. These two factors can be used to distinguish fall from ADL in its inception. Vicon 3-D motion analysis system was used in this study. High level of correlation between thigh and torso segments (corr $>$ 0.99) was found for fall activities and low correlation coefficients (mean corr for lateral movements is 0.2338 and for sagittal movements is -0.665) were observed in ADL. By applying the hypothesis, all simulated falls could be detected with no false alarms and around 700 ms lead-time before the impact was achieved in pre-impact fall detection. It is the longest lead-time obtained so far in pre-impact fall detection.

Keywords: Motion analysis system; Vicon; Faint fall; Syncope; Elderly

1. Introduction

Trauma resulting from falls in the elderly living in the community is one of the most significant causes of injury and death (King and Tinetti, 1996; Hausdorff et al., 1997) costing an estimated $10 billion annually (Sattin, 1992). Among these traumas, fractures of the neck and trochanteric regions of the femur, the major bone in the hip joint, are currently one of the most serious health care problems faced in aging populations (Marks et al., 2003). Most hip fractures (60–99%) are related to direct trauma to the hip (Cummings and Nevitt, 1989; Hipp et al., 1991; Chapuy et al., 1992; Lauritzen and Askegaard, 1992). Energy absorption rather than bone strength alone has been suggested to be the main determinant of hip fractures, with insufficient soft tissue energy dissipation during the fall (Lauritzen and Askegaard, 1992). The failure of a protective response during the fall—due to aging, cerebrovascular disease (e.g. syncope or fainting), or concurrent medication (particularly the excessive use of sedatives)—contributes to the increased risk of fracture on the occasion of a fall (Meunier, 1993). Among the causes of falls, fainting (syncope) is one important factor in older people and also related to unexplained and recurrent falls (McIntosh et al., 1993). Studies into non-accidental falls, or falls with no evident explanation, show that these falls are mainly related to fainting. Syncopal episodes or fainting related falls are unwitnessed in 40–60% of older people over 65 (McIntosh et al., 1993) and causing considerable mortality and morbidity among those. The most promising prevention strategies for falls and syncope involve the identification of individuals who are at increased risk and the implementation of appropriate interventions. Intervention programs include physical restraint (Tinetti, 1990; Gross et al., 1990), investigation of fall-related fractures prevention strategies (Van den Kroonenberg et al., 1996; Smeesters et al., 2001; Yamamoto et al., 2006), study of characteristics and risk factors of syncope (Kenny and O'Shea, 2002; Peczalski et al.,

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2006), and multifactorial risk assessment and management (Weatherall, 2004; Sjösten et al., 2007). In fall intervention strategies, one of the key concerns in preventing or reducing the severity of injury in the elderly is to detect fall in its descending phase before the impact. A few groups have attempted to detect falls prior to impact (Wu, 2000; Nyan et al., 2006; Bourke and Lyons, 2008). Some researchers have developed inflatable hip protectors to cushion the fall prior to impact (Ulert, 2002; Davidson, 2004; Lockhart, 2006). Wu detected pre-impact falls by thresholding the horizontal and vertical velocity profiles of the trunk using motion analysis system. Wu showed that falls could be distinguished from activities of daily living (ADL) 300–400 ms lead-time before the impact. Bourke and Lyons (2008) developed a threshold-based algorithm to detect pre-impact falls using a bi-axial gyroscope sensor mounted on the trunk. Resultant angular velocity, resultant angular acceleration, and resultant change in trunk-angle were used in the algorithm and falls can be distinguished from ADL with 100% accuracy for a total data set of 480 movements. However, lead-time was not addressed in their pre-impact detection (Bourke and Lyons, 2008). Then, Nyan et al. (2006) also detected pre-impact fall by locating gyroscope sensors at three different locations—the sternum, front of the waist, and under the arm. Nyan achieved 100% sensitivity with about 200 ms lead-time before the impact; however, 16% of ADL events tested were misdetected as falls. At the instant when fall is detected, the angle of body configuration off the vertical axis is 40–54° (Nyan et al., 2006). In pre-impact fall detection, if fall can be detected in its earlier stage, efficient feedback approach can be strategized in longer lead-time for injury minimization.

The purpose of this study is to explore a new approach in pre-impact fall detection in which fall can be distinguished from ADL in its inception. The authors propose the following hypothesis: (1) thigh segment normally does not go beyond certain threshold angle to forward and sideways directions in ADL and (2) even if it does, the angular characteristics measured at torso (LPSI and SACR) and thigh (RTHI and RKNE) differ from one another in ADL whereas in the case of fall they become congruent and these two factors can be used in pre-impact fall detection. Vicon 3-D motion analysis system was used and sideways, forward, and backward falls were studied and presented in this paper.

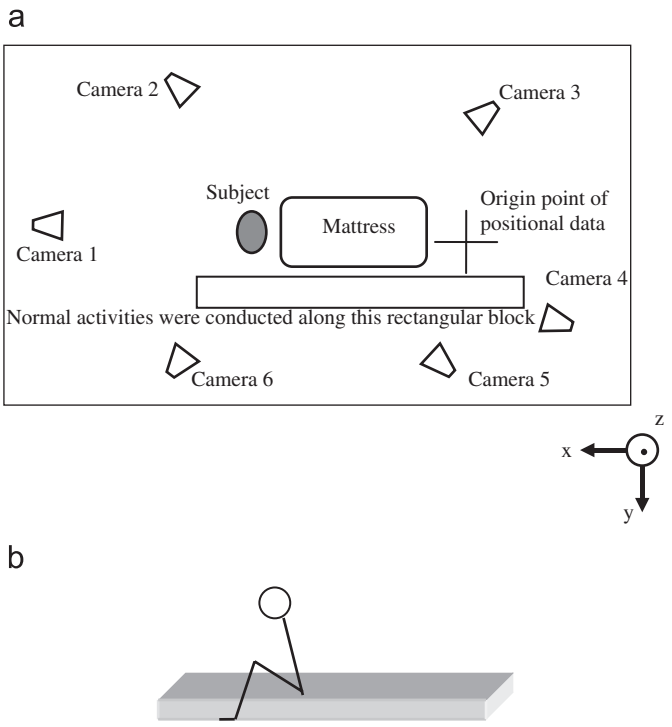

Fig. 1. Schematic layout of experiment setup (a) and the body posture while sitting on the mattress (b).

Fig. 2. Locations of reflective markers on the body.

2. Methods

The Vicon v460 system was used in the experiment and it is located in the Gait Lab at the Orthopaedic Diagnostic Centre, National University Hospital, Singapore. The schematic layout of the experimental setup is shown (Fig. 1). A total of six cameras operating at 50 frames per second (fps) were used to obtain an all-round view of coverage for the activities to be performed by each subject, with each camera specifically adjusted for height, angle of target ray, and field of vision. The origin and 3-D axes of the system were fixed for all sessions. The subjects whose motions were to be captured had a number of retroreflective markers attached to their bodies (Fig. 2).

Ten healthy individuals, two females and eight males, aged 19–24 years were asked to perform the test activities. The mean height and mass ± standard deviation of the subjects were 171.7 ± 7.2 cm and 65.8 ± 14.19 kg, respectively. A post hoc power analysis showed group size is sufficient to prove that current detection method has better performance than our previous study (Nyan et al., 2006). More than 99% power (1% level of significance) is obtained in the comparison of current method, averaged lead-time of all falls is 727 ± 190 ms, to previous method, averaged lead-time of sideways fall (sideways fall has longest lead-time) is 220 ± 76 ms, using the independent samples *t*-test. All subjects