



Validation of Centre of Pressure Trajectory from a Portable Gait System

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Abstract— In New Brunswick, an average of eight seniors are admitted to hospital each day for a fall-related injury, costing the New Brunswick health care system almost \$250M per year and representing the largest single contributor to injury-related health care costs in the province. Although international fall-risk assessment guidelines exist for identifying seniors at risk of falls, they are subjective and rarely employ technology. StepScan™ (Charlottetown PE) pressure sensitive tiles offer a potential solution for integrating portable technology into routine falls-risk assessment that can be performed in community clinics or the home; however, have not yet been subjected to head-to-head comparison with an accepted “gold standard” measurement system, for suitable tests of mobility and balance. The aims of this study were to fill this gap in knowledge. Fifteen healthy participants performed quiet standing, 5-times sit-to-stand task, and a surrogate test for walking – the step-up/step/down task, on the StepScan™ pressure tiles mounted on top of in-floor, rail mounted AMTI (Amherst MA) force plates in a motion analysis laboratory. Simultaneous registered trajectories of the centre of pressure (CoP) during standing and stepping tasks were compared for accuracy in global position (random error + bias) and relative position (random error only). Slow tasks such as standing had high bias (>20mm) but very good accuracy (1-2mm). Moderate speed tasks such as the 5-times sit-to-stand also had high bias (>20mm) but did not have acceptable accuracy (>15mm). Rapid stepping tasks had very low bias (<2mm) and acceptable accuracy (4-7mm). We conclude that StepScan™ CoP measurements have excellent precision for static balance assessment, and acceptable precision and trueness during a rapid stepping task, but limitations may exist for motor tasks such as the sit-to-stand. The variable bias observed for the different standing and stepping tasks is highly curious and requires more study.

Keywords— Balance, Standing, Sit-to-Stand, Stepping, Stability, Instrument Accuracy.

INTRODUCTION

Falls are a leading cause of injury-related hospitalizations among older adults in Canada, with hip fractures accounting for a significant portion of these cases. Despite the severe consequences of falls, effective fall risk assessment methods remain limited [1]. Motion capture cameras and in-floor

force platforms offer precise measurements but are expensive, non-portable, and impractical for routine clinical or home use [2].

StepScan™ (Charlottetown, PEI) pressure tiles offer a possible solution. These modular pressure sensing tiles are portable and configurable into any stepping surface, making them attractive for gait and balance assessment in community settings [3]. In addition to capturing highly detailed maps of plantar pressure, a key feature of the StepScan™ tile system is the possibility of quantifying the stability of the body's centre of mass (CoM) in the horizontal plane via measurements of centre of pressure (CoP) from the soles of the feet.

To our knowledge, however, the StepScan™ CoP measurement has yet to be compared head-to-head with an accepted gold-standard. Force platforms such as the AMTI™ (Amherst, MA) in-floor rail mounted system are the gold-standard for such measurements but are not portable. Therefore, the primary aim of this study was to validate the StepScan™ system against the accepted gold-standard for CoP measurement during a variety of standing and stepping tasks.

Although balance related tasks, such as “quiet standing” and the “5-times sit-to-stand task” can be performed in limited space environments [4], a significant challenge exists for assessment of gait which generally requires about 10m of unobstructed walk-way space [5]. An alternative is the step-up/step-down (SUSD) test [6] which can be performed in limited space environments, and has been shown to be a sensitive test of balance impairment [7].

The ability to quantify stability of standing and stepping tasks requires accurate estimation of the CoM in the horizontal plane via the CoP trajectory. Therefore, the secondary aim of this study was to compare the accuracy of CoP estimation during slow (quiet static standing, SS), moderate (5-times sit-to-stand task, ST) and fast (SUSD) movement tasks.

METHODS

Participants

Because the aim of the study was to compare measurement systems, only healthy adults with no balance or other impairments affecting gait were asked to participate. Participants

were screened using the Get Active Questionnaire [8] for any health conditions that would contraindicate moderate intensity exercise. Fifteen healthy adults (9 women, 6 men), aged 19 to 48 years, participated in the study.

The study was reviewed and approved by the University Research Ethics Board and all participants provided signed informed consent prior to laboratory measurements.

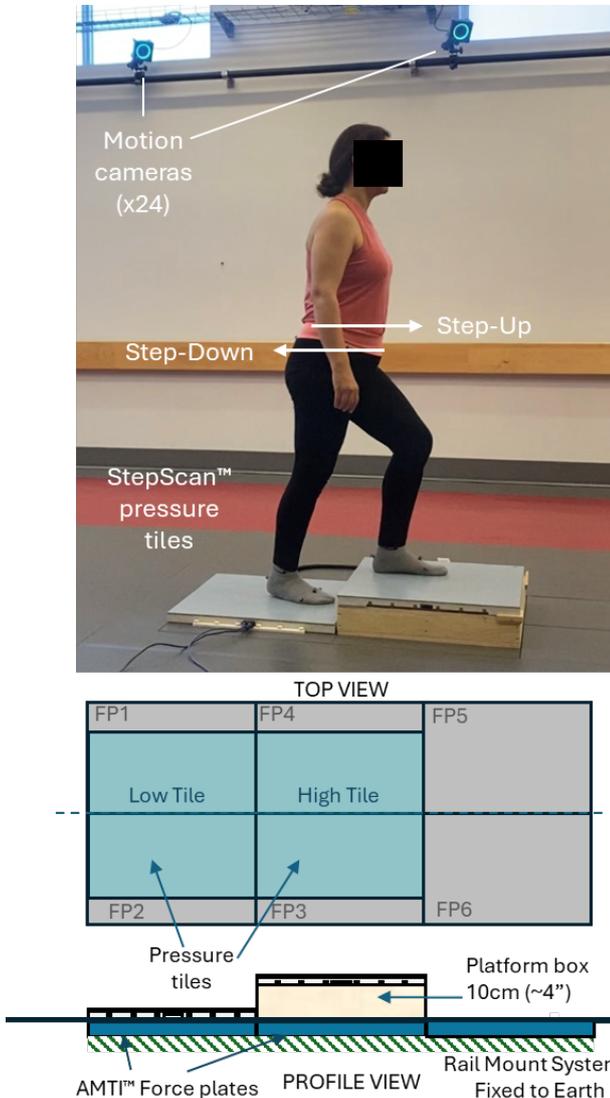


Figure 1. The step-up/step-down task and experimental setup with StepScan™ tiles on top of the in-floor AMTI™ force plates.

Instrumentation

The experiment was conducted at the Centre for Adaptive Rehabilitation Engineering (CARE) at the Institute of Biomedical Engineering on the University of New Brunswick Fredericton campus. The CARE Mobility Laboratory utilizing 24 wall-mounted motion capture cameras and 6 in-floor force platforms. Two StepScan™ tiles (each 600mm x 600mm) were positioned on the force plates (each 400mm across and 600mm long): the first tile (Low tile) was placed directly on the first two force plates, while the second tile (High tile) was mounted on a rigid wooden box with a height of 10 cm and placed on the adjacent two force plates. The tiles were connected with a flexible cable so that the two tiles remained isolated upon their respective pairs of force plates. AMTI™ force plates were sampled at 1000Hz and down-sampled to 100Hz to match the sampling rate of the StepScan™ system. Figure 1 illustrates the instrumentation set-up for the experiment.

Protocol

Prior to participant testing, a calibration device was used to register the Low and High tile positions in global laboratory coordinates relative to the AMTI force plates.

The participant's dominant limb was first determined by the imaginary ball kick test, and their comfortable walking pace was then determined by having them walk around the indoor track of the motion lab. Participants then performed the following battery of tests:

1. Static (quiet) standing (10s) on the Low tile
2. Static (quiet) standing (10s) on the High tile
3. 5-times Sit-to-Stand test with feet on the Low tile and seat on the High tile
4. Paced SUSD test (30s) leading with dominant leg
5. Paced SUSD test (30s) leading with non-dominant leg

Quiet standing tests were performed with eyes open, feet hip width apart, and arms folded over the chest. For the sit-to-stand tests, the chair height was adjusted for the participant's knee height and positioned with feet on the low tile and buttocks on the chair box which was positioned on the High tile. On the go command the participant performed 5 sit-to-stand cycles.

As illustrated in Figure 1, the SUSD test is a repeated stepping task where the participant steps forward and up on to the platform then backward and down to the ground level in a fluid stepping pattern. A metronome was used during SUSD tests to control participants' pace. Participants first completed the SUSD leading with their dominant limb, and then repeated the SUSD test while leading with their non-dominant limb. Participants rested for 30-60s between trials.



Data Analysis

Raw force plate and pressure tile CoP trajectories were computed using a custom Matlab program written by the authors. CoP trajectory from the AMTI™ force plates was determined by combining the sensor results of the two underlying plates for each tile to give a resultant CoP trajectory that would be the projection of the moving CoM to the surface of the feet in contact with the ground. Likewise, the CoP trajectory from the pressure tile was determined by calculating the resultant centre of force on the tile during each time frame of the task.

Horizontal coordinates in X (forward direction) and Y (lateral direction) were analyzed separately. Assuming the AMTI™ is provide a ground truth measurement, the accuracy of the StepScan™ CoP was assessed in two ways:

1. Comparison of the co-registered CoP global X and Y coordinates, which includes both the systematic bias between systems and the random error inherent in the StepScan™ measurements
2. Comparison of the co-registered CoP X and Y coordinates relative to their trial mean – that is, with the systematic bias removed.

Given that the pressure cell dimension of the StepScan™ is 5mm x 5mm, we set the criteria for acceptable agreement between systems to be on average 5mm, with errors larger than 10mm being unacceptable.

RESULTS

Results of the CoP X and Y comparison can be seen in Table 1. Absolute errors for all trials ranged considerably between 4mm and 20mm. Errors varied by trial type, with static stand (SS) trials having an absolute position error ranging between 9-17mm, chair rise (ST) having absolute position error ranging between 11-21mm, and the SUSD tests (SD and SN) having absolute errors in the range of 4-10mm.

After removing the trial mean from the respective AMTI and StepScan coordinates, relative error for the SS tests reduced considerably to less than 2mm, a reduction in the error for the ST test to just under 10mm, but little change to the SUSD error range, which only improved slightly to 4-8mm.

Figure 2 illustrates the degree of bias in the SS trial, for a representative participant. The panel on the left is the CoP trajectory (Low tile) in global laboratory coordinates, while the panel on the right shows the same data relative to their

trial mean, which indicates a very high degree of agreement between system responses to body motion.

Curiously, removing the bias from the SUSD tests did not improve the result, suggesting that the faster stepping movements are less susceptible to bias. The excellent degree of tracking between StepScan and AMTI CoP coordinates is illustrated in Figure 3 for the same representative participant.

Table 1. CoP X and Y uncertainties for StepScan™ relative to AMTI™ for standing (SS), sit-to-stand (ST), and SUSD tests leading with dominant limb (SD) and non-dominant limb (SN), for both the Low and High tile (except for the ST where only the Low tile is included).

Task		Absolute error (mm)		Relative error (mm)	
		Mean	SD	Mean	SD
SS-Low	X	9.42	6.92	1.27	.78
	Y	9.92	6.58	1.44	.67
SS-High	X	17.40	6.45	1.48	.63
	Y	8.91	5.56	1.57	.67
ST-Low	X	21.10	4.79	9.66	2.53
	Y	11.54	4.21	9.89	3.70
SD-Low	X	6.15	1.56	5.88	1.26
	Y	5.41	2.16	5.37	2.66
SD-High	X	10.11	3.94	7.53	1.91
	Y	3.73	1.05	3.78	.98
SN-Low	X	6.60	1.81	6.08	1.49
	Y	4.57	1.68	4.60	1.86
SN-High	X	9.44	4.04	6.97	1.36
	Y	3.84	1.19	3.88	.99

DISCUSSION

Although the StepScan™ system has been commercially available for over a decade, this study is the first to independently evaluate its measurement response characteristics during various mobility and balance assessment tasks for which it was designed.

While the results are generally encouraging, with some noted limitations, they must be interpreted within the clinical context of diagnosing or assessing individuals for balance impairments.

For quiet static standing tests, the global coordinates of the CoP are typically not the primary focus. Instead, the degree

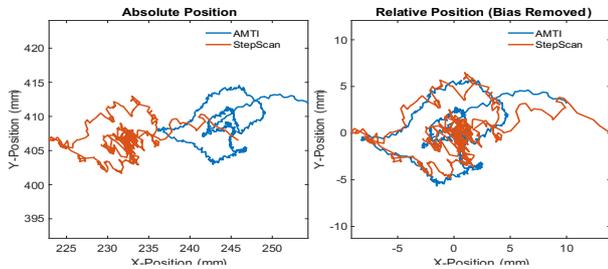


Figure 2. Static stand CoP for a representative subject: Left: Global coordinates; Right: Relative coordinates.

of scatter in the X-Y trajectory—representing the participant’s effort to maintain a steady posture—is of greater importance. As illustrated in Figure 2, the CoP trajectory exhibits the same shape and contour across both systems. Additionally, Table 1 shows that removing the bias results in exceptional agreement, achieving accuracy within a measurement “pixel” of the StepScan™ system.

In contrast to the SS trials, the ST trials revealed a high

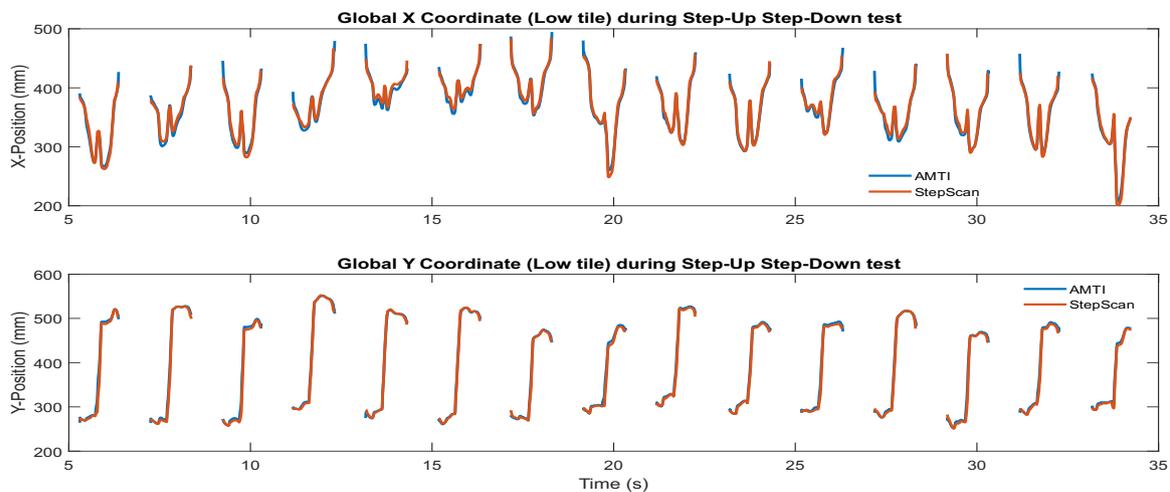


Figure 3. SUSD Global CoP for a representative subject. Top: CoP X coordinate; Bottom: CoP Y coordinate.

degree of bias in the global positioning of signals. However, unlike the SS trials, removing this bias in the ST trials only reduced the errors to just below 10 mm.

The SUSD task was again different from SS and St tasks. Here, almost no offset bias was observed in the global coordinates, as seen in Figure 3. Table 1 further supports this observation, showing nearly identical error magnitudes after bias removal for both SD and SN trials.

While these results are promising, they raise several important questions. What accounts for the varying degrees of offset bias in the CoP X-Y trajectories across different movement tasks? Why does the SUSD task exhibit higher accuracy

and lower bias compared to the Sit-to-Stand task? Furthermore, why do the static standing tests demonstrate such a high degree of bias yet maintain excellent relative accuracy? These are intriguing questions that will guide future exploration in this project.

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