Psychiatria Danubina, 2019; Vol. 31, Suppl. 3, pp 324-330 *Conference paper*

METROLOGICAL PERFORMANCE OF INSTRUMENTS USED IN CLINICAL EVALUATION OF BALANCE

Frederick R. Carrick[1,2,3,4], Ahmed Hankir[2,5,6], Rashid Zaman[2,7,8] & Cameron H. G. Wright[1,9]

[1]*Department of Neurology, Carrick Institute for Graduate Studies, Cape Canaveral, FL, USA*
[2]*Centre for Mental Health Research in association with University of Cambridge (CMHR-CU), Cambridge, UK*
[3]*Department of Neurology, University of Central Florida College of Medicine, Orlando, FL USA*
[4]*Department of Medical Education, MGH Institute for Health Professions, Boston, MA, USA*
[5]*Department of Psychiatry, Carrick Institute for Graduate Studies, Cape Canaveral, FL, USA*
[6]*South London and Maudsley NHS Foundation Trust, London, UK*
[7]*Hertfordshire Partnership University NHS Foundation Trust, UK*
[8]*Department of Psychiatry, University of Cambridge, Cambridge, UK*
[9]*Department of Electrical and Computer Engineering, University of Wyoming, Laramie, WY, USA*

SUMMARY

Clinical assessment of a patient, monitoring the progress of a condition, and/or titration of a therapy is dependent on the metrological characteristics of diagnostic equipment. While metrological performance of instruments is commonly assessed in research, it is not so often done in clinical practice. Physical rehabilitation applications may benefit individuals with mental health concerns and are associated with an accurate analysis of balance and gait. There is a paucity of published data regarding the metrological characteristics of commonly used clinical instruments used in posturographic measurements. We desired to assess the accuracy, trueness, precision and resolution of four posturography systems that we use clinically in practice: a Bertec BP-5050, a Vestibular Technologies CAPS® Professional and a Vestibular Technologies CAPS® Lite three-component balance platforms, and a NeuroCom® Balance Manager SMART EquiTest®. Metrological performance by posturography instruments was recommended in 2013 by the International Standardization Committee for Clinical Stabilometry of the International Society for Posture and Gait Research (ISPGR). Clinical and research findings may be erroneous, or at the least misleading, if the instruments used to make clinical decisions are associated with significant error. We suggest that there is a strong need for posturographic instrumentation with appropriate metrological characteristics used in clinical applications. The ISPRG recommendations appear to be reasonable and appropriate, and our results show they are obtainable. Physical measurements and functional testing used to correlate and design mental health and physical based rehabilitation strategies are often dependent upon the accuracy and metrological integrity of diagnostic instruments used in posturography.

Key words: *postural balance – instrumentation - data accuracy – standardization - metrological characteristics*

* * * * *

INTRODUCTION

The development of safe diagnostic instruments that have acceptable levels of metrological performance (e.g., accuracy, trueness, precision, resolution, repeatability, reproducibility) is critical if clinical decisions will be made based on the results obtained using such instruments (Webster 2010). Inconsistency and differences in metrological characteristics between diagnostic instruments are problematic for clinicians whose applications are based upon a presumed "accuracy" of the instrumentation. If instruments properly measure what they purport to measure they might be considered sufficiently reliable to document outcomes of the treatment of a condition or progression of disease. Repetitive subject functional testing is useful only if changes of the measured results are not due to inherent variability of the instrument (Pagnacco et al. 2015). If an instrument's metrological characteristics are not appropriate for a specific clinical application, then comparing these results with those obtained with different instruments may lead to error in diagnosis and treatment affecting patient outcomes.

This seems to be an issue of particular interest in posturography, where there appears to be some conflicting results based on the utilization of varied instrumentation. For example, Johnson and colleagues used static and dynamic posturography during a whole-body leaning task to measure sway, spatial accuracy and directional control of tasks in Parkinson's patients with bilateral deep brain stimulation of the globus pallidus pars interna (Johnson et al. 2015). They found differences in sway that were dependent upon medication and deep brain stimulation. Prosperini and colleagues determined that the Center of Pressure (CoP) path measurement in the static position is an accurate tool for detecting potential falls in subjects affected by Multiple Sclerosis, if the posturographic measurements are sufficiently sensitive (Prosperini et al. 2013). Cappa and colleagues demonstrated clinical applicability of accurate movement measurements of a novel parallel spherical robot (SR) for dynamic posturography (Cappa et al. 2010). The Sensory Organization Test (SOT) has been applied with dynamic posturography by Fu and colleagues to assess postural sway angle to provide clinical

guidance associated with the treatment of multiple ankle sprains when there is a deficiency of ankle proprioception and standing balance (Fu & Hui-Chan 2005).

On the other hand, Yeh and colleagues found that the Sensory Organization Test (SOT) was not "sensitive" enough to "accurately" quantify postural control in elderly patients with vestibular disorders (Yeh et al. 2014). They enhanced the performance of the SOT by using a nonlinear algorithm of empirical mode decomposition (EMD), and verified the differences of effects caused by aging and/or illnesses as benefits to clinical diagnosis. They found that EMD successfully improved the "accuracy" of SOT measurements by increasing the "sensitivity" of the analysis. Their outcomes suggest that when an instrument's "sensitivity" is increased, clinical applications might be developed with greater "accuracy". Alahmari and colleagues found significant correlations between the Balance Rehabilitation Unit (BRU) and the SOT using the SMART EquiTest ® device, ranging from 0.64 to 0.81 for Center of Pressure (CoP) area and from 0.44 to 0.76 for CoP velocity (Alahmari et al. 2014). The reliability and validity of CoP measurements obtained during testing of the sensory integration processes were demonstrated using the BRU, but these conclusions are dependent upon the reliability and validity of the SMART EquiTest®. Clearly, the BRU is as reliable and valid for CoP measurements as is the SMART EquiTest®, or perhaps equally as inaccurate. Rossi-Izquierdo and colleagues attempted to validate two different posturographic techniques as part of their research looking for clinically useful risk factors for predicting falls (Rossi-Izquierdo et al. 2014). They found that assessment with a free-field body sway analysis (using the VertiGuard® device) is more efficient in identifying fallers than the parameters of the SOT. Similarly, Bhatt and colleagues demonstrated that the Timed Up & Go test predicts fall outcomes better than static posturography (Bhatt et al. 2011). Pawlak-Osińska and colleagues found that posturography results did not provide specific difference in finding between children with vertigo and healthy controls (Pawlak-Osińska et al. 2006). The apparently conflicting results of these studies would seem to be counterintuitive when considering the measurements possible with posturography, unless the "accuracy" and "sensitivity" of the instruments used were not appropriate to the task.

In 2013, to help address the issues arising from insufficient metrological performance of the posturographic instruments, the International Standardization Committee for Clinical Stabilometry of the International Society for Posture and Gait Research (ISPGR) recommended for CoP measurements an "accuracy" of 0.1 mm and a "precision" and "resolution" of 0.05 mm (Scoppa et al. 2013). These are much more restrictive than the accuracy of 1 mm previously suggested (Bizzo et al. 1985, Browne & O'Hare 2000).

Accuracy, precision and resolution are measures of the error expected when using an instrument and are part of the metrological performance characteristics of all instruments. Over time the meaning of these terms in the technical and scientific literature has evolved and changed, unfortunately leading to some possible confusion. In this paper, we use the definitions set forth by the ISO 5725:1994 standard (ISO 1994):

*§ 3.6 – **accuracy**: The closeness of agreement between a test result and the accepted reference value.*

*§ 3.7 – **trueness**: The closeness of agreement between the average value obtained from a large series of test results and an accepted reference value.*

*§ 3.12 – **precision**: The closeness of agreement between independent test results obtained under stipulated conditions.*

According to ISO 5725:1994, accuracy is a combination of trueness and precision. Resolution, although not defined in ISO 5725:1994, is traditionally defined as the smallest change an instrument can detect in the quantity that it is measuring. It should be noted that there is no mention of trueness in the ISPGR recommendations, which instead refer to accuracy, precision and resolution; we suspect that they were using the old definition of accuracy, replaced in the ISO 5725:1994 with trueness.

In our clinical work, we use a variety of instruments based on force platform technology to assess sway and balance. Our review of the scientific literature found a paucity of information on the metrological performance characteristics of posturographic instruments even though they are commonly used in many of the investigations we previously mentioned. Therefore, we decided to investigate the metrological performance of the posturographic instruments that our team uses to assess if they satisfy the ISPGR recommendations. To further evaluate how the instruments' performance affects the measures, we also quantified maximum sway and mean CoP velocity measured when a static weight is used as a subject.

MATERIALS AND METHODS

We tested the following instruments that we utilize in our clinical testing:

- a NeuroCom® Balance Manager SMART EquiTest® using the NeuroCom® SMART EquiTest®/InVision/ HT-SOT Version 9.1 software (NeuroCom®, a division of Natus®, Clackamas, OR, USA);
- a Bertec BP-5050 three-component balance platform using the Bertec Digital Acquire Version 4.0.11.407 software (Bertec Corporation, Columbus, OH, USA);
- a Vestibular Technologies CAPS® Professional and a Vestibular Technologies CAPS® Lite three-component balance platforms using the Vestibular Technologies Force Platform Control Panel Software Version 3.0 (Vestibular Technologies, LLC, Cheyenne WY, USA).

At the time we performed these tests, the instruments had been in use in our clinics for several years and had been maintained according to the manufacturer's

Table 1. Trueness, precision and resolution for the different instruments at various loading levels

Load			NeuroCom® SMART EquiTest®	Bertec BP 5050	Vestibular Technologies CAPS® Lite	Vestibular Technologies CAPS® Professional
15 kg	ML	Trueness (mm)	1.26 ± 0.10	0.72 ± 0.02	0.15 ± 0.03	*0.09 ± 0.01*
		Precision (mm)	1.69 ± 0.29	0.89 ± 0.04	0.12 ± 0.03	0.09 ± 0.00
		Resolution (μm)	*6.18 ± 9.83*	*0.10 ± 0.00*	*0.03 ± 0.03*	*0.17 ± 0.19*
	AP	Trueness (mm)	2.26 ± 0.18	0.74 ± 0.01	0.14 ± 0.03	*0.10 ± 0.01*
		Precision (mm)	2.86 ± 0.19	1.05 ± 0.03	0.12 ± 0.04	0.09 ± 0.01
		Resolution (μm)	106.84 ± 83.71	*0.10 ± 0.00*	*0.04 ± 0.06*	*0.17 ± 0.21*
	2D	Trueness (mm)	2.83 ± 0.12	1.16 ± 0.03	0.23 ± 0.05	0.15 ± 0.01
		Precision (mm)	3.14 ± 0.05	1.27 ± 0.04	0.15 ± 0.04	0.11 ± 0.01
		Resolution (μm)	109.40 ± 53.77	*0.07 ± 0.07*	*0.01 ± 0.01*	*0.03 ± 0.02*
35 kg	ML	Trueness (mm)	0.35 ± 0.04	0.09 ± 0.01	*0.06 ± 0.01*	*0.03 ± 0.00*
		Precision (mm)	0.32 ± 0.04	0.08 ± 0.01	*0.05 ± 0.01*	*0.02 ± 0.00*
		Resolution (μm)	*14.81 ± 0.08*	*0.11 ± 0.05*	*0.01 ± 0.01*	*0.07 ± 0.13*
	AP	Trueness (mm)	1.03 ± 0.05	0.12 ± 0.01	*0.06 ± 0.01*	*0.04 ± 0.01*
		Precision (mm)	1.28 ± 0.03	0.11 ± 0.00	*0.04 ± 0.00*	*0.04 ± 0.01*
		Resolution (μm)	118.09 ± 4.93	*0.09 ± 0.04*	*0.01 ± 0.01*	*0.06 ± 0.06*
	2D	Trueness (mm)	1.17 ± 0.06	0.17 ± 0.01	*0.10 ± 0.01*	*0.05 ± 0.01*
		Precision (mm)	1.25 ± 0.03	0.11 ± 0.01	*0.05 ± 0.01*	*0.04 ± 0.01*
		Resolution (μm)	*49.80 ± 8.52*	*0.05 ± 0.05*	*0.00 ± 0.00*	*0.01 ± 0.01*
53 kg	ML	Trueness (mm)	0.36 ± 0.02	0.18 ± 0.01	*0.04 ± 0.01*	*0.02 ± 0.00*
		Precision (mm)	0.44 ± 0.03	0.19 ± 0.01	*0.04 ± 0.01*	*0.02 ± 0.01*
		Resolution (μm)	*14.82 ± 0.61*	*0.07 ± 0.04*	*0.01 ± 0.01*	*0.04 ± 0.05*
	AP	Trueness (mm)	0.74 ± 0.03	0.12 ± 0.02	*0.04 ± 0.01*	*0.03 ± 0.00*
		Precision (mm)	1.02 ± 0.02	0.12 ± 0.02	*0.03 ± 0.00*	*0.02 ± 0.00*
		Resolution (μm)	86.50 ± 0.77	*0.11 ± 0.10*	*0.03 ± 0.05*	*0.05 ± 0.06*
	2D	Trueness (mm)	0.91 ± 0.03	0.23 ± 0.02	*0.06 ± 0.01*	*0.04 ± 0.00*
		Precision (mm)	1.05 ± 0.03	0.21 ± 0.01	*0.04 ± 0.00*	*0.03 ± 0.01*
		Resolution (μm)	88.23 ± 24.91	*0.03 ± 0.02*	*0.00 ± 0.00*	*0.01 ± 0.00*
75 kg	ML	Trueness (mm)	0.27 ± 0.03	0.10 ± 0.00	*0.02 ± 0.00*	*0.02 ± 0.00*
		Precision (mm)	0.38 ± 0.05	0.10 ± 0.00	*0.02 ± 0.00*	*0.01 ± 0.00*
		Resolution (μm)	*14.66 ± 0.27*	*0.03 ± 0.02*	*0.01 ± 0.01*	*0.02 ± 0.02*
	AP	Trueness (mm)	0.72 ± 0.06	0.18 ± 0.01	*0.03 ± 0.00*	*0.02 ± 0.00*
		Precision (mm)	0.95 ± 0.06	0.16 ± 0.01	*0.03 ± 0.01*	*0.02 ± 0.00*
		Resolution (μm)	67.59 ± 11.00	*0.04 ± 0.02*	*0.01 ± 0.01*	*0.01 ± 0.01*
	2D	Trueness (mm)	0.83 ± 0.06	0.22 ± 0.01	*0.04 ± 0.00*	*0.03 ± 0.00*
		Precision (mm)	0.98 ± 0.06	0.16 ± 0.01	*0.03 ± 0.00*	*0.02 ± 0.00*
		Resolution (μm)	59.41 ± 9.89	*0.03 ± 0.02*	*0.00 ± 0.00*	*0.00 ± 0.00*

ML: medio-lateral; AP: antero-posterior; 2D: two-dimensional; the results are reported as Mean ± Standard Deviation of the 10 repetitions; values satisfying the ISPGR standards are in italic; Trueness, and precision are in millimeters, the resolution is in micrometers, i.e. 10-3 mm.

instructions. As described in detail by Pagnacco and colleagues (Pagnacco et al. 2014), trueness, precision and resolution characteristics of force platforms can be assessed either by applying known forces in known discrete locations on the surface of the instrument, or by applying dynamic forces using a system similar to what was proposed by Morasso and colleagues (Morasso et al. 2002) such that the resultant CoP is continuously varying during the test. Comparing these two methods, Pagnacco and colleagues concluded that using a continuously varying CoP produces loading conditions that include shear forces and are more representative of what happens when a subject is standing on the instrument, allows one to easily test a larger number of CoP locations, and is a superior method to determine "in situ" the metrological characteristics of force platforms that satisfy the stringent recommendations adopted by the ISPGR (Pagnacco et al. 2014). Therefore, to assess the trueness, precision, and resolution of the instruments, we used a custom device similar to the one suggested in (Pagnacco et al. 2014). The rotating mass of 0.200 kg was positioned at a radius of 0.173 m and a height of 0.480 m. The fixed ballast masses used were 15.01 kg, 34.86 kg, 53.37 kg, and 74.62 kg. As in (Pagnacco et al. 2014), the maximum rotational speed considered was 4 Hz for the two smaller ballast masses and 4.5 Hz for the others; the minimum was 0.5 Hz. The resultant span of the CoP for each ballast mass value was approximately 3.3-72.7 mm,

1.5-31.5 mm, 1.0-26.0 mm, and 0.7-18.6 mm respectively. For each ballast mass, 10 repetitions were performed and the trueness and precision were averaged across the repetitions. The maximum sway and the mean CoP velocity the instruments measure when a static weight is used as a test subject were quantified by stacking up to four 25 kg steel weights in the approximate center of each instrument. A total of 10 repetitions of 5 s each were performed for each load. Data were acquired from all instruments at 100 Hz and exported as a text file using the software's export function. The NeuroCom® system available for this investigation did not have the capability to acquire custom tests, therefore the SOT protocol tests with static support surface were used to collect the data. Subsequent data analysis was performed in MATLAB® (The MathWorks Inc., Natick, MA, U.S.A.). The trueness and precision were computed considering the absolute distance of each CoP location sampled by the instrument and the corresponding theoretical CoP location obtained by the equations describing the theoretical CoP trajectory. The resolution was determined considering the average across the repetitions of the smallest non-zero distance between CoP locations collected during each test. The maximum sway was determined considering two times the maximum radial CoP excursion from the average CoP location during the test. The mean CoP velocity was computed by dividing the length of the CoP path by the test duration.

All tests were performed at our clinical facility and the local value of the gravity acceleration was determined to be 9.7953 m/s² by using the online NGS Surface Gravity Prediction tool of the US National Oceanic and Atmospheric Administration.

RESULTS

Table 1 reports, as mean ± standard deviation, for each value of the testing device mass and the four instruments, the trueness, precision and resolution in the antero-posterior (AP) and medio-lateral (ML) directions as well as in terms of two-dimensional distance (2D).

The corresponding 95th percentile of the absolute CoP error is reported in Table 2.

Figure 1 shows an example of the CoP trace obtained during the experiments. The case considered is the one that had, on the NeuroCom® device, the overall smallest 95th percentile error for that device.

Table 3 reports, as mean ± standard deviation, for each of the four static loads considered, the maximum CoP sway and the mean CoP velocity obtained for the four instruments.

Table 2. 95th percentile absolute CoP error for the different instruments at various loading levels

		NeuroCom®	Bertec	Vestibular Technologies	
	Load	SMART EquiTest®	BP 5050	CAPS® Lite	CAPS® Professional
ML	15 kg	4.54 ± 0.69	2.75 ± 0.10	0.36 ± 0.08	0.25 ± 0.01
	35 kg	1.00 ± 0.14	0.26 ± 0.03	0.15 ± 0.03	0.06 ± 0.00
	53 kg	1.21 ± 0.04	0.62 ± 0.02	0.12 ± 0.02	0.07 ± 0.01
	75 kg	1.08 ± 0.16	0.33 ± 0.01	0.07 ± 0.01	0.05 ± 0.00
AP	15 kg	8.28 ± 0.87	2.54 ± 0.05	0.38 ± 0.10	0.29 ± 0.03
	35 kg	3.67 ± 0.20	0.35 ± 0.02	0.15 ± 0.02	0.11 ± 0.03
	53 kg	2.95 ± 0.07	0.38 ± 0.05	0.10 ± 0.01	0.07 ± 0.01
	75 kg	2.88 ± 0.25	0.51 ± 0.02	0.08 ± 0.02	0.04 ± 0.00
2D	15 kg	9.24 ± 0.49	3.67 ± 0.13	0.49 ± 0.15	0.36 ± 0.02
	35 kg	3.72 ± 0.20	0.39 ± 0.01	0.18 ± 0.02	0.12 ± 0.03
	53 kg	3.12 ± 0.10	0.70 ± 0.03	0.15 ± 0.02	0.10 ± 0.02
	75 kg	3.04 ± 0.27	0.55 ± 0.02	0.11 ± 0.01	0.06 ± 0.00

ML: medio-lateral; AP: antero-posterior; 2D: two-dimensional; the results are reported as Mean ± Standard Deviation of the 10 repetitions

Table 3. Mean CoP Velocity in mm/s and Maximum CoP Sway in millimeters reported by the instruments at different static loading levels

		NeuroCom®	Bertec	Vestibular Technologies	
Load		SMART EquiTest®	BP 5050	CAPS® Lite	CAPS® Professional
25 kg	Mean Vel (mm/s)	34.55 ± 5.62	5.88 ± 0.23	0.43 ± 0.02	1.60 ± 0.05
	Max Sway (mm)	2.06 ± 0.40	0.29 ± 0.03	0.04 ± 0.00	0.15 ± 0.02
50 kg	Mean Vel (mm/s)	17.90 ± 6.45	3.28 ± 0.36	0.26 ± 0.03	0.80 ± 0.07
	Max Sway (mm)	1.01 ± 0.09	0.15 ± 0.02	0.02 ± 0.00	0.07 ± 0.00
75 kg	Mean Vel (mm/s)	12.34 ± 4.41	7.68 ± 1.83	0.38 ± 0.08	0.53 ± 0.02
	Max Sway (mm)	0.69 ± 0.09	0.31 ± 0.09	0.02 ± 0.00	0.05 ± 0.00
100 kg	Mean Vel (mm/s)	9.79 ± 3.90	5.20 ± 0.70	0.40 ± 0.10	0.44 ± 0.05
	Max Sway (mm)	0.68 ± 0.43	0.25 ± 0.04	0.03 ± 0.01	0.04 ± 0.01

The results are reported as Mean ± Standard Deviation of the 10 repetitions

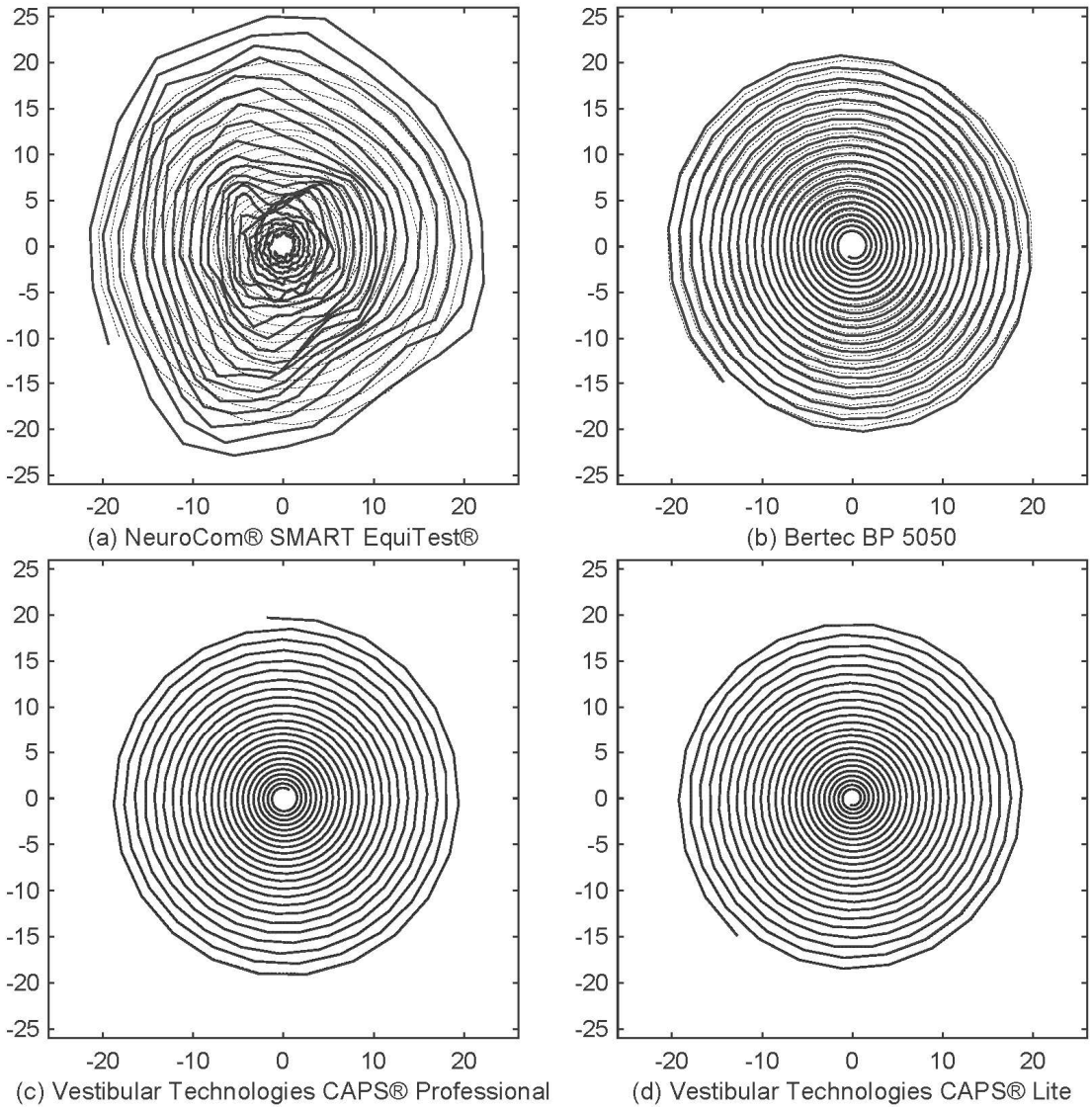

Figure 1. Example of experimental (continuous line) and theoretical (dashed line) spiral CoP traces for the different instruments at the 75 kg load; dimensions are in millimeters

DISCUSSION

The results in Table 1, together with what was previously reported by other investigators (Cappello et al. 2011, Bartlett et al. 2014) show that many instruments commonly used in clinical practice (as well as research) to measure human sway do not satisfy the recent recommendations adopted by the ISPGR. Cappello and colleagues found that force platforms designed for gait studies (AMTI OR6, Bertec 4060-08, Bertec 4080-10, and Kistler 9286A) have at best, after a very sophisticated non-linear in situ recalibration possible only in research environments, a 2D trueness of 0.5 mm and a 2D precision of 0.2 mm (Cappello et al. 2011). Analyzing an AMTI OR6-6-1000 and a Nintendo Wii™ Balance Board, Bartlett and colleagues reported at best a trueness of 1.6 mm with a precision of 1.7 mm for the Wii device and a trueness of 1.2 mm with a precision of 1.1 mm for the AMTI instrument (Bartlett et al. 2014).

In our tests, the NeuroCom® system, one of the devices most cited in the literature, also has a trueness and precision both in the order of a millimeter. Our results for the Bertec BP-5050 show that force platforms designed for balance studies (i.e., balance platforms) can have better trueness and precision than what has been previously reported for models from the same manufacturer designed for gait analysis (Cappello et al. 2011), but they do not necessarily meet the ISPRG recommendations.

The results of this investigation confirm the results for the two Vestibular Technologies CAPS® systems previously reported by Pagnacco and colleagues (Pagnacco et al. 2014), and meeting the ISPRG recommendations: the CAPS® instruments, both 8 years old at the time of the experiments, did so, at least at loads of 35 kg and greater, a weight that according to the Centers for Disease Control is reached by most before the 11th birthday (CDC 2000). At a load of 15 kg, a weight reached by most before the 4th birthday (CDC 2000), no

device meets the new recommendations. However, while the other devices show, at that load, a 2D trueness and precision worse than a millimeter, the CAPS® devices are still on the order of 0.1 mm, which is similar to what was found for the other instruments at the higher loads.

Perhaps the most interesting results for both clinicians and researchers are the absolute CoP errors reported in Table 2. As described in the Introduction, the ISPGR recommendations appear to aim for a CoP error ("accuracy" according to ISO 5725:1994) of less than 0.2 mm. This is again much smaller, often by an order of magnitude, than what studies have reported for force platforms designed for gait studies: from the results presented by Cappello and colleagues (Cappello et al. 2011), it is easy to estimate that, even with advanced non-linear in situ recalibration, the errors are in the order of 1 mm; with a more conventional in situ recalibration, they are in the order of 2-5 mm. Similar results were found by Bartlett and colleagues (Bartlett et al. 2014). Our investigation found the NeuroCom® device to have 2D CoP errors of over 3 mm, which are similar to the aforementioned level of error. The Bertec balance plate, although still not satisfying the recommendations, had smaller errors than a gait platform from the same manufacturer (as reported in (Cappello et al. 2011)). The difference between the errors of the previously mentioned non-ISPGR-compliant devices, and those of the two ISPGR-compliant Vestibular Technologies CAPS® Systems can easily be appreciated. To put these results in perspective, CoP errors of millimeters are of the same order of magnitude of the amount of sway of a person (Browne & O'Hare 2000, Moghadam et al. 2011), and those above 0.5 mm can be greater than the Minimum Detectable Change (MDC) for some subjects (Pagnacco et al. 2015).

The results reported in Table 3 provide an indication as to how the trueness and precision affect the maximum CoP sway and mean CoP velocity the instruments measure for a dead weight: because of noise, instruments not satisfying the ISPGR recommendations can measure values comparable to those reported in the literature for human subjects. For instance, Moghadam and colleagues reported, for subjects standing with eyes open on a rigid surface, a mean CoP velocity of 13.7 mm/s with a MDC of 3.9 mm/s (Moghadam et al. 2011).

In most clinical measurements, errors having the relative magnitude as those reported in the literature and in our results for non-ISPGR-compliant devices would be considered unacceptable because they are larger than the clinical MDC of some subjects. The error of a device satisfying the ISPGR recommendations appear to be much more acceptable. In light of these results, it is possible that the values reported by investigations using instruments not meeting the ISPGR recommended trueness and precision could be incorrectly estimating the amount of sway, its velocity and related measures. While this is of great consequence in research, we suggest that it is also important in clinical applications where ameliorating poor metrological characteristics of the instruments via statistical methods is typically not possible.

CONCLUSIONS

Clinicians need and depend upon accuracy in their diagnostic instruments. Mental health practitioners are increasing the use of physical rehabilitation procedures in their therapies. Posturographic measurements must be better than bedside testing, or there is no rationale for them when simple standard physical examination criteria will suffice. As more clinical applications in the treatment of neuro-psychiatric disorders are being derived from posturographic measurements, clinicians need to be assured that the measurements are more accurate than their own observational skills. Research investigations rely on the accuracy of the instruments used. Poor metrological performance of some instruments is a possible logical explanation for the often-conflicting findings of some prior investigations.

The scientific and clinical consequences associated with accuracy of measurement should be self-evident. Measures obtained and data collected are only as good as the instrument used to collect them. Clinical and research findings could be erroneous, or at the least misleading, if measurement errors are too large.

We suggest that there is a strong need for a greater accuracy (as the combination of trueness and precision) of posturographic instrumentation, especially if the data obtained are to be used in a clinical application or in correlation studies with other quantitative outcomes. The 2013 ISPRG recommendations appear to be reasonable and appropriate, and our results show they are obtainable yet our clinical team and others often use instruments that do not meet them. Incorrect measurements may contribute to a widespread perception of posturography being "experimental". We believe this will change only when the accuracy of posturographic measurements meets higher standards, such as the minimal standards recommended by the ISPRG.

Acknowledgements:

We would like to thank the Carrick Institute and the Centre for Mental Health Research in association with the University of Cambridge (CMHR-UC) for their support and encouragement to undertake this project.

Conflict of interest: *None to declare.*

Contribution of individual authors:

Frederick R, Carrick, Rashid Zaman & Cameron H. G. Wright conceived the idea of the study, contributed to the literature review and revised the manuscript.

Ahmed Hankir organised the study, collected the data, and contributed to the literature review and revised the manuscript.

References

1. Alahmari KA, Marchetti GF, Sparto PJ, Furman JM & Whitney SL: Estimating postural control with the balance rehabilitation unit: measurement consistency, accuracy, validity, and comparison with dynamic posturography. Arch Phys Med Rehabil 2014; 95:65-73
2. Bartlett HL, Ting LH & Bingham JT: Accuracy of force and center of pressure measures of the Wii Balance Board. Gait Posture 2014; 39:224-8
3. Bhatt T, Espy D, Yang F & Pai YC: Dynamic gait stability, clinical correlates, and prognosis of falls among community-dwelling older adults. Arch Phys Med Rehabil 2011; 92:799-805
4. Bizzo G, Guillet N, Patat A & Gagey PM: Specifications for building a vertical force platform designed for clinical stabilometry. Med Biol Eng Comput 1985; 23:474-6
5. Browne J1 & O'Hare N: A quality control procedure for force platforms. Physiol Meas 2000; 21:515-24
6. Cappa P, Jackson JL & Patanè F: Moment measurement accuracy of a parallel spherical robot for dynamic post-urography. IEEE Trans Biomed Eng 2010; 57:1198-208
7. Cappello A, Bagalà F, Cedraro A & Chiari L: Non-linear re-calibration of force platforms. Gait Posture 2011; 33:724–6
8. CDC: 2000 CDC Clinical Growth Charts - Data Table of Weight-for-age Charts for Children 2 to 20 years. National Center for Health Statistics, Centers for Disease Control and Prevention, Atlanta, 2000
9. Fu AS & Hui-Chan CW: Ankle joint proprioception and postural control in basketball players with bilateral ankle sprains. Am J Sports Med 2005; 33:1174-82
10. ISO 5725-1:1994 Accuracy (trueness and precision) of measurement methods and results – Part 1: General principles and definitions. ISO, Geneva, 1994
11. Johnson L, Rodrigues J, Teo WP, Walters S, Stell R, Thickbroom G et al.: Interactive effects of GPI stimulation and levodopa on postural control in Parkinson's disease. Gait Posture 2015; 41:929-34
12. Moghadam M, Ashayeri H, Salavati M, Sarafzadeh J, Taghipoor KD, Saeedi A et al.: Reliability of center of pressure measures of postural stability in healthy older adults: effects of postural task difficulty and cognitive load. Gait Posture 2011; 33:651–5
13. Morasso P, Re C, Giacomozzi C & Macellari V: A testing device for the verification of the accuracy of the COP measurements in stabilometric platforms. Gait Posture 2002; 16(Suppl 1):S215-6
14. Pagnacco G, Carrick FR, Wright CHG & Oggero E: In-situ verification of accuracy, precision and resolution of force and balance platforms. Biomed Sci Instrum 2014; 50:171-8
15. Pagnacco G, Carrick FR, Wright CHG & Oggero E: Between-subjects differences of within-subject variability in repeated balance measures: consequences on the minimum detectable change. Gait Posture 2015; 41:136-40
16. Pawlak-Osińska K, Kaźmierczak H, Kuczyńska R & Szaflarska-Popławska A: Vertigo in children. Int Tinnitus J 2006; 12:185-9
17. Prosperini L, Fortuna D, Gianni C, Leonardi L & Pozzilli C: The diagnostic accuracy of static posturography in predicting accidental falls in people with multiple sclerosis. Neurorehabil Neural Repair 2013; 27:45-52
18. Rossi-Izquierdo M, Basta D, Rubio-Rodríguez JP, Santos-Pérez S, Ernst A, Sesar-Ignacio Á et al.: Is posturography able to identify fallers in patients with Parkinson's disease? Gait Posture 2014; 40:53-7
19. Scoppa F, Capra R, Gallamini M & Shiffer R: Clinical stabilometry standardization: Basic definitions – acquisition interval – sampling frequency. Gait Posture 2013; 37:290–2
20. Webster JG: Medical Instrumentation: Application and Design, 4th Edition. John Wiley & Sons, New York, 2010
21. Yeh JR, Hsu LC, Lin C, Chang FL & Lo MT: Nonlinear analysis of sensory organization test for subjects with unilateral vestibular dysfunction. PLoS One 2014; 9:e91230

Correspondence:

Prof Frederick R. Carrick, DC, PhD, MSc-HPEd
Department of Neurology, Carrick Institute for Graduate Studies 8910
Astronaut Blvd Suite 102, Cape Canaveral, Florida 32920, USA
E-mail: drfrcarrick@post.harvard.edu