iWALKER: A 'REAL-WORLD' MOBILITY ASSESSMENT TOOL

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INTRODUCTION

In 2001, nearly 2.5 million Canadian adults reported difficulty with mobility tasks, such as walking, climbing stairs, or standing for long periods of time. Mobility aids, such as canes, crutches and walkers, play an integral role in addressing mobility impairments. The rollator (or 'four-wheeled walker') is an assistive mobility aid prescribed to facilitate standing and walking activities. Although North American numbers have yet to be compiled, 1 in 16 people aged 56-84 years in Denmark, and an estimated 250,000 Swedish (4% of the country's population) are rollator users [1]. Despite the explosion in use, the literature examining the effectiveness and the underlying mechanisms in which rollators may influence mobility in everyday life is limited.

Studies in patients with chronic obstructive pulmonary disease (COPD) reported increased walking distances [2, 3] and improved efficiency [4] with rollator use. Biomechanical analyses of rollator walking in healthy subjects has revealed significantly reduced ankle and knee extensor moments, coupled with an increase in hip contribution to progression [5]. Recently, rollator use has been shown to provide specific benefits to frontal plane balance control [6, 7], and potentially hazardous limitations [8, 9]. However, the translation of these findings to mobility in everyday circumstances and situations are tenuous. Current clinical and laboratory assessments cannot reproduce the complex, dynamic, and often unpredictable combination of environmental conditions presented by the 'real-world'. The real-world is a complex environment filled with noise, flashing lights, moving objects and constantly changing conditions, requiring adaptations or accommodations of the biological systems that control mobility [10]. We do not know whether rollators are effective solutions to mobility impairments in these real-world situations and environments, or what circumstances rollators facilitate, or restrict, mobility.

Published data assessing the performance of rollators in the real-world is limited to satisfaction surveys [1]. Approaches such as surveys, self reports or continuous monitoring systems sampling at slow rates do not provide adequate precision and temporal resolution to establish specific relationships between environmental factors and mobility. Also, the specific combination and the timing in which environmental factors are encountered are key factors determining behavioural strategies. For example, the phase of walking in which an obstacle is encountered is a key determinant in choice of balance recovery reactions from a trip [11].

Advances in ambulatory monitoring techniques are creating opportunities to permit researchers to record and measure in the real-world environment. These advances in sensing and acquisition technology allow measurements to be taken outside the lab, over long durations and with far greater sensitivity and reproducibility than self-report measures. Importantly, real-world measurement has the advantage of informing about associations that may not have been previously hypothesized. We propose a novel ambulatory monitoring tool capable of assessing mobility measures autonomously for long durations in the real-world environment. In preparation for full-scale studies, current work is aimed at characterizing rollator usage for balance control as a basis for interpretation, and algorithm development for data processing.

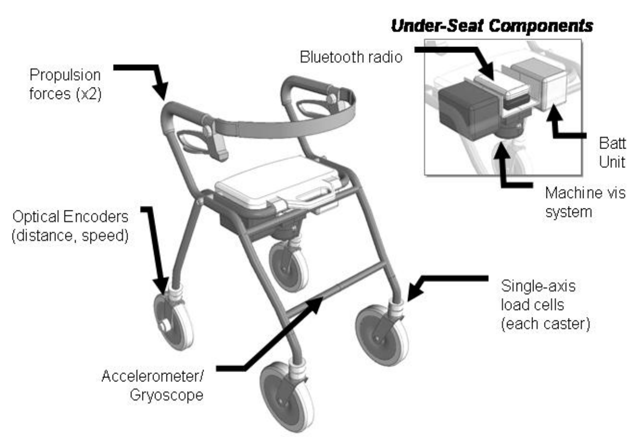

Figure 1: Key features of the instrumented rollator (iWalker)

iWALKER

An instrumented rollator, called the iWalker, provides a platform for a 'mobile gait lab', capable of capturing both mobility measures (balance, progression) and the environmental context (spatial surroundings, terrain, lighting conditions) of rollator users with the precision and resolution needed to provide a basis for an accurate reconstruction of events. Figure 1 illustrates the essential elements of the iWalker.

Balance Control

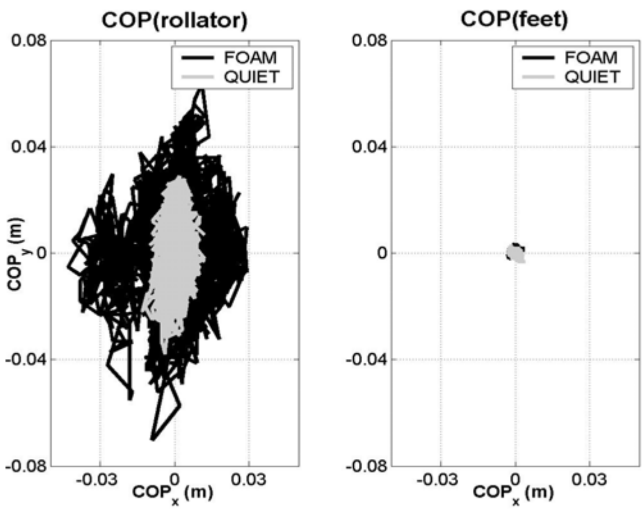

Figure 2: Centre-of-Pressure (COP) plots under the rollator (left) and under the feet (right) under baseline (grey) and balance challenge (black) conditions

To address the lack of studies investigating the role of the rollator for stability, we first conducted a study to characterize the manner in which the rollator is integrated into the overall balance control system [6]. Young, healthy subjects were asked to stand with a rollator under quiet and balance challenged (eyes closed, feet together, compliant support surface) conditions. Separate forceplates were used to record ground reaction forces beneath the feet and the rollator. Centre of pressure (COP) excursion under the rollator was observed to increase with the added balance challenge in both frontal and saggital places, with no appreciable increase in COP excursion applied through the feet (Figure 2). The results support the hypothesis that significant stabilizing forces are generated by the hands to maintain standing balance with rollator use.

Understanding that the hands play a significant role in overall balance control behaviour implies that balance may be measured through forces transmitted to the walker frame. The iWalker incorporates four single-axis button load cells (Transducer Technologies, USA) mounted vertically to the rollator frame. Signal conditioning units (Lorenz Messtechnik GmbH, Germany) are mounted underneath the seat. COP is calculated from the relative difference in vertical load between the front and rear (saggital plane), and left and right legs (frontal plane). Further studies to characterize stabilizing forces transmitted through the rollator while performing dynamic stability tasks, such as obstacle avoidance and collisions, are on-going.

Progression

Defined as the ability to produce limb movements to propel the body in the desired direction, progression is typically measured clinically by walking speed. For example, studies in the a COPD population reported that rollator use increases self-selected speed [2, 3].

To measure speed, the iWalker was fitted with optical encoders quantifying wheel rotation and direction (i.e., forward and reverse). High-contrast wheel markings were painted onto the wheels to provide fine graduations of wheel rotation (Fig. 3, left), with a resolution of 6.28 mm/mark. Rollator maneuvering is determined by observing the relative difference in speed between the two rear casters. In addition to rollator speed and distance, a combination 6-D accelerometer/gyroscope sensor unit (IMU 6DOF, Sparkfun Electronics, USA) is mounted to the frame. These sensors record iWalker maneuvers that are not captured by the wheel rotation encoders, such as lifting the rollator over curbs or skidding. The gyroscope sensors provide orientation information, useful for sensing inclines such as ramps.

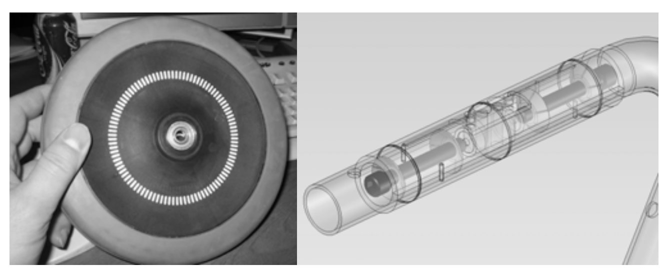

Figure 3: Progression sensors. Optical encoders transduce painted wheel graduations into distances (left). Mechanical design of propulsion force transducer mounts (right).

Mechanical designs to embed single-axis load cells into the handles of the walker to capture propulsion forces have been prepared (Fig. 3, right). The user's hands grip a high-density plastic sheath that isolates forces propelling the rollator. Rollator turning moment can be estimated from the relative contribution of the left and right handles.

Environmental Context

Offering the most flexibility and richness of information, vision was selected over ultrasound and infrared as our sensing modality to capture the environmental context. A machine vision system, comprising of a portable camera (Archos Helmet Camcorder, Archos, France) and digital recording unit (Archos 404, Archos, France), is used to continuously capture the spatiotemporal context of the immediate environment (Figure 4). Anticipated visual features include terrain transitions (e.g., thresholds, carpeting, sidewalks), lighting changes, targets (e.g., curbs, furniture, doorways), pedestrian traffic, and the placement of the feet behind the walker. Algorithms will be developed to filter data records to flag periods or incidents for further inspection. For example, segmentation by movement task will aid in identifying segments to measure variability (e.g., stride time variability), as well as flag transition times to measure transient effects.

Figure 4: Machine vision samples of environmental context (left) and foot placement (right).

Data Acquisition and Power

Analog signals from load cells, optical encoders and accelerometer/gyroscope sensors are converted to digital and transmitted wirelessly via Bluetooth radio (BlueSentry-AD, Roving Networks, USA). A Bluetooth-enabled PDA device (iPaq hx2190, HP Inc., USA) worn by the subject receives and store the data using acquisition software developed in LabView (National Instruments, USA). A major advantage of this system is the flexibility in which future sensors may be added or omitted, depending on the required measures. All on-board electronics are powered by a high-capacity rechargeable 18.5V lithium-ion battery pack (BatterySpace, USA).

‘REAL-WORLD’ PILOT STUDY

Initial studies will employ a natural laboratory model that permits the measurement of behavioural data of the participants outside a traditional clinical/laboratory setting. Participants will be asked to ambulate through pre-defined walking route commencing in the Toronto Rehabilitation Institute (Figure 5, location 1+2), outside into the community and consisting of a range of typical challenges and common everyday mobility tasks. Potential challenges include ramps, street crossings, pedestrian traffic, varying surface conditions (e.g., curbs, sidewalks, street car tracks). Participants will also engage public transit access points (Fig. 5, location 5) and local commercial sites, such as a convenience store (Fig. 5, location 7) and coffee shop.

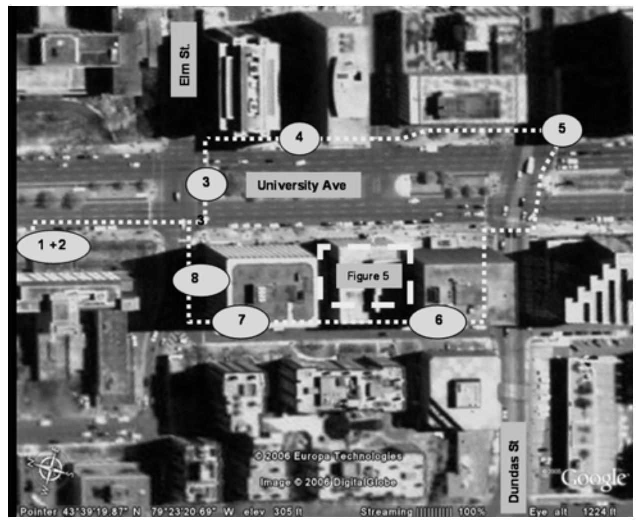

Figure 5: 'Real-world' pilot study walking route.

SUMMARY

The iWalker is an ambulatory monitoring tool designed to continuously measure the stabilizing forces applied through the rollator, distances traveled, instantaneous walking speed and accelerations. A machine vision system captures features of the immediate physical environment, such as obstacles, terrain changes, lighting, precipitation, and foot placement.

On-going work involves further characterization of dynamic balance control related to rollator use by introducing perturbations during walking tasks, and image processing algorithm development to automate extraction of relevant environmental features from the vision records. Handle mounts for sensors measuring forces used to propel and maneuver the rollator are in fabrication.

Detailed information about the stability and progression of rollator users in response to ‘real-world’ environmental cues will uncover novel behaviour expanding our knowledge of motor control with assistive devices, leading to improved training, prescription, design and testing standards towards safe mobility.

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