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Multimodal evaluation of gait and stride dynamics in relapsing and progressive forms of multiple sclerosis

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Abstract

Ambulation measures are being increasingly recognized as highly relevant to the quantification of multiple sclerosis (MS) severity and response to treatment. Feet paths are highly informative for gait analysis and we have recently designed a new system, which captures the position of the feet in real time. We use several range laser scanners (RLS) to analyze a horizontal slice of the scene in which each foot is considered as a point, and the vertical movements are ignored. Neat ambulation measures may be easily extracted such as walking speed, distance between feet over time, swing phase duration, and gait asymmetry in specific settings of walking recommendations. Our RLS platform is much cheaper than existing sensor-based and motion capture systems and may be more convenient for the development of multicentric clinical trial settings since patients can be easily and rapidly assessed without tags or sensors in the hallway of an outpatient clinic. We use 4 BEA LZR-i100 RLS arranged in a corridor of at least 10m long and 4m width, devoid of obstacle. The scanned plane is chosen to be located at 15 cm above the floor, which is right above the tibio-tarsal joint of the ankle in a barefoot configuration for adult individuals in stance phase.
We expect further studies to validate and empower the meaning of non-intrusive RLS-derived gait measures that should pave the ground for major improvements in the way we will assess the efficacy of disease-modifying treatments (DMTs), physical therapy and symptomatic interventions on walking impairment, ataxia and fatigability in MS. RLS-derived gait measures may also reveal to be crucial in the near future for the development of treatments that would specifically target progressive forms of MS.

Keywords: g*ait, stride, ambulation metrics, multiple sclerosis, foot dynamics.*

INTRODUCTION

Human gait is remarkable. The healthy locomotor system integrates input from the motor cortex, cerebellum, and the basal ganglia, as well as feedback from visual, vestibular and proprioceptive sensors to produce carefully controlled motor commands that result in coordinated muscle firings and limb movements. When everything is working properly, this multi-level neural control system produces a stable gait and a highly consistent walking pattern. In fact, the kinetics, kinematics, and muscular activity of normal gait appear to remain relatively constant from one stride to the next, even during unconstrained walking.

Multiple sclerosis (MS) is a chronic multifocal disease of the CNS, which produces a wide range of neurological deficits but ambulation impairment is recognized as a prominent feature of disability in MS, both by physicians and people with MS (pMS) (1). The mechanisms underlying gait impairment are obviously complex and partially elusive because the quantification of gait performances in MS used to remain limited to the simple anamnestic recall of the maximum reported walking distance (MrWD) (2), the manual stopwatch measurement of walking speed on short distance walking tests (3, 4) through various settings and methodologies (5-10), and the measurement of the maximum distance performed in a given time (11). In contrast to maximum walking distance, walking speed (WS) is believed to be a far more stable parameter, which is less day-to-day variable and can be extracted from various walking paradigms (12, 13). Only few studies have investigated the behavior of pMS' performances on longer distance walking tests, with variable results and using exclusively manual stopwatch-based methodologies, as well as small population samples (11, 14, 15).

RESULTS AND DISCUSSION

Since gait is such a complex motor behavior, which can only be roughly disentangled by a single walking test, we previously hypothesized that a multimodal walking assessment of gait would allow a better delineation and quantification of the functional impairment, which is present early in MS before the Expanded Disability Status Score (EDSS) score has reached a value of 2.5 (6, 15). We have recently developed new outcome measures showing that the comparative assessment of WS on short and long distance may represent a feasible way to measure gait fatigability in pMS. We have compared head to head the Timed 25-Foot Walk Test (T25FW), a corrected version of the T25FW with a dynamic start (T25FW+), the Timed 100-Meter Walk Test (T100MW), and the Timed 500-Meter Walk Test (T500MW) according to the paradigm «as fast as possible» (15). We observed that deceleration during a long demanding walking task (T500MW) is a measurable parameter reflecting motor fatigue. Furthermore, we have compared the maximal walking speed on short distance with a static start (conventional T25FW) or with a dynamic start allowing a 3 meters run-up (T25FW+). This latter analysis has demonstrated that the maximum WS and the capacity of MS patients to accelerate on a specific distance may be independently regulated and assessed separately (10). Our refinement of ambulation measurement provides a greater sensitivity in detecting subtle and specific abnormalities, especially in patients where the level of disability remains low or unapparent.

The most commonly used sensors devoted to capture gait are cameras (16-18), electronic walkways (such as the GAITRite (19)), and motion capture systems (e.g. CodaMotion units CX1 (20)). These systems have however significant drawbacks such as the lack of reliability of the information obtained with color cameras since it depends on lighting conditions. The GAITRite system is expensive and provides only information regarding the position of the feet in the stance phase. Motion capture systems are also expensive and require that the users wear (active or passive) tags, which is not possible in most applications.

As feet paths are highly informative for gait analysis and recognition (21), we have recently designed a new system which captures the position of the feet in real time (22). We use several range laser scanners (RLS) to analyze a horizontal slice of the scene in which each foot is considered as a point, and the vertical movements are ignored. Useful information may be easily extracted such as walking speed, distance between feet over time, swing phase duration, and gait asymmetry in specific settings of walking recommendations (22).

Our RLS platform is cheaper than existing motion capture systems and GAITRites, is insensitive to lighting conditions (22), measures stride kinetics through feet positions in both swing and stance phases, and will be convenient for the development of multicentric clinical trial settings since patients can be easily and rapidly assessed without tags or sensors in the hallway of an outpatient clinic.

We are currently running a prospective, controlled and multicentric trial using 4 BEA LZR-i100 (BEA, Belgium) RLS arranged in a corridor of at least 10m length and 4m width, devoid of obstacle (Fig. 1).

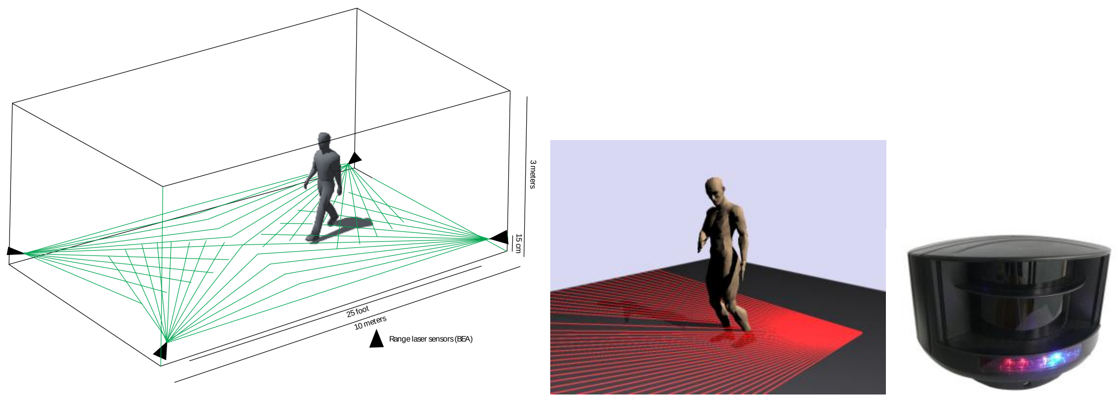

Figure 1. Schematics of the corridor. Our feet tracker is based on the distance profiles provided by the BEA RLS displayed on the right.

The 4 RLS measure distances in 274 directions spanning 96°, in a plane, at 15Hz. The scanned plane was chosen to be located at 15 cm above the floor, which is right above the tibio-tarsal joint of the ankle in a barefoot configuration for adult individuals in stance phase. Using several sensors allows us to reduce occlusions and to cover a wider area. Two video cameras will simultaneously record the global silhouette and upper/lower part of the subject's body during the walking tasks.

Some demonstrative sequences recorded with the current version of this setup (February 2012) are available at the following URL: http://www.montefiore.ulg.ac.be/~pierard/vgaims/demos_chu_february_2012/. Each sequence is accompanied by a video and graphs showing various features of the gait computed automatically from the acquired data. The following information are easily extracted from any walking task: global walking speed, mean speed of each foot, mean distance covered by each foot per gait cycle, lateral distance between feet over time, mean and maximum deviation of each foot/body center of mass from midline/useful trajectory, swing/stance phase durations.

The trial that we are currently running using RLS-based technology will be the first controlled and prospective trial to investigate pMS through ambulation outcome measures which are susceptible to capture stride abnormalities, gait ataxia, gait symmetry and distance-induced motor fatigue and spasticity.

We expect this trial to validate and empower the meaning of non-intrusive RLS-derived gait measures that should pave the ground for major improvements in the way we assess the efficacy of DMTs, physical therapy and symptomatic interventions on walking impairment, ataxia and fatigability in MS.

RLS-derived gait measures may also reveal to be crucial in the near future for the development of treatments that would specifically target progressive forms of MS.

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