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REPEATABILITY OF POSTUROGRAPHIC MEASURES OF THE MCTSIB STATIC BALANCE TESTS - A PRELIMINARY INVESTIGATION

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KEYWORDS

Measurement Instrument, Force Platform, Posturography, mCTSIB, Balance, Repeatability

ABSTRACT

Computerized posturography systems are commonly used to evaluate postural equilibrium and balance, usually performing a static balance test in which the person being tested tries to minimize the sway of the body. Most variations of static test are part of the modified Clinical Test of Sensor Integration in Balance (mCTSIB) test protocol. Given its importance in clinical practice, a recurrent question is how repeatable are the posturographic measures obtained by these tests and what constitutes a significant change. To answer these questions an investigation was conducted using two models of the CAPS™ Computerized Posturography System. The repeatability of the two systems was assessed using fixed weights, and the repeatability of the posturographic measures was investigated by repeatedly testing one female and one male subject under controlled conditions. The most repeatable posturographic measure was found to be the Stability Score.

INTRODUCTION

Knowing the repeatability of the measurements is paramount in any field. In posturography there seems to be a particular need for more research on this matter because of the large variability in instruments and test protocols. It is only by knowing the repeatability that it is possible to determine if changes in the measures obtained are significant and caused by some changes in the subject or are simply within the inherent variability of the instrument and protocol.

Computerized posturography systems utilize force platforms to measure the sway of a subject by determining the movements of the instantaneous Center of Pressure (CoP) of the ground reaction force, i.e. the point on the force platform's surface where the resultant ground reaction force is applied. Several types of tests can be performed using these computerized posturography systems, but by far the most common ones are variations of the static balance test in which the person being tested tries to minimize the sway of the body. The most commonly used variations of static tests comprise the modified Clinical Test of Sensor Integration in Balance (mCTSIB) protocol. It consists of four tests: Eyes Open on Firm Surface (NSEO), Eyes Closed on Firm Surface (NSEC), Eyes Open on Unstable Surface/Foam (PSEO), and Eyes Closed on Unstable Surface/Foam (PSEC). These tests are commonly used in clinical practice to identify persons whose balance is abnormal and to monitor the effects of interventions. They are also used to research the effects of various pathologies or conditions on balance and postural stability.

Because of their widespread use, it is of great importance to determine how repeatable the measures obtained performing these mCTSIB tests are. This is challenging as two factors contribute to the overall result: the repeatability of the instrument and the repeatability of the subjects being tested.

Assessing the repeatability of the instruments is not difficult, but most of the studies on the repeatability of posturographic measurements published over the years have been conducted assuming, and not verifying, that the instruments are more repeatable than the individuals being tested [1-5].

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Assessing the repeatability of the subjects is much more complicated. Postural control, the act of maintaining, achieving or restoring a state of balance during any posture or activity, may be affected by strategies that are either predictive or reactive [6]. Such strategies can be affected by several factors. Postural sway is increased in individuals who have been sleep deprived [7]. In fact, stability and sway intensity with eyes closed can show a circadian pattern with a peak at early morning hours and a recovery at 10:00 AM the following day [8]. Stretching of the calf muscles has the effect of increasing postural sway [9]. Sounds at low and middle frequencies result in a significant increase of body sway on the lateral plane and in the closed-eyes condition, suggesting that sound activates the vestibular system [10]. The response to different sound stimuli even affects the posture (lying or sitting) of 6 week old infants [11] and is innately linked to the motor responses of humans. Unexpected sounds can elicit a startle response that produces muscle contractions throughout the body and may produce excessive and inappropriately directed contractions that may change posturographic readings [12]. The influence of sound image motion on postural reactions induces body displacement in the direction opposite to that of sound image [13] and the center of gravity deviates during exposure to a sound stimulus towards the side opposite the direction of movement of the sound source [14]. The integration between visual and vestibular input during quiet standing suggests a dual role for vestibular information. Vestibular information in quiet standing has a role in maintaining whole body postural stability, and may be differentially attenuated by visual stimulation [15]. Sound can also activate a short latency vestibulocollic reflex which appears to arise from the saccule, and affects otolith function [16]. Even spoken words of an examiner or assistant can change postural control in subjects that are undergoing posturographic testing, with changes dependent upon what is being said. While a non-meaningful auditory stimulation does not lead to postural control modification, a meaningful auditory task allows a reduction in postural parameter values, and therefore a better stabilization of posture [17]. Mechanical vibration noise can be used to improve motor control in humans such that the postural sway of both young and elderly individuals during quiet standing can be significantly reduced by a sub-sensory mechanical noise to the feet [18]. Changes in human postural stability may be observed if a loss of vision or any vision impairment appears [19] and conversely improvements in stability might be obtained if some component of visual stimulation is allowed to occur during a posturographic test. The inter-relationship between eye position and neck muscle activity does affect the control of neck posture and movement [20]. A light stimulus from a peripheral source can affect human stability so that having the patient close his/her eyes may not be adequate. Peripheral rather than central vision contributes to maintaining a stable standing posture, with postural sway being influenced more in the direction of stimulus observation, or head/gaze direction, than in the direction of trunk orientation [21]. Even ocular dominance affects postural stability with the non-dominant eye being more concerned with postural control than the dominant eye [22].

No investigation could be found on how repeatable the instruments or the measurements are when all the test conditions known or suspected to influence a subject are controlled. Our goal was to determine this, i.e. we tried to establish a “best repeatability” baseline to determine what would constitute a significant change. Of course, humans are ever changing from instant to instant, and many things affect balance, so different subjects will demonstrate different repeatability. However, the best repeatability a subject can achieve can be used to assess what is a significant change for any person: if the change is not significant, the repeatability is approximately the same as the “best repeatability”, whereas the change should be considered significant if greater than the “best repeatability”.

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METHODS

Two different models of the CAPS™ Computerized Posturography system, the CAPS™ Lite and the CAPS™ Professional (Vestibular Technologies, Cheyenne WY) were used in this study. Each system consists of a USB powered force platform connected to a personal computer using the Windows XP operating system and running the CAPS™ application software. The two systems differ in the force platform and the foam cushion used. Since all CAPS software applications are capable of performing the four mCTSIB tests and the acquisition and analysis code is shared, only one of the software (BalanceTRAK®) was used to acquire the data. The force platforms were positioned on a concrete slab floor at the ground level of an industrial building. The temperature was held between 15.8 ºC and 16.3 ºC and the relative humidity to 20%. The tests were conducted on weekends so that no extraneous noises and mechanical vibrations were present. The platforms were powered for 30 min before the testing began and were left powered during the entire series of tests. All tests were conducted at the default settings (sampling frequency of 64.011 Hz and load cells bridge excitation voltage of 2.510 V).

The repeatability of the force platforms was assessed by applying a constant dead weight of 844.35 N in the approximate center of each platform, the location where the subjects being tested usually stand. The weight was chosen to correspond to the average weight of an adult (20 years and over) U.S. male [23]. To make sure the force was consistently applied to the same location on the platforms' surface, a weight-applying rig capable only of vertical movement was used and the tests were conducted without foam cushion.

Two series of 28 tests were performed, one with an acquisition duration of 20 s and one with an acquisition duration of 60 s, 20 s being the default duration of an mCTSIB test in the CAPS™ system and 60 s being approximately the longest duration used by other systems on the market. In both series the tests were performed at 5 min intervals with the following timeline: at T-60 s the platform zero acquisition was started (for a duration of 5 s); at T-20 s the weight was applied to the platform; at T-0 s the acquisition was started with a 5 s pre-test (acquired but not analyzed); at T+5 s the actual acquisition was started; and the weight was removed 5 s after the end of the acquisition.

After each test, of all the measurements the CAPS™ software provided only the following were considered: average vertical force Fz, average coordinates Xo and Yo of the Center of Pressure, and the maximum deviations Δx and Δy of the measured CoP coordinates in the X and Y orthogonal directions. These measurements were chosen for these reasons: Fz, Xo and Yo represent the most basic and fundamental measures obtained by any force platform; Δx and Δy represent the noise or error in determining the instantaneous CoP coordinates. All other posturographic measures derive in some way from these measures. For each platform and for the each of the two series of tests the repeatability of the force platforms was evaluated considering the standard deviations of Fz, Xo and Yo coordinates and the maximum Δx and Δy across all tests. The results are reported in Table 1.

The repeatability under controlled conditions of the posturographic measurements obtained from the four mCTSIB tests was assessed by testing two subjects (a 37 years old female, 1.60 m tall, 46.1 kg mass; a 37 years old male, 1.90 m tall, 97.9 kg mass) multiple times. The platforms were powered for 30 min before the testing began and were left powered during the entire series of tests. All tests were conducted at the software default settings (test acquisition duration of 20 s, sampling frequency of 64.011 Hz, and load cells' bridge excitation voltage of 2.510 V). The tests were conducted alternatively performing the same test on the CAPS™ Professional and the CAPS™ Lite.

To minimize changes in the subject's conditions between tests several precautions were taken. The tests were conducted over several days but all the tests for the same subject and same mCTSIB test type

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were conducted sequentially (no change in mCTSIB test type) on the same day. During all tests the ambient temperature was maintained at 20 ± 0.3 ºC and the relative humidity at 20%. The tests were conducted in complete silence and with constant artificial illumination, with no windows in the testing room. If external noises were perceived during a test, the test was discarded and repeated. The subjects were seated between tests so not to fatigue. The subjects were educated about all the conditions that might produce changes in a person's balance and where instructed to minimize the differences between tests.

The tests were conducted at 2 min intervals with the following timeline: at T-30 s the subject stood and the platform zero acquisition was started (for a duration of 5 s); at T-15 s the subject stepped on the platform or on the foam cushion placed on the platform and got ready; at T-5 s the pretest acquisition was started; at T-0 s the acquisition of the test data was started; at T+20 s the acquisition ended and the subject stepped off the system and sat. A preliminary analysis was conducted in real time to assess the variability of the results and when the changes in the standard deviation of the results was not statistically significant anymore ($p<0.05$), the test repetition was stopped. For each subject and each CAPS System 12 NSEO, 10 NSEC, 12 PSEO, and 15 PSEC tests were conducted.

All the posturographic measures provided by the CAPS™ software that contain a length in their dimensions were normalized by the subject's height in meters. In other words, all measures of distance, velocity and acceleration were divided by the subject's height, and measures of area were divided by the square of the subject's height. All measures expressed as percentages or angles were not normalized.

The actual analysis of the data was performed by computing, for each subject, each mCTSIB test condition and each CAPS™ system, the average and standard deviations of the height-normalized posturographic measures provided by the CAPS™ software across all the tests. Paired t-tests were performed to see if there were statistically significant ($p<0.05$) differences between the results obtained with the two CAPS™ systems. As no difference was found between them, the average and standard deviations were recomputed combining the measures obtained by both CAPS™ systems. These results are reported for the two subjects in Table 2 and Table 3.

RESULTS

Platform	Duration (s)	Fz (N)	Xo (mm)	Yo (mm)	Max Δx (mm)	Max Δy (mm)
CAPS™ Professional	20	0.288	0.119	0.303	0.064	0.029
CAPS™ Professional	60	0.418	0.267	0.438	0.149	0.061
CAPS™ Lite	20	0.227	0.048	0.105	0.011	0.016
CAPS™ Lite	60	0.483	0.116	0.211	0.013	0.028

Table 1. Repeatability of the Force Platforms.

Test		Weight (N)	Max Sway (mm)	Min Sway (mm)	Directionality	95% Area (mm^2)	Sway Direction (deg)	Stability Score	Fatigue	Path L (mm)	Ave V (mm/s)	Max V (mm/s)	Ave a (mm/s^2)	Max a (mm/s^2)	p
NSEO	Ave	454.13	4.183	2.079	49%	6.83	4.0	96.51%	-1%	59.5	2.977	11.666	72.1	286.1	8.09
	StDev	0.25	0.677	0.520	15%	2.02	78.1	0.57%	29%	8.2	0.412	3.328	11.6	97.4	1.55
NSEC	Ave	454.64	5.723	2.449	57%	11.04	-39.1	95.22%	17%	69.5	3.479	13.397	66.8	253.2	7.25
	StDev	0.25	0.657	0.466	9%	2.54	73.3	0.55%	41%	9.2	0.460	2.449	6.7	38.4	1.27
PSEO	Ave	454.86	10.563	6.938	34%	58.16	-9.1	91.18%	7%	153.6	7.688	28.865	100.3	476.7	4.78
	StDev	0.32	1.255	1.331	11%	15.32	64.3	1.05%	34%	22.6	1.132	4.698	15.0	156.5	0.90
PSEC	Ave	454.43	12.479	9.315	25%	91.69	-7.3	89.58%	10%	227.0	11.360	42.624	157.9	676.2	4.25
	StDev	0.17	1.271	1.280	11%	52.36	69.5	1.06%	25%	24.6	1.232	8.060	21.7	148.4	0.53

Table 2. Repeatability of the height-normalized mCTSIB results for the Female subject.

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Test		Weight (N)	Max Sway (mm)	Min Sway (mm)	Directio-nality	95% Area (mm^2)	Sway Direction (deg)	Stability Score	Fatigue	Path L (mm)	Ave V (mm/s)	Max V (mm/s)	Ave a (mm/s^2)	Max a (mm/s^2)	p
NSEO	Ave	892.29	4.550	1.779	57%	6.36	2.3	96.20%	10%	59.8	2.995	14.564	60.8	292.5	6.87
	StDev	0.39	1.278	0.340	16%	2.30	75.9	1.07%	40%	13.2	0.661	4.347	14.9	86.1	1.74
NSEC	Ave	889.02	5.481	1.619	70%	6.95	-9.2	95.42%	15%	97.4	4.876	22.454	90.2	386.0	4.56
	StDev	0.74	0.845	0.537	11%	2.38	87.8	0.71%	41%	15.0	0.750	3.737	14.9	67.7	0.93
PSEO	Ave	890.21	10.489	6.378	38%	52.71	-5.9	91.24%	12%	142.4	7.125	30.924	113.4	503.6	6.09
	StDev	0.41	1.767	1.003	14%	12.88	63.4	1.48%	42%	21.3	1.066	4.973	23.9	93.7	1.22
PSEC	Ave	895.95	14.432	11.136	22%	126.51	7.1	87.95%	7%	296.6	14.843	64.359	233.9	1137.1	4.42
	StDev	0.38	1.281	1.390	11%	45.48	69.0	1.07%	26%	47.3	2.365	10.674	45.4	312.4	0.62

Table 3. Repeatability of the height-normalized mCTSIB results for the Male subject

DISCUSSION

The repeatability tests on the force platforms (Table 1) show that the standard deviations tend to increase with the longer test durations. This increase does not appear to be linear with the duration. It could be that a drift in the measurements was occurring as the instruments were still stabilizing under load. In any case, comparing the results of Table 1 with those of Tables 2 and 3 shows that, for posturographic tests, the force platforms are much more repeatable than the overall repeatability of the mCTSIB tests, and that the majority of the repeatability issues arise from the subjects, not the instruments. The results also indicate that the CAPS™ Lite force platform is more repeatable than the CAPS™ Professional model. This is explained by the fact that the CAPS™ Lite is about twice as sensitive and has a much lower measurement range than the CAPS™ Professional (1.5 kN vs. 5 kN).

The repeatability tests on the mCTSIB measurements showed no difference between the CAPS™ Lite and CAPS™ Professional in terms of the mCTSIB results, even though the two systems are different in terms of construction and foam cushion used. The results also show that some of the posturographic measures considered appear to be more repeatable than others. This is even more apparent if the ratio between the standard deviation and the average is considered. It seems that the Stability Score is the most repeatable measure and that Sway Direction and Fatigue are highly unrepeatable, with the Directionality only slightly better. A possible explanation for the variability in the Sway Direction and Directionality is that, being the subjects tested free of pathological conditions, their sway was quite random in direction and not very directional, as can be expected for healthy subjects. Similarly, the variability in the Fatigue can be explained by the fact that no particular Fatigue trend was present in the subjects. Whatever the explanation however, it seems that multiple tests should be performed to confirm a Sway Direction, Directionality, and Fatigue result.

This was a preliminary investigation limited to two subjects, but the results between them seem to agree, even if the subjects were very different in everything except age. To have more certainty in the results the tests will have to be conducted with more subjects of different ages. However there are strong indications that the results might not change significantly if more subjects are considered.

CONCLUSIONS

The results indicate that as long as a posturographic instrument is properly designed, the results of the mCTSIB tests and of other static balance tests will be comparable, and that the repeatability of the results depends mostly on the subjects, not the instruments.

The results also indicate that the Stability Score is the most repeatable of the posturographic measures, with a standard deviation of about 0.56 for the tests on stable surface (NSEO and NSEC) and of 1.06 for the tests on unstable or perturbing surface (PSEO and PSEC). This means that a change in the stability score of more than 1.1 points for the stable surface tests and of more than 2.1 points for the tests on unstable surface are statistically significant to a 95% confidence level.

Although this was a preliminary investigation on a limited number of subjects, the results can provide an initial guideline to other researchers and clinicians as to what can be considered a statistically significant difference in the test results.

REFERENCES

[1] P. Forsman et al., “Daytime changes in postural stability and repeatability of posturographic measurements”. J Occup Environ Med. Vol. 49, No. 6, pp. 591-6, 2007.

[2] C. Eliott and A. Murray, “Repeatability of body sway measurements; day-to-day variation measured by sway magnetometry”. Physiol Meas., Vol. 19, No. 2, pp. 159-64, 1998.

[3] J.L. Helbostad et al., “Short-term repeatability of body sway during quiet standing in people with hemiparesis and in frail older adults”. Arch Phys Med Rehabil., Vol. 85, No. 6, pp. 993-9, 2004.

[4] S. Uimonen et al., “The repeatability of posturographic measurements and the effects of sleep deprivation”. J Vestib Res. Vol. 4, No. 1, pp. 29-36, 1994.

[5] H. Ishizaki et al., “Repeatability and effect of instruction of body sway”. Acta Otolaryngol Suppl. Vol. 481, pp. 589-92, 1991.

[6]. A.S. Pollock et al., “What is balance?”. Clin Rehabil. Vol. 14, No. 4, pp. 402-6, 2000.

[7] M. Fabbri et al., “Postural control after a night without sleep”. Neuropsychologia. Vol. 44, No. 12, pp. 2520-5, 2006.

[8] Y. Morad et al., “Posturography as an indicator of fatigue due to sleep deprivation”. Aviat Space Environ Med. Vol. 78, No. 9, pp. 859-63, 2007.

[9] A. Nagano et al., “Influence of vision and static stretch of the calf muscles on postural sway during quiet standing”. Hum Mov Sci. Vol. 25, No. 3, pp. 422-34, 2006.

[10] M. Alessandrini et al., “Posturography frequency analysis of sound-evoked body sway in normal subjects”. Eur Arch Otorhinolaryngol. Vol. 263, No. 3, pp. 248-52, 2006.

[11] J. Bench et al., “Studies in infant behavioural audiometry. II. Six-week-old infants”. Audiology. Vol. 15, No. 4, pp. 302-14, 1976.

[12] J.S. Blouin et al., “Startle responses elicited by whiplash perturbations”. J Physiol. Vol. 573, No. Pt 3, pp. 857-67,2006.

[13] M.Y. Agaeva et al., “[The effect of auditory image moving in vertical plane upon posture responses of humans]”. Ross Fiziol Zh Im I M Sechenova. Vol. 91, No. 7, pp. 810-20, 2005.

[14] M.Y. Agaeva et al., “Effects of a sound source moving in a vertical plane on postural responses in humans”. Neurosci Behav Physiol. Vol. 36, No. 7, pp. 773-80, 2006.

[15] L.R. Bent et al., “Visual-vestibular interactions in postural control during the execution of a dynamic task”. Exp Brain Res. Vol. 146, No. 4, pp. 490-500, 2002.

[16] Colebatch JG. “Consequences and assessment of human vestibular failure: implications for postural control”. Adv Exp Med Biol. Vol. 508, pp. 105-10, 2002.

[17] D. Deviterne et al., “Added cognitive load through rotary auditory stimulation can improve the quality of postural control in the elderly”. Brain Res Bull. Vol. 64, No. 6, pp. 487-92, 2005.

[18] A. Priplata et al., “Noise-enhanced human balance control”. Phys Rev Lett. Vol. 89, No. 23, pp. 238101, 2002.

[19] V. Juodzbaliene, K. Muckus. "The influence of the degree of visual impairment on psychomotor reaction and equilibrium maintenance of adolescents”.. Medicina (Kaunas). Vol. 42, No. 1, pp. 49-56, 2006.

[20] C.S. Bexander et al., “Effect of gaze direction on neck muscle activity during cervical rotation”. Exp Brain Res. Vol. 167, No. 3, pp. 422-32, 2005.

[21] A. Berencsi et al., “The functional role of central and peripheral vision in the control of posture”. Hum Mov Sci. Vol. 24, No. 5-6, pp. 689-709, 2005.

[22] K. Asakawa et al., “Effects of ocular dominance and visual input on body sway”. Jpn J Ophthalmol. Vol. 51, No. 5, pp. 375-8, 2007.

[23] C.L. Ogden et al., “Mean body weight, height, and body mass index, United States1960–2002”. Advance data from vital and health statistics, No. 347, Hyattsville, Maryland: Centers for Disease Control and Prevention - National Center for Health Statistics. 2004.