SS 10 - Assessment of balance during functional walking in stroke survivors

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Abstract—**Regaining balance function is often one of the key goals of stroke rehabilitation. Improvements in balance function can be the result of restitution or compensational strategies. In previous studies, the processes of restitution and compensational strategies have been established for straight-line walking. The development of these processes, however, are still largely unknown for other gait activities such as turning and side-stepping. Here, we present a fully ambulant gait analysis system that can be used for an objective evaluation of balance during functional tasks. The results of two individuals are presented: one individual with adequate balance function and one individual with impaired balance function. The analysis showed that the individual with adequate balance function was able to walk with increased instability when compared to the individual with impaired balance function. Based on these results, we conclude that the fully ambulant system is feasible for an objective quantification of balance function.**

I. Introduction

After stroke, an important objective during rehabilitation is to regain adequate balance function. Although functional recovery of walking balance might be quite substantial, little is known about the underlying mechanisms that contribute to the process of recovery [1]. Balance is frequently assessed using standardized clinical tests to predict functional performance [2,3].Current clinical tests evaluate walking balance on an activity level by describing the ability to complete a task and the time needed to complete a task. It remains unclear if an individual stroke survivor functionally recovers by restitution or by learning to compensate for the lack of restoration of body function. To gain more insight in these mechanisms, an objective assessment on the level of body function during walking is required.

Nearly every activity during daily living includes variable walking speed, changing walking directions, stepping sideways, transfers etc. [3]. These variable walking patterns are more challenging than straight line walking for those with an impaired walking balance [4]. Current research and rehabilitation practice is mostly focused on lab based instrumented assessment of straight line walking. This means that we have a limited understanding of the restoration and compensation of changing walking directions, stepping sideways, transfers etc. One of the reasons for this, that it is challenging to objectify. For an objective evaluation of balance over multiple strides and during turns in a lab or in a daily life setting, wearable sensing systems may be a more suitable solution [5]. Therefore, a concept of a wearable sensing system to evaluate walking in a daily life setting was developed [6].

The aim of this study is to present a method for the objective evaluation of balance during functional walking in stroke survivors that may be used for objective evaluation of restitution and compensation of walking balance in stroke survivors.

II. Material and Methods

Two stroke survivors performed a Timed ªUp & Goº (TUG) test. Furthermore, the Berg Balance score (BBS) was assessed. The local medical ethics committee approved the experiments and all participants signed written informed consent before participating.

Ground reaction forces and position changes of both feet were measured using instrumented shoes and used to estimate the position of the center of mass (CoM).

Balance control and efficiency metrics were defined to evaluate functional walking under variable conditions [7] and intra- and inter-participant variations for different phases of the TUG test were examined.

A pair of Xsens ForceShoes™ (Xsens Technologies B.V., Enschede, The Netherlands) was used to acquire full 3D kinematic and kinetic data of both feet. Each instrumented shoe was equipped with two 3D force/moment sensors and two 3D inertial measurement units (IMU), positioned on the heel and forefoot segments. Additionally ultrasound sensors were attached to the forefoot segment of the shoe to estimate the distance between both feet. Methods described and validated by Weenk, et al. [6] and Schepers, et al. [8] were used to respectively estimate relative feet positions and the position of the center of mass (CoM) during standing and walking.

III. Results

Fig 1a and 1b show a top-down view of the kinematic reconstruction of the steps made by the two while performing a single TUG test. Both participants have different scores on the clinical assessment scales. Participant #3 who has a BBS

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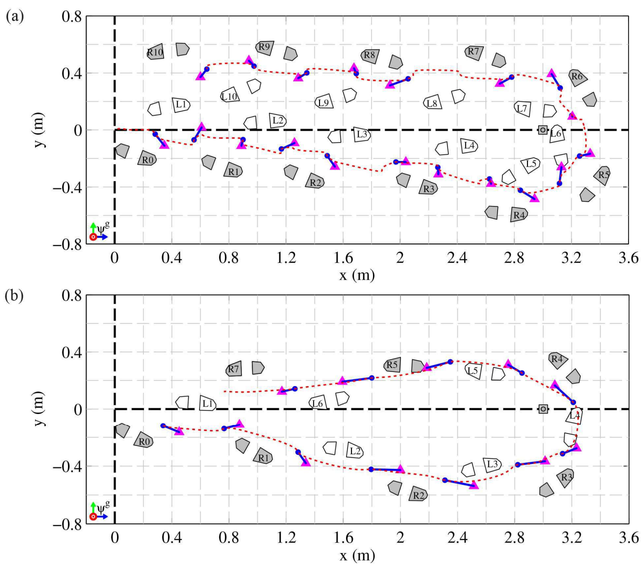

Fig. 1. Top-down view of steps made during a TUG test. (a) Participant #3, left side affected, turn from L4-R4 to L7-R7, BBS: 43/56, TUG 19.5 s. (b) Participant #10, left side affected, turn from R2-L3 to L5-R5, BBS: 55/56, TUG 8.3 s. Both participants started at the origin of the graphs and walked around a turn marker (coordinate (0,3)) 3 m away from the starting position. Left (L1, L2, etc.) and Right (R1, R2, etc.) step numbers are indicated in the forefoot segment of the shoe. Blue dots and pink triangles respectively represents the CoM' and XCoM' position at the first sample of a double stance phase. The blue line between CoM' and XCoM' indicates the direction of the CoM velocity (from CoM to XCoM) just at the beginning of each double support phase, i.e., instantaneous walking direction or *x*-axis of the local reference frame ψ_w. The dashed red line is the trajectory of the CoM' during the selected part of the TUG test.

who has a BBS score of 54. This figure indicates that the person with the higher BBS showed less variable walking velocity and walking direction. This is primarily reflected in the fact that the direction of the CoM velocity (blue arrow) is directed towards the walking direction (red dots). Fig. 2. shows the stability margins of both participants. This figure indicates that the individual with a higher BBS walks more unstable during both straight-line walking as well as during turns.

IV. Conclusion

Based on the presented results, we conclude that the presented system is able to objectively quantify balance function of individuals after stroke. The information that is gained for the ambulant gait analysis system can be used to guide rehabilitation.

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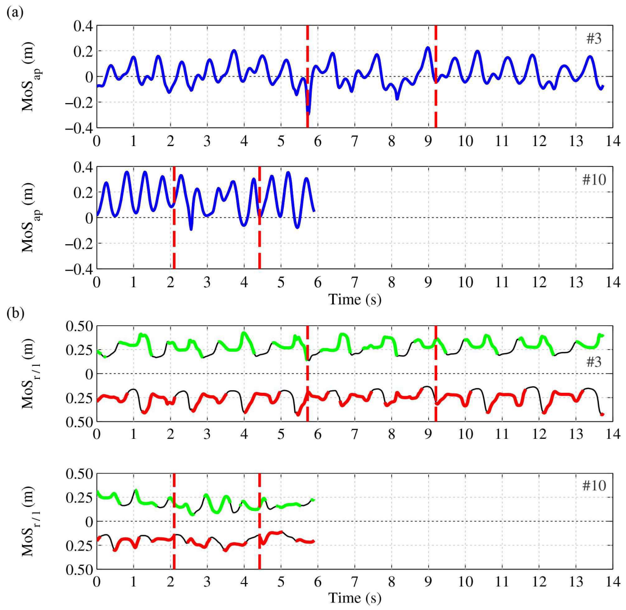

Fig. 2. Margin of stability while performing a single TUG test. (a) Anterior-posterior margin of stability, the distance XCoM' to border of (v)BoS, in direction of velocity of CoM. The value is positive when the XCoM' position is outside the (v)BoS and negative when the XCoM' position is inside the (v)BoS. (b) Medial-lateral margin of stability, at each moment the maximum distance between a shoe and the vector between CoM' and XCoM' (x-axis of ϕw). The green line (in both graphs the upper thick line) indicates the maximum distance of the left shoe (affected side) to the x-axis of ϕw (MoSl), while the foot is in contact with the ground. The red line (in both graphs the lower thick line) indicates the maximum distance of the right shoe to the x-axis of ϕw (MoSr), while the foot is in contact with the ground. The black lines represent the distance between the shoes and x-axis of ϕw when the foot is in swing phase. Participant #3 (first and third graph) and #10 (second and fourth graph). The red vertical lines indicate the begin and end moments of the turn phase, after and prior to a straight line walking phase. Metrics were evaluated till the second red line.

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