



Contents lists available at ScienceDirect

Journal of Biomechanics

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# Multi-sensor assessment of dynamic balance during gait in patients with subacute stroke

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## ARTICLE INFO

Article history:  
Accepted 22 July 2017  
Available online xxxxx

Keywords:  
Stroke  
Gait stability  
Acceleration  
Inertial sensors  
Locomotion  
Fall risk

## ABSTRACT

The capacity to maintain upright balance by minimising upper body oscillations during walking, also referred to as gait stability, has been associated with a decreased risk of fall. Although it is well known that fall is a common complication after stroke, no study considered the role of both trunk and head when assessing gait stability in this population. The primary aim of this study was to propose a multi-sensor protocol to quantify gait stability in patients with subacute stroke using gait quality indices derived from pelvis, sternum, and head accelerations. Second, the association of these indices with the level of walking ability, with traditional clinical scale scores, and with fall events occurring within the six months after patients' dismissal was investigated. The accelerations corresponding to the three abovementioned body levels were measured using inertial sensors during a 10-Meter Walk Test performed by 45 inpatients and 25 control healthy subjects. A set of indices related to gait stability were estimated and clinical performance scales were administered to each patient. The amplitude of the accelerations, the way it is attenuated/amplified from lower to upper body levels, and the gait symmetry provide valuable information about subject-specific motor strategies, discriminate between different levels of walking ability, and correlate with clinical scales. In conclusion, the proposed multi-sensor protocol could represent a useful tool to quantify gait stability, support clinicians in the identification of patients potentially exposed to a high risk of falling, and assess the effectiveness of rehabilitation protocols in the clinical routine.

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## 1. Introduction

Falls are known to produce physical and psychological consequences imposing a tremendous economic burden on the health care system, bringing the efficacy of the entire rehabilitative pathway into question (Langhorne et al., 2000). Several studies focused on the identification of risk factors that could help recognising and treating patients exposed to a high risk of falling, such as persons who experienced cerebrovascular events (Campbell and Matthews, 2010; Fletcher and Hirdes, 2002). Among the huge number of risk factors that has been reported in the literature (Masud and Morris, 2001), the presence of gait instability has been

acknowledged as one of the most important fall predictors (Campbell and Matthews, 2010; Hamacher et al., 2011). It has been shown, in fact, that individuals with impaired mobility are 1.65 times more likely to experience a fall and that up to 70% of the falls occurs during walking (Fletcher and Hirdes, 2002). As walking is one of the most frequent dynamic activities of daily living (Hamacher et al., 2011), the recovery of gait stability is one of the most important aim of neurorehabilitation (Paolucci et al., 2008). Gait stability can be referred to as the capacity to minimise oscillations, in a progressive way, from the lower to upper levels of the human body, and thus to maintain upright balance during walking (Cappozzo, 1981). In this framework, the development and validation of protocols aimed at objectively quantifying gait stability, and that can be regularly employed in the clinical routine, is crucial.

Traditionally, clinical performance scales based on questionnaire checklists or patients' qualitative observation are used. However, these scales may lack inter-rater reliability and specificity

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(Mancini and Horak, 2010; Senden et al., 2012). For these reasons, instrumented gait analysis is used, allowing the estimation of numerous parameters based on biomechanical measures (Hamacher et al., 2011). However, the estimation of these parameters is limited to the laboratory environment and, due to the complexity of their interpretation, their clinical application is still limited (Cimolin and Galli, 2014). Therefore, technology-based protocols relying on the use of wearable Inertial Measurement Units (IMUs) have been recently proposed and flanked to clinical scale routines (Buckley et al., 2015; Iosa et al., 2012a; Senden et al., 2012). These protocols aim at collecting information directly in-the-field and obtaining concise quantitative metrics of the overall quality of gait (namely gait quality indices), that are able to assess patients' motor ability at person level and that take into consideration features like maintenance of balance during walking and gait symmetry (Capozzo, 1983; WHO, 2001).

Several studies have focused on the assessment of gait stability using a single IMU located at the pelvis level and quantified the amount of accelerations and/or the gait symmetry in patients with Parkinson's disease (Lowry et al., 2009), stroke (Iosa et al., 2016), cerebral palsy (Iosa et al., 2012b), lower limb amputation (Iosa et al., 2014), and in individuals at risk of falls (Isho et al., 2015; Senden et al., 2012). All these studies agree in associating to decreased gait stability higher values of accelerations and decreased gait symmetry.

The use of a single IMU, however, does not allow to obtain information about the role of the whole trunk and head, which, in stroke patients, is crucial both in movement control and postural balance (Isho and Usuda, 2016). It has been reported, in fact, that the control of the head movements during walking allows for the stabilisation of the optic flow, for a more effective processing of the vestibular system signals, and for the consequent control of equilibrium (Berthoz and Pozzo, 1994; Capozzo, 1981; Mazzà et al., 2008). In addition, the literature suggests that difficulties in controlling the upper body accelerations are also associated with a higher risk of fall (Marigold and Patla, 2008). In this respect, the use of a multi-sensor approach to gain insight on the way accelerations are attenuated from the pelvis to the head, in patients with stroke, may represent an added value for clinicians, supporting them in the definition of patient-specific treatments and in the assessment of rehabilitation programs' efficacy.

The literature provides examples of multi-sensor assessment of gait stability in the elderly (Doi et al., 2013; Mazzà et al., 2008; Menz et al., 2003a) and in patients with Parkinson's disease (Buckley et al., 2015) or cerebral palsy (Summa et al., 2016), but lacks of studies on patients with stroke in the subacute phase (1-to-6 months post-stroke event). Furthermore, whereas a large number of studies focused on the ability of the abovementioned quantities to discriminate between healthy and pathological populations (Buckley et al., 2015; Iosa et al., 2014, 2012a, 2012b; Summa et al., 2016), no information is available about their capability to discriminate among different levels of walking ability, as defined by currently administered clinical scales, like the

Functional Ambulation Classification scale (Holden et al., 1984). Finally, it is still unclear whether an association exists between these quantities and clinical scale scores, as well as whether the former could be of additional value in current fall risk screening.

The primary aim of the present study is, thus, to propose a multi-sensor protocol to quantify the stability of patients with subacute stroke during level walking, using indices based on accelerations measured at head, trunk, and pelvis levels. Second, the association of the estimated gait quality indices with the following aspects was investigated: (i) the level of walking ability; (ii) the scores of commonly administered clinical scales; (iii) the occurrence of fall episodes within the six months following patients' dismissal. The outcome of the proposed multi-sensor protocol is expected to corroborate the following hypothesis: patients with stroke in the subacute phase present a lack of ability in attenuating accelerations from the pelvis to the head while walking, and thus a deficit in maintaining the head stable. This deficit is assumed to endanger the stabilisation of the optic flow and the physiological processing of the vestibular system signals, exposing the patients to an increased risk of fall.

## 2. Methods

### 2.1. Participants

Two groups of subjects participated in this study, which was conducted according to the World Medical Association Declaration of Helsinki and was approved by the S. Lucia Foundation Ethics Committee (CE/AG4/PROG.383-11 and successive integrations). The first group was composed of 45 inpatients with subacute stroke (SG, age:  $63 \pm 13$  years, 18 males) (Table 1) complying with the following inclusion criteria: first ever stroke with unilateral hemiplegia, stroke event occurred within the previous six months, and ability to walk without any device or need of continuous physical assistance (Functional Ambulation Classification  $\geq 3$ ). Exclusion criteria were: cognitive deficits affecting the capacity of patients to understand the task instructions (Mini Mental State Examination  $>24$ ), severe unilateral spatial neglect, severe aphasia, and presence of neurological, orthopaedic or cardiac comorbidities. The second group was composed of 25 adults without neurological, orthopaedic, or cardiothoracic conditions that may have affected their walking (CG, age:  $54 \pm 8$  years, 19 males). Each participant gave written informed consent.

### 2.2. Experimental protocol

All acquisitions were performed in the rehabilitation gym of the S. Lucia Foundation hospital before patients' dismissal.

First, for each patient, the walking ability, the risk of fall, the presence of impairment in balance function, and the degree of independence in various activities of daily living were assessed, by an expert physiotherapist, using the following clinical scales:

**Table 1**  
Demographic characteristic of the three groups of stroke patients (SG1, SG2, SG3).

|                           |                    | SG1  | SG2  | SG3  |
|---------------------------|--------------------|------|------|------|
| Age [years]               | Mean               | 58.0 | 65.8 | 63.2 |
|                           | Standard deviation | 12.7 | 14.0 | 9.2  |
| Male sex [%]              |                    | 25.0 | 34.6 | 63.6 |
| Time since stroke [days]  | Mean               | 30.3 | 46.4 | 71.0 |
|                           | Standard deviation | 13.6 | 17.7 | 29.0 |
| Stroke type, ischemic [%] | Ischemic           | 85.2 | 84.6 | 83.4 |
| Stroke location [%]       | Right              | 45.8 | 51.6 | 44.0 |

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