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Clinical Gait Assessment of Older Adults using Open Platform Tools

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Abstract— **Gait impairment is associated with increased falls risk. The gait of 321 community dwelling elderly adults was assessed using the TRIL Gait Analysis Platform (GAP), which was specially designed for ease of use in a research clinic setting by non-experts. The GAP featured body-worn kinematic sensors, a pressure sensitive electronic walkway, and two orthogonally mounted web cameras, and was developed using open platform tools. This flexible platform was applied to objectively measure gait parameters in different gait assessments. The results from the 6 meter walk assessment are presented here. In this assessment, participants were categorized by clinical falls history as 'fallers' or 'non-fallers'. Temporal and spatial gait parameters were examined. Significant differences in spatial parameters were observed when fallers and non-fallers were compared. Temporal parameters were found to differ, though not significantly.**

I. Introduction

HEALTHCARE systems are facing new challenges as the world's population ages. As the older population increases, the incidence of geriatric conditions, such as falls, also increases. If preventative measures are not taken, the number of injuries caused by falls is projected to double by the year 2020 [1]. It has been estimated that the cost of falls in older adults, in the USA alone, may reach $54.9 billion by 2020. Gait impairment is one of the most predictive factors for identifying elderly adults at risk of falls and has been recommended by the American Geriatric Society and British Geriatric Society as a screening tool in both primary and clinical settings [2].

Gait can be assessed in numerous ways, ranging from subjective observation of gait to objective optical motion analysis. Observational methods are typically used in primary care, and depend on the clinician's subjective interpretation of normal and abnormal gait. Gait speed has been associated with falls risk [3], and can be measured objectively by recording the time to walk a fixed distance. However, this single parameter alone does not provide information on the subject's ability to carry out this task safely. Sensor-based methods, employed in clinical settings, can provide more detailed gait parameters. Sensor-based insoles and footswitches provide information on the timing (temporal parameters) of individual steps and strides, and the stride-to-stride variation of these parameters. Sensor-based walkways, such as the GAITRite (CIR Systems Inc., PA, USA) and Tekscan (Tekscan Inc., MA, USA) systems, measure the location of footsteps (spatial parameters) as well as their timing. Body worn gait assessment systems range in complexity from basic step counters , to systems employing inertial sensors to measure spatial and temporal gait parameters [4, 5]. Laboratory-based gait analysis using a force-plate and/or optical motion analysis is considered to be the gold standard. However the cost of these systems and the expertise required to use them, render them less suitable for large scale clinical assessments

This paper describes a bespoke Gait Assessment Platform (GAP), which records data from three sensor modalities (body-worn sensors, walkway, and web cameras) and provides geriatricians with objective measures of temporal and spatial gait parameters, and gait variability. This flexible platform was developed using open platform tools to measure different gait and balance tasks in a geriatric research clinic. The gait parameters of 321 older adults, performing the 6m walk assessment, were measured using GAP to identify which gait parameters discriminate between fallers and non-fallers.

II. System Overview

A. GAP Software

The GAP software was developed in a modular fashion, using an open shareable technology platform. The BioMOBIUS™ research platform was developed by TRIL Centre researchers and developers, to allow researchers to rapidly develop sophisticated technology solutions for biomedical research [6].

A multidisciplinary team, including software and hardware engineers, designers, and geriatricians, collaborated to iteratively develop usage models, user interfaces, and gait

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parameters necessary for the 6m walk and other assessments, which utilized GAP. It was designed to be suitable for use by clinicians, who were not technical nor gait analysis experts.

The GAP consisted of a pressure sensing walkway (S4 Sensors Walkway, S4 Sensors, Victoria, BC, Canada), two kinematic sensors worn on the subject's shanks (SHIMMER™, Shimmer Research, Dublin, Ireland), and two orthogonally mounted web cameras (Creative Technology Ltd., Singapore), as illustrated in Figure 1. An intuitive BioMOBIUS GUI was developed, to allow clinicians to capture data for each individual assessment, using simple "Start" and "Stop" buttons. Standard BioMOBIUS blocks were applied to capture data from the wearable sensors and webcams, display data, and to record data in a single synchronized file and in a comma delimited flat files. Bespoke BioMOBIUS blocks were developed to record clinical and technical comments in the trial database for each walk, to interface to the S4 Sensors walkway, and to display walkway data on the GUI.

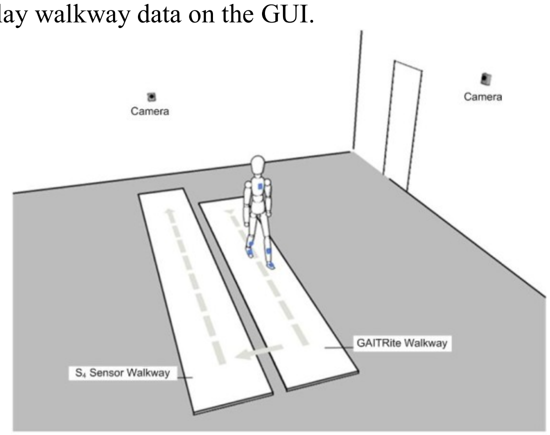

Figure 1 Experimental setup and system overview

B. The 6m Walk Clinical Protocol

The gait of 321 community-dwelling older adults, from the TRIL Clinic cohort, was assessed using the GAP. Participants received a full bio-psycho-social assessment, and provided informed consent, in accordance with the TRIL Clinic protocol. Ethical approval was obtained from the St. James' Hospital.

Table 1 Demographic data for patients included in the study, categorized by falls history

	Fallers (mean±std)	Non-fallers (mean±std)
N (Male/Female)	40/142	60/79
Mean age (years)	74.54±7.26	70.37±6.82
Mean Weight (kg)	70.07±13.71	77.70±14.07
Mean Height (m)	1.63±0.09	1.69±0.09

Participants were categorized as 'fallers' or 'non-fallers' based on their clinical history. Subjects were categorized as fallers if they had fallen more than once in the previous 12 months; or if they had fallen once in the previous 12 months, and that fall resulted in a loss of consciousness and/or a fractured bone or severe injury and/or other severe consequences for the subject (e.g. to the extent that they would regard themselves as fallers).

Shimmer kinematic sensors were secured to the shank of each participant using elasticated tubular bandages (TubiGrip, Mölnlycke Health Care AB, Göteborg, Sweden). The sensor was positioned such that its measuring axis was aligned with the medio-lateral axis of the shank of the leg. Participants were instructed to walk at a comfortable pace for 6 m to the end of the room, then to turn through 180°, and to walk 6 m back towards their starting position along the S4 Sensor Walkway. The protocol was demonstrated to each subject before beginning the assessment.

C. Data Analysis

Video, body-worn sensor and electronic walkway data were reviewed offline for data and protocol integrity using BioMOBIUS. Temporal and Spatial parameters were calculated off-line using MATLAB (The Mathworks™, Natick, Massachusetts, USA).

1) Spatial gait analysis

The S4 Sensor walkway was used by the GAP to measure the spatial parameters of gait. The walkway measured 0.91 m x 4.57 m, and consisted of pressure sensors spaced 2.54 cm apart along both dimensions. An additional 1 m non-sensing extension was attached to each end of the walkway, to maximize the number of steady state steps captured by the active sensing area of the walkway. Data were sampled at 20 Hz and stored for post processing and analysis.

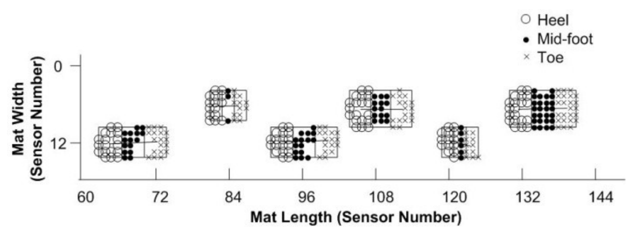

Figure 2 Sample of electronic walkway validation data after processing

The maximum value recorded by each pressure sensor over the duration of the walking trial was extracted, providing a single matrix representing the entire walk. Data were median filtered with a 3 x 3 window. Footprints were automatically detected using a rule based algorithm: the width of a single footprint was required to be at least 3 and at most 8 active sensors, the length of a single footprint was required to be at least 6 and at most 13 active sensors, and a space of 4 or more inactive sensors in any direction was not permitted within a single footprint. This footprint detection algorithm was validated against chalk-mark data using a method previously reported method by McDonough *et al.* [7]. Each footprint was trisected into area representing heel, mid-foot and toe points. Heel centroids (HC), toe centroids (TC) and mid-foot (MF) points were calculated for each footprint and used to calculate Stride length, Stride width, and Step width.

2) Temporal gait analysis

Gyroscope data from the SHIMMER kinematic sensors were used to calculate temporal parameters of gait for each walk for each patient. Data were transmitted from each sensor to the data acquisition PC at 102.4 Hz via Bluetooth.

Heel strike (HS, the time of initial foot contact with the ground) and toe-off (TO, the time of the terminal foot contact) times were calculated from the gyroscope derived medio-lateral angular velocity signal recorded from each patient's left and right shank using a previously reported method [8]. The following temporal gait parameters were subsequently derived: stride time (s), step time (s), stance time (s), swing time (s), double support time (%), and single support time (%).

3) Statistical analysis

The mean value of each of the temporal and spatial gait parameters were calculated, along with the coefficient of variation (CV) of each parameter over the duration of the walking trial (Table 1). Analysis of variance (ANOVA) was used to examine whether each gait parameter could significantly differentiate between patients with a history of falling and those without. P-values less than 0.05 were considered statistically significant, and it was also noted if a P-value was less than 0.005. All statistical analyses were carried out using SPSS (SPSS Inc., Chicago, IL, USA). The Pearson correlation coefficient was used to examine correlations between temporal and spatial gait parameters in the faller and non-faller populations.

III. RESULTS

Table 2 Mean and coefficient of variation (CV) of each gait parameter are presented along with their standard deviation (SD). Asterisks indicate that a significant difference (* p<0.05; ** p<0.005) was identified between fallers and non-fallers for that parameter.

	Fallers	Non-Fallers	P
Mean			
Stride length (cm)	108.04±22.23	122.76±21.09	**
Stride width (cm)	12.43±4.78	11.37±3.91	*
Step length (cm)	53.68±11.09	60.82±10.99	**
Step width (cm)	55.76±10.18	62.55±10.39	**
Stride time (s)	1.23±0.19	1.20±0.14	
Stance time (s)	0.81±0.18	0.79±0.16	
Swing time (s)	0.51±0.09	0.51±0.08	
Step time (s)	0.66±0.12	0.66 ±0.13	
Single support (%)	75.86±14.21	78.24±13.57	
Double support (%)	34.58±21.29	34.33±24.28	
CV (%)			
Stride length	8.59±8.18	7.76±8.88	
Stride width	24.98±15.17	25.25±15.41	
Step length	14.09±12.56	12.69±12.07	
Step width	12.40±11.10	10.57±9.99	
Base width	24.72±16.04	25.26± 17.26	
Stride time	19.24±9.42	18.59±9.88	
Stance time	30.30±15.89	33.04±18.54	
Swing time	32.35±18.37	30.96±18.52	
Step time	34.19±18.44	31.79±17.29	
Single support	21.37±15.66	20.09±18.29	
Double support	61.43±31.39	62.58±36.99	

Gait parameters for fallers and non-fallers are reported in Table 1. Correlations between all derived temporal parameters were also examined; notable differences were found in the correlation of stance time, step time and swing time with stride time when fallers and non-fallers were compared. Stance time was markedly more correlated with stride time for subjects with a history of falling (Fallers: R = 0.80; Non-fallers: R = 0.48), step time was also more correlated with stride time for subjects with a history of falling (Fallers: R = 0.83; Non-fallers: R = 0.48), however swing time was notably less correlated with stride time for subjects with a history of falling when compared to subjects with no history of falls (Fallers: R = 0.17; Non-fallers: R = 0.49).

Fallers exhibited significantly shorter stride lengths (p<0.005) and step lengths (p<0.005), and significantly narrower stride width (p<0.05) and step width (p<0.005), than non-fallers. To account for the gender bias in the cohort, the female and male participants were also examined individually, and each of these effects were statistically significant for both genders (p<0.05).

Increased variation in stride length, step length and step width, and decreased variation in stride width and base width were also noted for fallers, however these relationships were not statistically significant. The correlation between each spatial parameter with all others was also examined. Notably, stride length, step length and step width were strongly inter-correlated ($R^2 > 0.95$ for all correlations).

IV. DISCUSSION

The Gait Analysis Platform developed for this study was designed to meet the needs of a geriatric clinic with appropriate amounts of physical space, such as the TRIL clinic. However, in order to examine spatial and temporal gait parameters outside of a large clinic or laboratory setting, a purely body-worn sensor-based system was developed by reusing elements in the GAP platform. This system is a portable alternative to the GAP and places no limits of the number of strides collected.

It should be noted that 69% of the participants of this clinical study were female. Additionally, 64% of the female cohort was classified as fallers, whereas 40% of the male cohort was classified as fallers. The biases revealed by these demographics should be taken into consideration when interpreting the findings of this study. Furthermore, the population sample used in this study represented a sample of convenience recruited through St. James hospital Dublin and may represent a less frail population than that reported in other studies. In future work we intend examining the utility of the reported system and method in prospectively predicting falls using a longitudinal study design.

The relatively short distance of the walking trial performed by each patient (6 m) may not have been sufficient to adequately evaluate temporal gait parameters and variability. One might expect that evaluating patients over a longer distance might yield significant differences [9]. We are currently applying the portable GAP system to investigate this in the TRIL Clinic. The significant differences in spatial parameters noted between fallers and non-fallers suggest the distance used in the study is appropriate for evaluation of spatial gait parameters. The results of this study suggest that the spatial and temporal parameters of gait differ between elders with and without a history of falls. These differences may be due to musculoskeletal impairments [10], neurological or vestibular impairments, psychological factors such as a fear of falling [11], or differences in medication dosages [12]. The mean value of stride length, stride width, step length and step width provided significant discrimination between fallers and non-fallers. Participants with a history of falling exhibited a significantly shorter stride length than that of non-fallers. This result agrees with previous findings in the literature [13-15]. The results presented in this study indicate that fallers walk with shorter and narrower steps than non-fallers which may indicate different neuromuscular control strategies governing walking in the two groups. Together with the previously discussed findings of shorter stride length, these results are consistent with those of Barak et al. [13], who hypothesized that fallers walk in a more conservative fashion, with shorter strides, than non-fallers. It was also noted that mean step width was found to be highly correlated ($r > 0.95$) with mean step length as well as mean stride length, indicating that measurement of one of these variables may be sufficient for use as part of a falls risk assessment.

Significant differences in the gait of fallers compared with non-fallers were only observed for spatial parameters, however noteworthy changes were also observed in temporal parameters. Stride time, as well as stride time variability, were greater for fallers compared to non-fallers. Although this effect was not statistically significant, it is in agreement with the results of previous studies reported in the literature [16]. Stance time increased for fallers compared with non-fallers. Consistent with this finding, double support time was found to be longer in fallers compared to non-fallers. Single support time, the time spent on one foot, was also seen to reduce. These results suggest that fallers may take more time while on both feet, possibly to stabilize themselves, and may rush through the time on one foot due to lack of confidence or lack of muscle strength [17]. These results are in accordance with those of Lord et al. [17], who found a significant increase in percentage stance time for fallers compared to non-fallers. Notable differences in the Pearson correlation coefficient of mean stance time, mean step time and mean swing time with mean stride time were also observed when fallers and non-fallers were compared, suggesting that the timing of gait phases varies greatly between fallers and non-fallers.

V. Conclusion

A bespoke clinical gait analysis platform was developed and implemented to assess the gait of a large cohort of older participants in a clinical setting. This platform was able to discriminate between fallers and non-fallers using spatial parameters in a cross-sectional retrospective sample. These findings agree with existing research. Differences in temporal parameters were also identified, although not significant. It is hypothesized that differences in temporal parameters will be found to be significant over longer distances and with an older cohort. Additional analysis is underway to test this hypothesis and determine if the platform can prospectively predict those at risk of falling, based on changes in their gait parameters.

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